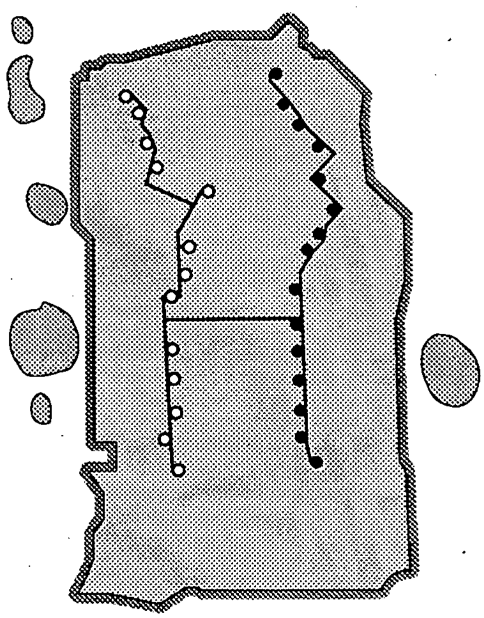
Water Authority
of Western Australia

WATER RESOURCES DIRECTORATE
Groundwater Branch

Jandakot Groundwater Scheme Stage 2 Public Environmental Review

Volume 1



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February 1991

JANDAKOT GROUNDWATER SCHEME — STAGE 2
PUBLIC ENVIRONMENTAL REVIEW

PUBLIC COMMENTS INVITED

The Environmental Protection Authority of Western Australia (EPAWA) invites public submissions on the above project.

This Public Environmental Review (PER) for the further development of the shallow groundwater resource, known as the Jandakot Mound, has been prepared by the Water Authority of Western Australia to meet with the requirements of the Western Australian Government. The proposal is summarised in the Summary Document and described in detail in Volume 1. Technical appendices are included in Volume 2. The PER describes the proposal, examines the likely environmental impacts and discusses the proposed environmental management procedures. The document will be available for comments for eight (8) weeks commencing 28 February, 1990 and closing 25 April, 1991.

Comments from Government agencies and from the public will assist the EPA to prepare an Assessment Report in which they will make recommendations to the Government.

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 with, disagree with, or comment on, the general issues and specific proposals discussed in the PER. 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 more environmentally acceptable.

When making comments on specific proposals in the PER:

- 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 PER.

If you discuss different sections of the PER, keep them distinct 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 SUBMISSIONS IS: 25 April, 1991.

SUBMISSIONS SHOULD BE ADDRESSED TO:

The Chairman
Environmental Protection Authority
1 Mount Street
PERTH WA 6000
Attention: Mr C. Murray

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SUMMARY

This Public Environmental Review (PER) has been prepared for the public and the Environmental Protection Authority (EPA). It contains an overall approach to the management of groundwater abstraction from the Jandakot Mound and describes the Water Authority's proposal to expand public groundwater abstraction. This report serves two main purposes:

- it enables the EPA to assess the proposal and provide its advice to the Minister for the Environment who will judge the environmental acceptability of the proposal, and
- it provides the public with further information about the proposal with an opportunity to provide feedback as to whether the Water Authority has satisfactorily balanced the benefits of an expanded private and public water supply with protection of the environment and community expectations.

The Water Authority now seeks the agreement of the Minister for the Environment to the implementation of the proposed Stage 2 expansion of the Jandakot Groundwater Scheme.

The proposed management of groundwater abstraction presented in this report is one of a number of management issues currently being developed for the Jandakot area; these include the proposed Beeliar Regional Park and Jandakot Botanical Park. The boundaries of the Beeliar Regional Park have been proposed, a planning study has been released (DPUD, 1990b) and a management plan will soon be developed. Neither the boundaries nor the management of the Botanical Park have been resolved. The Water Authority considers the formalisation of both Park proposals as integral to the development of a cohesive management plan for the Jandakot area and is supportive, in principle, of both proposals.

INTRODUCTION

The Water Authority of Western Australia is responsible for providing water services and managing the State's water resources for the benefit of the whole community. This includes the allocation of groundwater resources for public, private and environmental uses. The Water Authority is also responsible for providing scheme water for public supplies at least cost, subject to social and environmental objectives.

This proposal considers the total use of the groundwater resource, that is the combined effect of public and private abstraction on both the water resource and the environment.

Public Abstraction

Groundwater makes up half of the available water resources of the Perth-Mandurah region and provides a third of the Metropolitan scheme water supplies. The Jandakot Mound is an important part of this groundwater resource and has been specifically managed for quality and quantity since 1975 when the Jandakot Public Water Supply Area and the Jandakot Underground Water Pollution Control Area were proclaimed.

In the Jandakot Area the groundwater resource is referred to as The Jandakot Mound. This is due to the variation in the height of the water table in the area. The water table is higher in areas of higher ground. This causes a slow movement of groundwater towards the lower lying coast and rivers, and in cross-section gives the groundwater the appearance of a large mound.

Approval to develop both Stages 1 and 2 of the Jandakot Groundwater Scheme was given by the EPA in 1976. Stage 1 of the Scheme has supplemented the Metropolitan Water Supply Scheme since 1979.

The Water Authority now proposes to implement Stage 2. Because of the time which has elapsed since the original approval in 1976, the Water Authority has chosen to refer the development of the second stage to the EPA for reassessment. This will also allow full public participation. The EPA agreed with this approach and requested the preparation of a Public Environmental Review.

Under the Stage 2 development, public water supply abstraction from the shallow aquifer will be increased from 4 to 8 million cubic metres per year by adding a new line of wells to the west of the existing wellfield. The Jandakot Treatment Plant will be expanded to process the additional groundwater.

Private Abstraction

Groundwater of the Jandakot Mound is valuable as a source of private water supply for many uses including horticulture, gardens, industry and parks.

Under this proposal, private abstraction may be permitted to rise from 9 to 16 million cubic metres a year over a period of time. This is expected to be sufficient to meet the long term demands of most private users.

ENVIRONMENT — BACKGROUND

The Jandakot Mound area supports remnant wetlands and *Banksia* woodlands which depend on the shallow groundwater resource. In turn, the

wetlands and vegetation support a range of fauna which is highly valued by the community. Parts of the area have high visual appeal and recreational value and the area as a whole contributes significantly to conservation locally, regionally and internationally.

The shallow groundwater of the Jandakot Mound is recharged directly from rainfall. The quantity of recharge depends on rainfall, evaporation and water use by vegetation, all of which follow a seasonal pattern. This leads to wetland and groundwater levels fluctuating both seasonally and in response to long term rainfall trends. The plants and animals of the Jandakot Mound area are adapted to this regime of fluctuating groundwater levels.

The summer/autumn period has the lowest water levels and the highest water demand from private and public users and the environment. The component of the environment most sensitive to these low water levels is the wetlands.

In the Jandakot area there are proposals for a Regional Park (Beeliar) and a Botanical Park for conservation and recreation, as mentioned above, as well as impinging urban areas and proposals for further urban development.

The above factors have resulted in a complex and dynamic situation where the groundwater provides for many functions which contribute to the quality of life of the community.

ENVIRONMENT — PROTECTION

This environmental impact assessment approaches protection of the environment by identifying the components and functions of the environment supported by the shallow groundwater regime. Interim criteria are then set to protect those components and their interrelated functions. Many independent studies were sponsored by the Water Authority to provide information that was used as a basis for setting criteria.

Because of the dynamic nature of the Jandakot Area, criteria will need to be updated as the area changes and as our knowledge of it improves. For this reason, the philosophy or framework on which the criteria are based is discussed in considerable detail. This framework spells out the Water

Authority's objectives with regard to water management and the environment.

The groundwater scheme is designed to provide as large a public and private water supply as possible by abstracting as much water as feasible without compromising the environmental criteria or the water resource in the long term. A computer model was used to simulate the effects of different management scenarios. The location of the proposed Stage 2 wells and their abstraction pattern was optimised using the model. Using this approach, a strategy was developed which would meet the interim criteria. This ensures there are minimal effects on sensitive wetlands and upland vegetation of the Jandakot Area. The strategy also results in minimal competition with private water users.

Under this proposal changes in groundwater levels will be within the interim criteria. They will generally decrease by between a few centimetres and one metre depending upon the location. The greatest drawdowns will be confined mostly to the less sensitive areas of the terrestrial environment. Social impacts are expected to be minimal. By satisfying the environmental criteria, impacts on the wetlands and terrestrial environment, while noticeable in some instances, will allow the present environmental functions to be maintained. A programme of monitoring to check that the criteria are achieving their stated objectives will be undertaken.

Criteria

The criteria cover the following broad categories:-

- terrestrial habitats,
- major wetlands,
- the wetlands as a system, and
- air quality.

Terrestrial habitats' criteria cover well location, general drawdown of the water table, drawdown in areas of rare flora and System Six areas, and seasonally inundated wetlands.

The major wetlands for which detailed criteria are set are Thomsons, Forrestdale, Yangebup, North, Bibra and Kogolup Lakes.

The wetlands are protected as a system by specifying maximum habitat shifts based on the interrelationship between the wetlands.

Air quality criteria are set to minimise odours from hydrogen sulphide and to minimise the health risk from chlorine gas.

PUBLIC INVOLVEMENT

The Water Authority supports public involvement in decision making where complex judgements and community attitudes are important. Public involvement in relation to this environmental impact assessment included:

- meetings with a discussion group representing various community interests;
- an open day at the Jandakot Water Treatment Plant;
- encouraging the publication of newspaper articles promoting an understanding of groundwater; and
- an essay competition on groundwater for school children.

Responses from recent questionnaires on groundwater and environmental issues were taken into account.

There has also been extensive consultation with Government agencies which have responsibility for land planning and management.

MANAGEMENT COMMITMENTS

Apart from undertaking to ensure that groundwater abstraction is in compliance with the environmental criteria, thirty-four commitments are given. These commitments mainly relate to water conservation, management of private abstraction, land use management, project construction, expansion of the groundwater treatment plant, the monitoring programme and reporting. The Water Authority will report to the EPA and to a consultative groundwater committee annually on the results of monitoring and management. The consultative committee will have representatives from various local community interest groups and Government agencies.

CONCLUSIONS

This proposal has been arrived at by a process of scientific investigation and community consultation. Community input has come from numerous sources and the release of this document now permits even wider public input to the planning and decision making process. Public feedback to the Water Authority and the Environmental Protection Authority is important, particularly in making the ultimate judgement as to whether or not this proposal accommodates the various community needs and expectations.

The Water Authority considers that the proposed scheme recognises the multitude of uses and values for the groundwater resource and makes the best sustainable use of that resource. As knowledge of the complex hydrological, social and ecological system increases with time, the balance of water allocated to the various uses and the way in which it is utilised will certainly evolve. The present proposal is believed to make best use of the resource within the current limits of our confidence to manage the groundwater regime and not cause significant or irreversible changes.

1 Introduction

1.1 ROLE OF THE WATER AUTHORITY IN WATER SUPPLY

Two of the Water Authority's primary functions are: management of the State's water resources; and the provision of water related services. With regard to the management of the State's water resources, the Water Authority has formal responsibility to assess those resources and to plan and manage their allocation, development, use and conservation for the continuing benefit of the community. The Authority is also responsible for managing water sources to ensure maintenance of quality and quantity essential to the ongoing use of this renewable resource. An integral part of this is the allocation and management of water used by private developments.

Fundamental to providing water related services is the supply of water at minimum long-term cost, at a standard acceptable to customers. In providing this service, the Water Authority seeks to balance the cost of its activities, protection of the environment and community expectations.

The Water Authority must plan so that it can provide adequate water supplies for the community. It commences by predicting the likely demand on the water supply system. Using these forecasts, the Authority then examines the inventory of sources and determines the most appropriate order of developing them to meet potential demand on the public water supply system. This includes the expansion of existing sources as well as the development of new water sources.

The development of new water sources usually entails economic, environmental and social costs. These costs can be deferred by the active promotion of water conservation strategies. Water conservation relates to the efficient use of water supplies already available to the community.

The Metropolitan Water Supply Scheme (MWSS) is a complex network of water sources and consumers. The process of choosing the best means of continuing to meet the growing demand on the public supply scheme is correspondingly complex.

When determining the order to develop sources to increase water supply capacity, the Water Authority gives recognition to the particular benefits and costs associated with development of various sources. These may relate to the location of sources in the supply network, the quantity or quality of water provided, or the financial cost of development. Some sources provide a relatively large supply of water but involve considerable cost. Others provide small increases at low cost, or at strategic locations in the MWSS.

As part of the ongoing process of MWSS development to meet growing demand, the Water Authority proposes to expand the Jandakot Groundwater Scheme (Figure 1.1). This expansion consists of the development of a second line of wells (Stage 2) drawing additional water from the Jandakot Mound. This will provide an increase in yield to the MWSS of approximately 4 million cubic metres per year.

1.2 PURPOSE OF THIS PUBLIC ENVIRONMENTAL REVIEW

The development of new or expanded sources of water supply can affect the environment. Accordingly, under the provisions of the Environmental Protection Act (1986), such developments must be referred to the Environmental Protection Authority (EPA).

Upon receiving such a referral, the EPA may request additional information to enable it to assess the environmental effects of the proposal.

The EPA nominates the level of assessment and the form in which the requested information should be provided.

The EPA determined that the Stage 2 Jandakot Groundwater Scheme proposal should be formally assessed at the level of a Public Environmental Review (PER).

In response, the Water Authority prepared this PER, which is based on guidelines set by the EPA (see Appendix 1). This report serves two purposes:

- it provides the environmental review of the proposal requested by the EPA, enabling the EPA to assess the project and report to the Minister for Environment, and
- it provides a means of informing the general public about the proposal and obtaining broad community feedback as to whether or not the Water Authority is considered to have appropriately balanced the benefits of providing an expanded public water supply, protection of the environment and community expectations.

In proposing this project, the Water Authority believes it has achieved an appropriate balance between project cost, protection of the environment and the expectations of the community. Therefore, the Water Authority seeks the agreement of the Minister for Environment to the implementation of the project described in this PER.

1.3 SCOPE OF THIS PUBLIC ENVIRONMENTAL REVIEW

A Public Environmental Review is called for by the EPA when the significant environmental issues associated with a project are believed to be known and are relatively few in number. This is different from an Environmental Review and Management Programme, which addresses a much broader range of issues. This PER focuses on the likely impacts of the groundwater scheme on the wetlands and the specific terrestrial ecosystems of the Jandakot Mound, particularly those addressed in the System Six Report (DCE, 1983).

The approach to planning the Stage 2 Groundwater Scheme has been to develop criteria for protection of the environment and to then design, within the context of total sustainable groundwater use, a scheme which satisfies those criteria.

This PER reviews direct and indirect impacts of groundwater abstraction from the Jandakot Mound. For the purposes of this project the area addressed is referred to as the 'Jandakot Area'. It is approximately defined by the predicted extent of changes in groundwater levels due to water abstraction within the public water supply area (PWSA). This area (see Figure 1.1) includes:

- Thomsons Lake to the west,
- Forrestdale Lake to the east,
- North Lake to the north, and
- The Spectacles to the south.

This PER does not address pumping from the confined Leederville Formation aquifers as the surface environment is effectively isolated from the effects of this pumping (see section 5). However, leakage of water from the surface aquifer to the underlying Leederville formation is allowed for in computer modelling.

The PER does not address in any detail the impacts of land uses carried out in the area on the quality of groundwater. Management of groundwater quality is being addressed in detail in the Jandakot Land Use and Management Strategy and the Jandakot Mound Environmental Protection Policy. These documents are in preparation.

1.4 STRUCTURE OF THIS REPORT

The first five sections of this report basically contain background information. This includes:

- details on the nature of groundwater, its use, and its management,
- the need for the Jandakot Stage 2 development,
- a description of the Stage 2 development, and
- a description of the physical, biological and social environments in the Jandakot Area.

Sections 6 and 7 discuss the philosophy behind setting environmental criteria and the criteria themselves. Various operating strategies are presented in section 8 and the impacts of the selected strategy examined in section 9. Section 10 contains management and monitoring undertakings.

Since the specific criteria are presented in Chapter 7, while Chapters 2 to 6 are background justification to the criteria, an alternative approach to the document might be to proceed first to Chapter 7 and then return to the preceding chapters. This may put some of the background material into perspective at an earlier stage. A further alternative would be to read Table A12.1 in Appendix 12, which summarises the criteria detailed in Chapter 7, and then return to the earlier chapters.

2 Background

This section of the report provides the reader with a basic background in:

- the nature of groundwater,
- the existing scheme at Jandakot for withdrawing water for public use,
- the management of private abstraction,
- the proposal to extend the public scheme's capacity with additional wells,
- the principal potential environmental impacts and their management, and
- the involvement of the public in project planning.

2.1 WHAT IS GROUNDWATER?

Groundwater does not generally consist of underground streams or lakes but rather is in the spaces between sand grains and pebbles, or rock fractures and cracks. A sandy soil may consist of up to 35% empty space which can hold water. These small spaces in the soil are interconnected and thus allow water to move through them. In some soils water can travel up to 10 metres horizontally in one day, however, in most soils it will typically move between 50 and 100 metres in a year.

The "water table" is the surface or top of the groundwater. For example, the water table can be found quite easily at the beach by digging a hole. When the hole is shallow it is dry, as the spaces between the surrounding sand grains are occupied by air. As the hole is deepened below the water table, water from the spaces in the soil will seep into the hole. Many of the lakes near Perth are places where the surface of the land dips below the water table, just as in the hole at the beach.

The source of groundwater is rainfall, which drains through the sand to the water table. The availability of groundwater is ultimately limited by the amount of rainfall received. Much of the rain does not reach the water table because it evaporates from wet ground, vegetation and ponded water, or is drawn from the soil by plant roots and returned to the atmosphere by transpiration. However, the water that does reach the water table ensures that groundwater is a renewable resource.

Since rainfall, evaporation and groundwater usage by vegetation vary on a yearly cycle, the level of the groundwater (the water table) fluctuates up and down. This fluctuation varies depending on the area, but on the Swan Coastal Plain it is typically about 1 metre during a year although it may be up to several metres. Water table levels are usually highest at the end of winter and lowest at the end of summer.

The water table is higher in areas of higher ground. This causes a slow movement of groundwater towards the lower lying coast and rivers. Because of the higher water table levels under higher ground, the water table has the appearance of a large mound. A cross-section view is illustrated in Figure 2.1.

Groundwater may be divided into shallow (superficial or unconfined) and artesian (confined) groundwater. Shallow groundwater is found in the sand layer called an aquifer which covers large areas of the Swan Coastal Plain north and south of Perth. This sand layer can be 20 to 100 metres thick in places and contain 10% to 35% by volume of groundwater. The upper surface of the superficial aquifer is the water table. Artesian water is found in sandy aquifers between layers of watertight (impermeable) materials such as clay, shale and silt-stone, usually at a considerable depth below the ground surface. This water is typically under pressure and when a well is drilled into the aquifer, the water in the well rises and may even flow to the surface (see Figure 2.1). This artesian water is usually replenished (or recharged) some distance away, where the aquifer is closer to the surface, or by slow leakage through low permeability, superficial layers.

A typical public water supply well in the surface aquifer is around 40 metres deep. The groundwater is drawn through a perforated screen, typically about 12 metres long, at the bottom of the well. When water is being pumped from the well, the water table above the well forms a "drawdown cone" and may be depressed several metres. The size and shape of the drawdown cone depends on the soil characteristics of the area, but is usually limited to a few hundred metres from the well. Artesian wells on the Swan Coastal Plain generally vary between 100 metres and 1000 metres in depth.

Salts in groundwater originate mainly from rainfall and the solution of limestone. Of the total salt content about two-thirds is common salt (sodium chloride). Groundwater may also contain dissolved iron which causes the brown staining seen on walls and paths in some suburbs. Brown coloured water can also be caused by peat in the soil near wetlands. Nutrients are leached into the groundwater from fertilisers applied to gardens and crops. The process of nutrient enrichment is a natural process which occurs over time as organic material breaks down releasing nutrients into the soil and, eventually, the groundwater. Some human activities, such as fertiliser application to crops, increase the pace of nutrient enrichment and are referred to as cultural eutrophication.

The Water Authority's general policy for groundwater management is to ensure that fresh groundwater is not withdrawn at rates beyond the sustainable yield (that is, at rates less than the replenishment rate) to ensure the resource can be utilised in perpetuity.

2.2 THE EXISTING JANDAKOT GROUNDWATER ABSTRACTION SCHEME

Development and operation of the Jandakot Groundwater Scheme Stages 1 and 2 was approved by the EPA in February 1976 subject to certain conditions. These largely related to monitoring groundwater levels and the surface environment and reporting annually to the EPA on the effects of the scheme.

Stage 1 of the scheme (see Figure 1.1), comprising the eastern line of wells (15 superficial aquifer and 2 artesian) and the treatment plant, was commissioned in 1979. It now delivers around 4 million cubic metres per year of water from the shallow aquifer to the MWSS. The two artesian wells produce around 1 million cubic metres per year. In terms of manipulation and changes in the hydrological regime of the Jandakot Mound, this artesian groundwater abstraction is a relatively small factor.

Private groundwater use from the Jandakot Public Water Supply Area (PWSA) has been managed under provisions of the Metropolitan Water Supply Sewerage and Drainage Act 1909 since 1975. The Act requires all private wells to be licensed. At present there are around 1000 licensed private wells within the proclaimed PWSA having a total annual allocation of nearly 9 million cubic metres. The licences allow users to draw water for a number of purposes including domestic use, pasture irrigation, market gardens, stock watering and turf irrigation. The amount of water allocated is determined from the land use. Based on surveys of groundwater use, large users generally use less than their allocation and small users more. Overall, this usually results in less groundwater being drawn for private use than is allocated.

Monitoring of groundwater and wetland water levels on the Jandakot Mound has continued since commissioning of Stage 1 of the public abstraction scheme. In mid-1987, the Water Authority completed a review of the availability of groundwater and the requirement for groundwater management in the Jandakot PWSA (WAWA, 1987a). The study involved modelling the performance of the groundwater system under various climatic, land use and groundwater abstraction scenarios. It showed the impacts of Stage 1 of the scheme to be less than originally predicted by the Water Authority and judged acceptable by the EPA in 1976.

Application was made to the EPA in June 1988 to increase abstraction from the Stage 1 line of shallow wells from 2.7 to 4 million cubic metres per year. That increase was approved by the EPA.

2.3 PROPOSED DEVELOPMENT AND TIMING

For Stage 2 of the scheme, it is proposed to abstract around an additional 4 million cubic metres per year from a western line of wells consisting of up to 13 wells in the superficial aquifer (see Figure 1.1). This will be an inexpensive source of water as the existing Jandakot Water Treatment Plant can be upgraded, at very low cost, to handle the additional water from the second stage development. Commissioning of Jandakot Stage 2 will most likely be required by October 1993 and may be needed as early as October of 1992, the exact timing being dependent on future demand upon the MWSS.

2.4 ENVIRONMENTAL IMPACT ASSESSMENT

Considerable time has passed since the EPA first approved Stage 2 of this project. In this time, community expectations for thorough environmental impact assessment (EIA) of projects have increased considerably. Therefore the Water Authority chose to again refer the project to the EPA, which determined that reassessment was appropriate and set the level of assessment as a Public Environmental Review (PER).

This PER presents information to the EPA so that it can advise the Minister for the Environment as to the environmental acceptability of the scheme. It includes a discussion of total groundwater use and the allocation between private and public use. In addition, the PER provides sufficient information to enable public understanding of the project and its impacts, thereby facilitating public involvement in the decision making process.

2.5 THE NEED FOR ENVIRONMENTAL CRITERIA

The Jandakot wetlands are, in their natural state, a surface expression of the groundwater mound from which the Water Authority and private users are drawing water. The wetlands are an important component of the environment and of particular value and interest to the community.

The Water Authority, as water resource managers and developers of public water supplies, has recognised that uncontrolled abstraction from the groundwater mound has the potential to impact on the terrestrial environment and the wetlands.

The relationship between groundwater and the wetlands is complex, as are other processes in the wetlands, and not fully understood. This makes management of groundwater and the impacts on the wetlands difficult, necessitating a degree of caution. It also emphasises the need to acquire sufficient understanding of the function of the wetlands and the relationship with the groundwater in order to enable more confident management of both.

One way of protecting the environment of the Jandakot Area is to establish criteria for maintenance of remnant native vegetation, fauna and the wetlands. These criteria can then be used to define the limits of groundwater abstraction for both private and public use. The task then becomes one of optimising groundwater extraction while keeping environmental impacts within the acceptable limits defined by the criteria.

A number of major research projects aimed at developing robust environmental criteria in the areas of wetland hydrology, vegetation and fauna (see Appendix 2) have been initiated by the Water Authority in partnership with the EPA, the Department of Conservation and Land Management (CALM) and the Australian Water Research Advisory Council (AWRAC).

Until this information is available, interim criteria are needed to ensure that the current values of the Jandakot terrestrial and wetland environments are maintained. Aspects of particular concern in this regard are:

- social issues,
- terrestrial and aquatic vegetation,
- terrestrial (including avian) and aquatic fauna, and
- air quality.

Five studies were commissioned by the Water Authority to specifically assist in determining interim environmental criteria for design of the water abstraction scheme. These studies provide baseline information for conservative management and are as follows:

i) A six week study by Brian O'Brien and Associates (1988) which brought together specialists in the areas listed above to perform four functions:
   - collate available environmental information,
   - summarise the state of knowledge for both local information and relevant environmental criteria in general,
   - identify areas where there is insufficient existing information to permit environmental criteria to be determined, and
   - recommend interim environmental criteria.

ii) Establishment of baseline monitoring by E M Mattiske & Associates so that both short and long-term trends in the behaviour of native vegetation may be identified.

iii) A search by Mattiske & Koch (1989) of the State Herbarium and other records for rare and restricted flora.

iv) An assessment of hydrogen sulphide concentrations around the existing Jandakot Treatment Plant by Stephenson & Associates. Recommendations have been made as to acceptable concentrations and maintenance of a buffer zone.

v) Archeological and ethnographic investigations (O'Connor *et al.*, 1989) of Aboriginal sites and their significance.

The results from these studies have been integrated into the criteria contained in this report. Consultant's reports for studies i to iv are reproduced in Volume 2 of this Public Environmental Review. The full study team for the PER is listed in Appendix 3.

2.6 STEERING COMMITTEE

A Steering Committee met regularly to review and co-ordinate the environmental impact assessment (EIA) phase of the project. The committee consisted of representatives from the Water Authority, Department of Planning and Urban Development (DPUD) and the Department of Conservation and Land Management (CALM). The members of the Steering Committee are listed in Appendix 3.

2.7 PUBLIC INVOLVEMENT

The Water Authority supports the concept of public involvement in decision making where complex judgements and community attitudes are important. The public can only be meaningfully involved if sufficient information is available and opportunities are provided for informed participation in the decision making process.

As part of its ongoing public education and awareness programme in relation to the Jandakot Groundwater Scheme the Water Authority has:

- conducted an essay competition on groundwater and wetlands for local schools,
- held an open day at the Jandakot Groundwater Treatment Plant,
- encouraged the publication of newspaper articles promoting an understanding of groundwater, and
- met with the discussion group established for the Jandakot Area by the Western Australian Water Resources Council Research Group on Groundwater Management (RGGM, 1989). Members of this discussion group represent a wide range of local community interests (see Appendix 4 for a list of members).

It is planned that meetings will be held with local interest groups during the period that the EPA is receiving public submissions on this PER.

3 New Water Supply Developments

This section explains the need for the Jandakot Groundwater Scheme Stage 2 development. Private water supplies are considered because of the need to manage the total groundwater resource for both public and private abstraction.

3.1 PUBLIC WATER SUPPLIES

The Metropolitan Water Supply Scheme (MWSS) mainly supplies an area bounded by Quinns Rock to the north, Mandurah to the south and Kalamunda to the east. The bulk of demand for water from the MWSS comes from users within the Perth metropolitan area. This water is mainly used for domestic supplies and industrial and commercial applications. The proposed extension to the Jandakot Groundwater Scheme is required to supplement the MWSS system yield. Details of historical and projected demand for water from the MWSS can be found in the report 'Planning Future Sources for Perth's Water Supply (1989 Revision)' (WAWA, 1989a). This section also draws on the report 'Next Major Public Water Supply Source for Perth (post 1992)' (WAWA, 1988a).

The public demand for water is mainly determined by population size and the amount of water used per person.

3.1.1 Demand history

Water use from the MWSS increased through the 1960s and early 1970s (Figure 3.1). This was due to increases in both the population size and amount of water used per person.

Due to below average rainfall in 1975 and 1976 a public education campaign on water conservation was mounted in the summer of 1976/77. This resulted in MWSS water use being reduced by 10% compared to the previous year. Various levels of restrictions were imposed from July 1977 to May 1979 because of continuing below average rainfall. Since that time there have been no restrictions on water use. However, in 1987/88, restrictions were only averted due to a temporary decline in demand as a result of a successful publicity campaign. Following the lifting of restrictions in 1979, water use did not immediately return to pre-restriction levels. It is likely that further restrictions would have been necessary had it done so.

Private wells reduce the demand on the MWSS. It is estimated that there was a fifty percent increase in the number of private wells in the metropolitan area during the restriction period from 1977 to 1979.

3.1.2 Predicting future demands for water in the MWSS

Three demand projections have been developed — 'minimum', 'most likely' and 'maximum'. The 'most likely' demand projection assumes that the current conservation strategy is successful and that long term water use per person will be limited to the consumption of 1986/87. The 'minimum' projected demand assumes an increase in demand on the MWSS of around 1.5% per annum, the 'most likely' assumes 2% and the 'maximum' assumes around 3.5%. Under the current source development timetable (1989) for the 'most likely' demand, the Jandakot GWS extension is required by October 1993. The current 'maximum' and 'minimum' demand projections estimate the extension being required by 1992 and 2001 respectively. Planning is currently proceeding on the basis of being able to meet this earliest time (ie October, 1992).

3.2 PRIVATE WATER SUPPLIES

Private wells in the Jandakot PWSA are currently allocated a total of nine million cubic metres per year from the superficial aquifer. The bulk of this water is used for horticulture in the south-west of the PWSA in the Mandogalup area. Potential future demand is estimated to be up to 16.0 million cubic metres per year (See Figure 3.2).

The information in sub-sections 3.2.1 to 3.2.5, including demand forecasts, is largely drawn from the report 'Jandakot Public Water Supply Area Groundwater Management Review' (WAWA, 1987a).

3.2.1 Potential urban demand

Urbanisation within the Jandakot PWSA is currently limited to the north-west corner. The proportion of existing houses having domestic wells in this urbanised area could rise from the current value of less than 10% to around 25% based on results from the Domestic Water Use Study (MWA, 1985).

In 1988, the State Planning Commission (SPC, now Department of Planning and Urban Development), advertised an amendment to the Metropolitan Region Scheme to rezone land to the east of Thomsons Lake to urban (see section 5). That rezoning would increase the proportion of urban land in the PWSA from less than 5% to approximately 20%.

Assuming 25% of households establish wells, the total number of wells within the Jandakot PWSA would rise to about 3200. Based on an average annual draw of 750 cubic metres per lot, the total future domestic demand will be 2.5 million cubic metres per year.

Assuming that 10% of the total urban area is used for recreation and public open space and that about 40% of this is irrigated, an extra long term water requirement of 0.6 million cubic metres per year is anticipated.

The above figures must be considered only indicative of the potential demand since the number of domestic wells and the irrigation requirements for public open space are only estimates based on values for similarly sized urban developments.

3.2.2 Potential special rural demand

There are currently 550 special rural lots within the PWSA occupying about 13% of the total area. This may increase to 40% of the area based on current planning, comprising 1700 lots. Based on current licensing policy of 1500 m^3/yr per lot, the long term demand for special rural purposes will be around 2.5 million cubic metres per year.

3.2.3 Potential rural demand

The bulk of rural demand for groundwater is for market gardens and pasture which are mainly located in the Mandogalup area in the south-west corner of the Jandakot PWSA (see section 5). Market gardens and irrigated pasture account for 70% of the current rural allocation.

It is thought that the demand for water by new and existing developments will increase by around 0.5 million cubic metres per year to a peak of about 9.5 million cubic metres per year. The demand for water for rural uses may be limited by future restrictions on irrigated horticulture, necessary to protect groundwater quality for both public use and environmental maintenance, particularly in the Peel-Harvey drainage catchment.

3.2.4 Potential industrial demand

Industrial demand is estimated to increase from the current consumption of 0.4 million cubic metres per year to approximately 0.5 million cubic metres per year. Note that these figures do not include water used for sand mining as this water is largely recycled (i.e. returned to the aquifer).

3.3 FACTORS MODIFYING SUPPLY AND DEMAND OF GROUNDWATER

3.3.1 Water conservation

The Water Authority's policy on water conservation is to 'actively promote throughout the community the adoption of efficient practices in the utilisation of fresh water' (WAWA, 1987b). The Authority is undertaking active programmes in demand and supply management. Demand management is aimed at a gradual and permanent reduction in the demand per person from public and private sources. Supply management is aimed at improving distribution efficiency and increasing the utilisation of existing resources.

Demand Management

Specific programmes have been implemented to reduce demand by domestic, industrial, commercial and institutional, horticultural and rural users. These programmes are described in the Authority's 'Water Conservation Plan 1987-89' (WAWA, 1987b).

Strategies for demand management can be split into four broad groups, namely:

- Education — for example, information can be provided to teach people how to water their gardens efficiently,
- Design — water efficient washing machines and low flow shower heads are examples of design changes which can result in significant savings of water,
- Regulation — restrictions are one example of 'regulation'. Another example is to specify that only certain plumbing fixtures or appliances, such as dual flush toilets, can be connected to the public water supply, and
- Pricing — people tend to use water more carefully when they know that the more they use, the more they pay.

The Water Authority is also continuing studies into market based mechanisms to encourage the most efficient and productive use of water for agriculture without degrading environmental quality (WAWA, 1988b).

Supply Management

Supply management is mainly aimed at achieving better use of water in the supply system. Strategies for supply management include:

- leak detection and elimination programmes,
- reducing pressure in the reticulation system to reduce leakage and usage,
- recharge of groundwater by storm-water, and
- liaison with land use planning authorities and related agencies to promote urban designs and land use zoning which encourage water conservation.

Targets

The initial conservation target for the Perth metropolitan area is to return the average use per person to the 1986/87 level of 190 cubic metres per annum by 1991/92. This represents a reduction in the annual increase in water demand from the current 4% to 2%.

The 1987-89 Water Conservation Plan (WAWA, 1987b) suggested that targets be set for supply system losses but did not recommend specific targets.

Current Status of the Water Conservation Programme

The water conservation programme is estimated to be currently reducing Perth's annual water consumption by 3.6% compared to projected consumption without water conservation.

Since January 1, 1990, dual-flush toilet cisterns have been compulsory for all new and replacement installations connected to Water Authority schemes.

Annual water savings achieved from a leak detection programme have been estimated to be two million cubic metres per annum. This was less than anticipated and has been attributed to the generally good condition of the Water Authority's mains. The cost of the leak detection has proved to be greater than the cost of producing the saved water. For this reason, leak detection has been discontinued on a large scale. However, a reduced but regular leak detection programme is still carried out. This ensures that the state of the reticulation is monitored and if deterioration becomes evident, leak detection and repair activities will be increased.

The Water Authority is currently involved in the preparation of a research proposal to consider all aspects associated with reducing system pressures.

Recharge of groundwater using treated effluent is technically feasible but is expensive at an estimated 170 cents per cubic metre. This is a result of the treatment required to remove nutrients from the water and the large land areas required for aquifer recharge.

While water conservation of the order discussed above can significantly delay the introduction of new sources, it cannot prevent the need for them altogether, due to the underlying population growth factor. Also some water conservation proposals, such as the introduction of dual-flush toilets, will take many years to become effective in established buildings and residences. Thus the timing of medium-term rather than near-future water resource developments will be affected.

The Water Authority is currently preparing water conservation strategies to follow on from the 1987-89 Water Conservation Plan (WAWA, 1987b). However, even if new initiatives are introduced, the introduction of new sources in the short-term cannot be significantly delayed.

3.3.2 Climate change

Some scientists expect rainfall to decline in the south-west over the next 30 to 50 years. The Water Authority is seriously considering the implications of this, although the effect is not yet certain. Reduced water supply yield due to climate change could offset benefits of the water conservation programme in deferring source development in this region. This is allowed for in demand projections by assuming that rainfall and streamflow are reduced (See WAWA 1989a).

3.4 THE NEED FOR A NEW WATER SUPPLY DEVELOPMENT

3.4.1 The consequences of no development action

If water consumption continues to grow at the present rate, demand will exceed the design capacity of the existing supply system by 1993.

If no new sources are developed and demand conforms to the 'most likely' timetable, the probability of restrictions will increase significantly. By 1998 there could be restrictions for about one year in every two. The Water Authority believes that more frequent restrictions of the present style would not be acceptable to the community or to the Government. The Authority also believes that a sustained water conservation programme is preferable to implementing restrictions to reduce water use. This is partly because numerous restrictions could induce an increased demand for private wells with their associated environmental implications. The effects of climate change could also add to the above consequences of no development.

With the reduced demand growth associated with water conservation, the process outlined above would take longer but the final result would be the same. Hence, 'no source development' is not considered a viable option. In the short term, based on recent trends, the extension of the Jandakot GWS will most likely be required by 1993.

3.4.2 Alternative developments

The order of development of water sources is examined up to 25 years ahead. The most likely source development schedule for these sources is shown in Figure 3.3 (see also WAWA, 1989a). The Water Authority has an inventory of sources to supply Perth with water well beyond this 25 year time frame (WAWRC, 1988).

There are a number of water sources scheduled for development in the short term to supplement the system yield (see Figure 3.3). All these sources would provide water at low cost and, so long as they are environmentally acceptable, will need to be developed. Changing the order of development of these sources will not significantly affect the overall environmental impacts. Therefore, if the system yield is to be supplemented, there are no 'real' alternative water resource developments to the extension of the Jandakot GWS that will result in a reduced overall environmental impact.

Note that the timing for Jandakot GWS Stage 2 shown in Figure 3.3 is consistent with the latest published Sources Development Timetable (WAWA, 1989a), but is different to the timing given in sections 2.3 and 3.1.2. This is because the Water Authority regularly reviews short-term demand trends and these indicate that the project will be required slightly earlier than previously expected.

The extension of the Jandakot GWS will provide water at a cost of around 30 cents per cubic metre (see Table 3.1).

It could be argued that seawater desalination is the ultimate alternative, with the development itself having minimal environmental impacts. However, the energy requirement for desalination is significant and as such there is a significant environmental impact associated with the production of that energy. Also, it is believed that the cost of desalinated sea water at approximately $2.00 per cubic metre would not (presently) be acceptable to the community or the Government. Table 3.1 shows the cost of water from alternative sources.

Table 3.1 Approximate costs of water from various public water supply sources (including costs of conveyance to the Metropolitan area but excluding distribution costs which amount to 39 cents per cubic metre on average). Note that the cost is in December 1989 prices.

SOURCE	COST (cents/cubic metre)
CURRENTLY DEVELOPED SOURCES	
Hills sources (dams)	13
Treated groundwater	25
Untreated artesian groundwater	11
FUTURE SOURCES	
Treated groundwater	20-53
Hills sources north of Pinjarra	19-44
Rivers south of Pinjarra	46-74
Desalination of:	
— Brackish surface water	100
— Sea water	180
Water from the Kimberleys	345
Icebergs from Antarctica	Very expensive with present technology
Solar distillation	Not yet proven on a commercial scale

4 Proposed Scheme

This section describes the civil works and treatment systems associated with development of the Stage 2 groundwater scheme. These works involve the construction of new wells, collector mains and some minor extensions to the existing Jandakot Treatment Plant.

4.1 CIVIL WORKS AND TREATMENT SYSTEMS

Shallow groundwater requires treatment to remove naturally occurring impurities and ensure that the water is suitable for public water supply. Wells equipped with submersible pumps are used to abstract the groundwater. Collectively, these wells are termed a wellfield. The wells, which are spaced approximately 800 metres apart, are linked by a pipeline called a collector main. The water from each well is sent through the collector main to the groundwater treatment plant prior to storage in a service reservoir or distribution directly to consumers.

4.1.1 Wells

The Stage 2 extensions will involve drilling approximately 13 additional wells into the superficial aquifer. The wellfield will run on a north-south axis, parallel to and approximately four kilometres to the west of the existing Stage 1 wellfield (see Figure 4.1). The wells will each have an average capacity of 1500 m^3/day.

Well sites outside the area of urban development will be enclosed in fenced compounds. In urban areas, wells will be situated on the periphery of public open space and will remain unfenced. Sites will be approximately 25 metres square, but may vary slightly to suit local conditions. These sites will be levelled and surfaced with compacted limestone. The sites will contain some above-ground pipework and a small electrical cabinet.

4.1.2 Collector mains

The Stage 2 wellfield will require the laying of approximately twelve kilometres of collector mains. These will connect into the existing Stage 1 collector main near the intersection of Bartram and Lyon Roads, Jandakot. Well control cables will be laid in the collector main trench.

The collector main route will generally follow existing road reserves. Where this is not feasible, limestone tracks (approximately 1.2 kilometres) will be constructed along the route to allow access for construction and maintenance purposes.

Collector mains will be laid using established methods for main pipeline construction. Normally this requires a clearing of approximately 8 metres in width. It is anticipated that collector main sizes will range from 0.2 to 0.6 metre in diameter. The pipe trench will vary in depth from 0.9 to 1.4 metres. The pipeline will have at least 0.7 metre of soil cover.

During construction soil will be stockpiled on one side of the trench while the other side is used for access, i.e. crane and vehicle access, unloading pipes and standing welding machines. Where pipe-laying traverses undisturbed areas top-soil will be separated and replaced after construction, followed by rehabilitation. In the case of private land the owner may alternatively choose to be payed compensation for loss of vegetation. Sections of the collector main which must cross land subject to inundation will be scheduled for construction during summer when the water-table is at its lowest level.

Power supplies to the well sites will draw on existing SECWA power reticulation where possible. Some sites may require the construction of a feeder line and/or a pole-mounted transformer.

Workers involved in construction will be instructed on environmental protection procedures and will be required to work in an environmentally sensitive manner. Work will be closely supervised.

4.1.3 Treatment plant

Although the existing treatment plant was built and commissioned in 1979, it was designed with future extensions in mind. As a result, these additions will not have a great impact on the site. The extension will involve the following items:

- AERATOR — this houses pipes known as headers which contain spray nozzles. Water passes through the nozzles and is sprayed into the air allowing an exchange of gases (e.g. oxygen, carbon dioxide and hydrogen sulphide). The aerator has a capacity of eight headers of which only four are presently installed. This will be increased to six as part of the extensions, unless other more efficient forms of aeration are considered feasible when detailed design is undertaken.
- CLARIFIERS — these are large circular concrete tanks where, on the addition of chemicals, the impurities in the water settle to form a sludge. At present there is one clarifier which is operating at near full capacity. A

second clarifier will be constructed as part of the extensions unless other, more efficient, means are available.

- FILTERS — these consist of large cube-shaped tanks containing a mixture of sand and anthracite (coal). The water from the clarifier passes through the filters prior to pumping into the distribution system. This removes most particulate material which does not settle out in the clarifier. At present, the treatment plant has three filters. One additional filter will be constructed as part of the extensions, unless other more efficient forms of filtration are considered feasible when detailed design is undertaken.
- CHLORINATION — chlorine is a gas which is harmful to humans, particularly at the concentrations which can result from large chlorine gas leaks.

  Chlorine is used as a disinfectant in the water treatment process. However, it is also used to remove hydrogen sulphide gas and oxidise any soluble iron and sulphides still present following aeration.

  Chlorine is supplied to the treatment plant in steel cylinders each containing around 920 kilogrammes of chlorine. The existing chlorine drum store at the treatment plant can hold up to nine cylinders with three in use, three on standby and three spare. There are no plans to expand chlorine storage with the Stage 2 extension.

  At present, chlorine is drawn from the cylinders as a gas. As there are physical limitations to the gas withdrawal rate, three cylinders are connected at the same time. Prior to commissioning Stage 2, the chlorination system will be converted to a liquid system. The chlorine will then be drawn from the cylinder as a liquid and passed through an evaporator to produce the gaseous form. This means that only one cylinder will be on line at any time, thus reducing the amount of gas which might escape in the event of a major leak.

  The chlorination building has been designed to contain any leaked chlorine (as a gas). In ten years of operation at Jandakot, no major leak has occurred. There have been several minor leaks, all of which have been contained within the building and have been dealt with quickly and safely. All operations staff are trained in chlorine handling and dealing with leakages. Chlorine gas leak detectors alert the plant operators in the event of a leak occurring.

Construction of the existing treatment plant entailed partially clearing the site. The extensions will cause minimal additional disturbance. Once completed, the extensions will not be visible from the public road reserve.

4.2 OPERATING REGIME

Since the Stage 1 abstraction scheme was commissioned in 1979, it has been operated each year from early October to early May. During the four months each year that the Scheme is shut down, two months are spent performing winter maintenance of the mechanical and electrical equipment at the wells and in the treatment plant.

To date the availability of pipehead dam water and a decrease in demand from consumers during winter have meant that it has not been necessary to operate the Jandakot wells and Treatment Plant during winter.

However, plant production rates are based on abstracting the full groundwater quota during the operating period.

The operating regime for the Stage 2 extension is discussed in section 8.

4.3 PROJECTED LIFETIME

The anticipated life of the civil engineering structures associated with the Treatment Plant is expected to be in the order of forty to fifty years. The wells have an expected life of 20 years although the pumping equipment often has a much shorter life. The collector mains will have a life of around 60 years. Maintenance and replacement schedules are based on these expected lives.

The groundwater resource is renewable and should be available for use in perpetuity. Adequate integrated land and water management is necessary to prevent water quality problems arising from pollution. The fact that the Jandakot Mound is an Underground Water Pollution Control Area provides a basis for protection of the groundwater from polluting activities. Moreover, the Water Authority has developed land use policies aimed at protecting the groundwater resource. These are contained in the report 'Land Planning and Groundwater Resource Protection Policy' (WAWA, 1988c). This policy and other initiatives aimed at protecting water quality are discussed in section 10.5.2.

4.4 POSSIBLE FUTURE EXPANSION

The Jandakot Mound water resource extends to the south of the Stage 1 and 2 abstraction Schemes. A proportion of this resource is allocated to public water supply and is proposed to be developed as an extension of the Jandakot Groundwater Scheme. It is currently referred to as the Jandakot South Groundwater Scheme. It is anticipated that the Treatment Plant capacity will be further increased to 100,000 cubic metres per day when Jandakot South is brought into production.

The Water Authority report 'Planning Future Sources for Perth's Water Supply (1989 Revision)' (WAWA, 1989a) provides further information on the location and possible timing of this proposal. The earliest that the Jandakot South Groundwater Scheme would be required is currently estimated to be 1998/99.

As Jandakot South will not be required for at least eight years, this PER is not seeking approval to proceed with this proposal.

5 Overview of Jandakot Mound

This section provides background or baseline information on the physical, biological and social environments of the Jandakot area. The main purpose of this baseline information is to provide a description of conditions existing prior to the Stage 2 development on which environmental criteria can be based and against which subsequent changes can be measured through monitoring.

The information in this section is largely drawn from the reports: 'Gnangara Mound Groundwater Resources Environmental Review and Management Programme' (WAWA, 1986), 'Jandakot Public Water Supply Area Groundwater Management Review' (WAWA, 1987a) and supporting papers in Volume 2 of this PER.

Wetlands are a very important part of the environment in the Jandakot Area. They represent a valuable fauna habitat, are an essential component of the surface drainage system and provide diverse recreational and educational opportunities. This PER places particular emphasis on wetlands because of their social and ecological importance and the relative amount of information available. Much of this importance is due to the significant decline in the number and area of such wetlands on the Swan Coastal Plain since European settlement.

5.1 REGIONAL PHYSICAL ENVIRONMENT

5.1.1 Climate

The Jandakot Mound area is characterised by a typically Mediterranean climate with hot, dry summers and mild wet winters.

Rainfall records for Perth span the last 113 years (1876-1989) (Figure 5.1). These show that Perth has an average annual rainfall of 870 mm, with approximately 90% of this rainfall occurring between April and October. The 10 year moving average shows periods of significantly wetter than average conditions in the 1920s and periods of significantly drier than average conditions since 1975.

The highest mean monthly maximum temperature is recorded in January and February (34°C) and the lowest mean monthly minimum temperature is recorded in August (7°C) (see Figure 5.2).

Annual water demand is seasonal with the greatest demand occurring in the hot, dry summer months. Therefore, when public, private and environmental water demand are highest, there is little rainfall and groundwater levels are at their lowest (Figure 5.2). All these factors lead to increased demands on the shallow aquifers.

5.1.2 Geology

The Jandakot Area is characterised by dune systems on an undulating coastal lowland known as the Swan Coastal Plain. Topographic relief is low, ranging from 10 to 40 metres above sea level.

The southern Perth area occupies the southern end of the Dandaragan Trough, which forms part of the Perth Basin. A detailed description of the Basin is given in Playford et al. (1976). This Basin contains sedimentary deposits, up to 13 kilometres thick, comprised of sand, silt, clay and minor limestone. To the east of the Basin and the Darling Fault the rocks are crystalline and of igneous or metamorphic origin. They have very limited porosity and store very little water. However, the sands within the sedimentary basin are porous and allow the storage and movement of groundwater.

The sequence of rock and soil layers to a depth of about 2000 metres is summarised in Table 5.1.

5.1.3 Hydrogeology

The groundwater resources of the Swan Coastal Plain, near Perth, have been described by Allen (1981). This section of the PER draws on this paper and the 'Jandakot Public Water Supply Area Groundwater Management Review' (WAWA, 1987a).

Groundwater in the superficial formations originates mainly from rainfall which drains through the sand to the water table. In the Jandakot Area, it forms a regional mound of shallow groundwater, known as the Jandakot Mound with a volume of around 2700 million cubic metres. The water table is up to 27 metres above sea level at the crest of the mound.

Groundwater flow from the mound is largely westward to the sea with some northerly and north-easterly flows to the Swan and Canning Rivers (Figure 5.3). Large groundwater losses occur via evaporation from the wetland chain on the western side of the mound. Significant evaporative losses also occur over the eastern flank of the mound where the groundwater is close to the surface.

The Osborne Formation is present beneath most of the Jandakot Area as a confining layer below the superficial aquifer. It restricts downward

Table 5.1 Sequence of rock and soil layer in the Jandakot Area. The layers were formed in and overlie each other in the order listed below. Note that T is the maximum thickness of the formation in metres.

FORMATION	AGE	T	COMPOSITION	GROUNDWATER POTENTIAL
superficial formations	Quaternary	90	Sand, limestone silt, clay	Major unconfined aquifer, mainly fresh groundwater
Osborne Formation	Early-late Cretaceous	150	Glauconitic shale siltstone, minor sandstone	Semi-confining bed, limited groundwater
Leederville Formation	Early Cretaceous	250	Sandstone, siltstone, shale	Major confined aquifer, fresh to brackish water
South Perth Shale	Early Cretaceous	130	Siltstone, shale, minor sandstone	Regional confining bed, minor aquifer at base
Yarragadee Formation	Early Cretaceous Middle Jurassic	2000	Sandstone, siltstone, shale	Major confined aquifer, brackish to saline water

leakage from the superficial aquifer. However, some leakage occurs where the Osborne Formation is sandy. This appears to be particularly so on the eastern side of the mound. In general, groundwater in the aquifers moves in separate strata-bound flows except at intake and discharge areas.

Underlying the Osborne Formation is the Leederville Formation. This is an older, confined aquifer with fresh to brackish water and has a limited potential as a water source.

In some parts of the Jandakot Area iron oxides have cemented the sand grains together to form layers of 'coffee rock' within the superficial formations. Perched water tables have, in some instances, been found overlying this 'coffee rock'.

5.1.4 The regional water balance

The amount of rainfall reaching the water table and remaining as groundwater (recharge) in the Jandakot Area depends on the amount of rainfall received, evapotranspiration, the existing soil moisture content, land use, and the depth to the water table.

Evapotranspiration

Evapotranspiration (ET) is a term used to describe the combined effect of transpiration by plants and direct evaporation. Plants rely on transpiration for cooling and to carry nutrients from the roots to the leaves. Different types of plants have varying water requirements. Direct evaporation mainly occurs from soil, from free water surfaces and by evaporation of water intercepted by plant canopies during rainfall. The rate of ET varies seasonally and is dependent on the depth to the water table, the air temperature and wind velocity, the moisture content of the air and soil and the presence and type of vegetation.

Based on various water balance techniques (Davidson, 1984), ET uses about 80% (75 million cubic metres) of the average annual rainfall (94 million cubic metres) onto the Jandakot PWSA (WAWA, 1987a). By comparison, public and private abstraction from wells currently accounts for 14% (12 million cubic metres) of the average annual rainfall.

Lowering of the water table will reduce ET losses, resulting in a greater fraction of rainfall being available for recharge and consequently abstraction. A small percentage reduction in ET will result in a relatively large increase in the amount of water available for abstraction. For example, a 5% reduction in annual evapotranspiration (4×10^6 m^3) is roughly equal to the proposed annual abstraction from the Jandakot GWS Stage 2 development.

The Water Balance

During winter, large areas of land near the crest of the mound are subject to inundation due to the shallow water table. Where the water table is deep (over 6 metres), more than 30% of the rainfall may reach the water table and remain as groundwater. If the water table is shallow, most of the water which reaches the water table is subsequently lost by ET. In some areas, particularly wetlands, ET losses exceed rainfall.

Other losses from the mound are flows to the sea, drains, adjacent rivers and to underlying formations.

The estimated current water balance, as derived from computer simulations, is shown in Figure 5.4. These simulations suggest that the average net recharge over the mound is about 20% of the annual rainfall. The bulk of the recharge occurs between April and October. Groundwater levels generally rise quickly after the start of winter rains to a peak of around 0.5 to 1.5 m above the preceding summer minimum which typically occurs in March-April.

The transition in land use, from natural-to-rural-to-urban, causes changes in the groundwater recharge and discharge processes and, hence, to the level of the water table. These changes are discussed further in section 5.2.2.

5.1.5 Groundwater quality

Groundwater salinity is generally lowest near the crest of the mound and increases as the groundwater flows towards the coast and rivers. Due to evaporation, higher concentrations of groundwater salinity occur downstream of wetlands. The downstream side of a wetland is generally that side furthest from the centre of the mound.

Groundwater with an average salinity of around 500 mg/L TDS (milligrams per litre total dissolved solids) is found in the vicinity of the Stage 1 wells, while the salinity averages 260 mg/L near the proposed Stage 2 wells. Near the coast and at depth this concentration can be in excess of 1000 mg/L TDS.

The chemical characteristics of shallow groundwater vary depending upon where the water occurs. In the limestone areas of the coastal strip it has a pH of 7 to 8, whereas closer to the centre of the mound the presence of organic acids from the wetlands causes the pH to be acidic with a pH of about 5 to 6.5.

Similarly, the hardness of groundwater ranges from hard to very hard near the coast and moderately soft to slightly hard beneath the centre of the mound.

The concentration of total dissolved iron in the groundwater is generally less than 1 mg/L. Concentrations are usually between 1-5 mg/L on those parts of the mound closest to the sea and rivers.

Nitrate, fluoride, boron and heavy metals are generally at low concentrations. Phosphorus concentrations, with the exception of a few locations, are less than 0.1 mg/L. The temperature of groundwater at the water table varies between 19°C and 23°C on a seasonal basis.

Compared to water from other groundwater schemes supplying the MWSS, groundwater from Jandakot is of a similar quality apart from slightly higher levels of salinity. The higher levels of salinity are compensated for by mixing the groundwater with lower salinity water from Hills sources before it is fed into the MWSS.

Contaminants

In the Jandakot PWSA there are 22 sources of animal based waste, 2 abandoned waste land-fill sites and one source of industrial waste (Hirschberg, 1989). Of these, it is only the industrial waste which has been identified as causing significant pollution. However, groundwater quality in the PWSA is not affected because this contamination source is located on the edge of Lake Yangebup, downstream from all wells in the PWSA.

5.1.6 Landforms and soils

The Swan Coastal Plain is almost entirely formed of material deposited by aeolian (wind-blown) and alluvial (river-borne) processes. The Jandakot Area primarily consists of aeolian deposits of different ages. The furthest inland and oldest is the Bassendean Dune System, while further to the west is the Spearwood Dune System. There are further divisions or units based on erosional modifications and the occurrence of swamps (Churchwood and McArthur, 1980) (see Table 5.2). The area near Lake Forrestdale occurs on the Southern River Unit where sand has blown over alluvial soils. This results in the wetlands having clay bases. Areas dominated by peaty swamps are separated into the Herdsman Unit.

5.2 REGIONAL BIOLOGICAL ENVIRONMENT

This section is largely a summary of the supporting papers of Mattiske and Associates (1988), Davis (1988) and Ninox Wildlife Consulting (1988) which are contained in Volume 2 of this PER. These papers will be respectively referred to as Mattiske (1988), Davis (1988) and Ninox (1988) hereafter.

Table 5.2 Summary of the dune systems and soil units on the Jandakot Mound (as defined by Churchward and McArthur, 1980).

SYSTEM	UNITS	DESCRIPTION
BASSENDEAN DUNES	BASSENDEAN	Sand plains with low dunes and occasional swamps, iron or humus layers.
	SOUTHERN	Sand Plains with low dunes and many intervening swamps; iron and humus layers, peats and clays.
SPEARWOOD DUNES	KARRAKATTA	Undulating landscape with deep yellow sands over limestone.
	HERDSMAN	Peaty swamps associated with Bassendean and Karrakatta units.

5.2.1 Wetlands

The most widely used definition of wetlands in Western Australia is that proposed by the Wetlands Advisory Committee (1977):

> Areas of seasonally, intermittently or permanently waterlogged soils or inundated land, whether natural or otherwise, fresh or saline, eg water logged soils, ponds, billabongs, lakes, swamps, tidal flats, estuaries, rivers and their tributaries.

However, a more recent definition based on Paijmans *et al.* (1985) depends on flora and fauna (DCE, 1986; WAWRC, 1987a; WAWA, 1987c; Middle, 1988; EPA, 1990b):

> Wetlands are lands permanently or temporarily under water or waterlogged; temporary wetlands must have surface water or waterlogging of sufficient frequency and/or duration to affect the biota and/or the soils. The occurrence at least sometimes of hydrophytic vegetation (plants whose habitat is water or very wet places) or use by water birds are necessary attributes.

Wetlands on the Swan Coastal Plain are relatively unique in a world context because of their shallow nature. (A study of 150 Northern Hemisphere lakes reported minimum, average and maximum depths of 1.7, 14.3 and 313 metres respectively (OECD, 1982), whereas most Swan Coastal Plain lakes are less than 3 metres in depth). This allows light to penetrate to the bottom and wind to regularly mix the entire water body, both of which have important ecological consequences (see Humphries *et al.*, 1989; Chambers and Davis, 1989). There is a natural progression in wetlands where they gradually fill with sediment and biological material and become terrestrial systems. This process may take thousands of years but can be accelerated by human intervention.

The System Six report (DCE, 1983) proposed two conservation reserves in Jandakot which contain large wetlands. These are the Cockburn Wetlands — Eastern Chain (M93) and Forrestdale Lake (M95). Previously, two large and important nature reserves had been created in the area, namely, Thomsons Lake Nature Reserve (A15556), created in 1955, and Forrestdale Lake Nature Reserve (A24781), created in 1957.

The Eastern Chain Wetlands (also known as the East Beeliar Wetlands), extend from North Lake southwards to The Spectacles (although The Spectacles were not included in M93) and are in the Bassendean Dunes near the interface with the Spearwood Dunes. They can be compared to the group of wetlands which occupy a comparable position on the Gnangara Mound. These Gnangara Mound wetlands include Lakes Pinjar, Adams, Mariginiup, Jandabup, Badgerup and Gnangara. However, there are some important differences (EPA, 1990a):

> Natural eutrophication (elevated nutrient levels) processes are further advanced in the southern wetlands which have deep lake deposits (eg 7-8 m at Bibra Lake).
>
> The east Wanneroo lakes are higher in the landscape (higher than 40 m AHD compared with 10-16 m AHD for the southern wetlands).
>
> The southern wetlands have been subjected to longer periods of disturbance, which includes rural uses (Thomsons Lake), industrial uses (Lake Yangebup), sanitary landfill (Bibra) and drainage (North, Yangebup, and The Spectacles).

EPA (1990b) lists the valued attributes and assigns management objectives for major wetlands in the Jandakot area. These objectives are dealt with in detail in section 5.3. The report 'Environmental Significance of Wetlands in the Perth to

Bunbury Region' (Western Australian Water Resources Council, 1987) listed North, Bibra, Yangebup, Thomsons, Banganup and Forrestdale Lakes and the Spectacles as lakes of regional to international significance.

Wetlands in the Jandakot area have been recently surveyed by Middle (1988). The wetlands were classified into lakes, sumplands and damplands using the system of Semenuik (1987). Under this system, lakes are basins that are permanently inundated, sumplands are seasonally inundated and damplands are seasonally waterlogged. The wetlands were then further subdivided depending upon whether they are natural, degraded or artificial. Figure 5.5 shows the wetlands classified by Middle (1988) while Table 5.3 lists the number of wetlands within the various groups. Note that recent work by Semenuik (1987) has identified wetland areas somewhat larger than those identified by Middle.

Table 5.3 A summary of the number of wetlands within the Jandakot Public Water Supply Area and adjacent System Six areas M93 and M95 as classified by Middle (1988).

Wetland Type	Natural	Degraded	Man-Made
LAKES	2	6	5
SUMPLANDS	12	20	0
DAMPLANDS	55	38	0

LeProvost *et al.* (1987) stated that of the large number of wetlands in the South Jandakot area between Thomsons Lake and Forrestdale Lake, Forrest Road and Rowley Road (see Figure 5.5), eight were considered to be of particular potential significance. These are summarised in Table 5.4. Note that the Bartram Road Wetland Complex refers to the wetland system east of Beenyup Road, and between Harper Road and Gibbs Road.

Wetlands which LeProvost *et al.* (1987) considered of significance (in order of decreasing significance) are:

Bartram Road Wetland Complex:

- diverse vegetation
- high potential for waterbird breeding
- internationally significant features

Beenyup Road Swamp:

- semi-pristine
- unusual vegetation
- low potential for waterbirds
- internationally important features

Twin Bartram Swamp:

- degraded in part
- high potential for waterbird breeding
- may be affected by urbanisation

Solomon Road Wetland:

- some of the vegetation is not widespread in the Bassendean Dunes
- low potential for waterbirds
- may be affected by urbanisation
- likely to be affected by the southward extension of the Kwinana Freeway.

Table 5.4 Summary of potentially significant wetlands between Thomsons Lake and Forrestdale Lake as determined by LeProvost *et al.* (1987). The urbanisation column indicates whether the wetland lies within the proposed South Jandakot Urban Development and may be modified. Max. Depth is the estimated maximum depth in the wetland at the end of winter.

Wetland	**Urbanisation**	**Max. Depth (metres)**
Hird Road Wetland	yes	.60
Twin Bartram (east)	yes	.60
Twin Bartram (west)	yes	.45
Branch Street Wetland	no	.10
Solomon Road Wetland	yes	.10
Russell Road Wetland	yes	.10
Bartram Road Wetland Complex	no	.80
Beenyup Road Wetland	no	unknown
Gaebler Road Wetland	no	unknown

Water Levels

Water levels in wetlands are particularly significant since they have a "strong influence on the vegetation and thus on the value of the habitat to wildlife as well as the value of the species-composition to man" (Carter *et al*, 1978). They also determine which waterbirds can feed.

Wetlands in the Jandakot Area are surface expressions of the unconfined groundwater system and as such their water level generally varies with that of the water table. Lake beds are generally clayey and peaty in varying degrees and thus are less permeable than the surrounding sandy layers of the aquifer.

The water balance of a wetland is depicted schematically in Figure 5.6. Apart from artificial sources, inflow consists of groundwater infiltration, direct rainfall and runoff, while outflow is comprised of evapotranspiration (ET), overflow/drainage and leakage/groundwater outflow. The effect of ET is quite pronounced in most Swan Coastal Plain wetlands.

A number of drainage systems affect water levels in wetlands in the Jandakot Area. The Peel and Birrega systems drain rural land in the southern part of the PWSA. The Peel main drain passes though The Spectacles. To the east of the PWSA is the Forrestdale main drainage system which drains land to the north-east of Forrestdale Lake to the Southern River. This is estimated to have reduced the water level in Forrestdale Lake by around 0.3 metres (WAWA, 1987a). Thomsons Lake has a rural drain flowing into it which has raised water levels by approximately 0.5 metres, The wetlands at the northern end of the East Beeliar wetland chain; North, Bibra and Yangebup Lakes, receive water from the largely urbanised catchments. North Lake also receives drainage water from the Murdoch University Veterinary School farm.

Probably the most difficult part of the water balance to quantify is the groundwater flow. Estimates of groundwater flows have, in the past, sometimes assumed that the whole thickness of the surface aquifer passes through the wetland or that only a shallow layer contributes to the wetland with the remainder passing beneath the wetland as underflow (Townley and Davidson, 1988). In general, a wetland (i.e. the lakebed and the water in it) behaves as a thin region of high permeability (low resistance) which draws the regional flow towards it, both horizontally and vertically (see Figure 5.7). In other words, the groundwater is taking the path of 'least resistance'. It is well documented that groundwater inflow into wetlands is normally largest at the shore and then decreases rapidly with distance from the shore (Reckhow and Chapra, 1983; EPA, 1989c).

Figure 5.8 shows the recorded water level variations for Bibra Lake since 1960 (this is called a hydrograph). This hydrograph is representative of water table levels in the north western part of the Jandakot Area over this period and shows three distinct phases:

- during the mid and late 1960s, above average rainfall led to a rise in water table levels. This situation may have been compounded by clearing of native vegetation with a subsequent reduction in evapotranspiration,
- from the late 1960s to the late 1970s water table levels declined as a result of reduced recharge due to low rainfall, and
- since the late 1970s, drainage and increased recharge from urban areas have generally led to steadily rising water levels in the northern end of the East Beeliar wetland chain.

Water levels are now so high in some lakes that there is a risk of local flooding, as was highlighted by EPA (1989a). During 1988, recreation areas at North and Bibra Lakes were inundated and Yangebup Road was close to flooding in places.

Table 5.5 shows water levels at which flooding of houses/roads and recreation facilities respectively are likely to occur. Also shown are the range of

Table 5.5 Summary of water level data for major wetlands in the Jandakot Area. All heights are in metres above Australian Height Datum (AHD). "n/a" indicates 'not applicable'

EFFECT	BIBRA	NORTH	YANGEBUP	KOGOLUP NTH	KOGOLUP STH	THOMSONS	FORRESTDALE
FLOODING							
— houses, roads	>16.0	>16.0	>18.0	>20.0		>24.0	>24.0
— rec. areas	>15.0	>15.0	n/a	n/a		n/a	>23.5
SURFACE AREA							
— 100%	15.6	15.3	17.4	15.6		13.5	22.8
— 50%	13.9	13.2	13.9	14.6		12.0	21.9
DRY							
— completely	13.0	12.4	13.6	14.0	13.6	11.8	21.6
— effectively	13.3	n/a	13.8	14.2	13.8	11.9	21.9
RANGE	12.5-15.7	11.8-15.3	13.1-17.6	12.9-15.6		10.7-15.6	21.2-24.2
'NATURAL RANGE'	13.5-15.3	13.1-14.8	14.4-16.0	13.5-15.0		11.3-12.8	21.5-22.5
VEGETATION							
— paperbarks	13.5-14.5	13.7-14.5	15.5-18.0	14.6-15.5		>13.5	23.0-24.0
— Typha	14.0-14.5	14.0-15.0	14.0-16.0	>14.2	>13.8	12.0-13.0	22.5-24.0
RESTRICTED FLOW	<14.7						

water levels that have occurred in the past and a 'natural range' which is representative of the range of water levels that has led to the existing fringing vegetation.

Hydrographs for the major wetlands are contained in Appendix 5. The average water table levels on the Jandakot Mound for 1988 are shown in Figure 5.9.

Volume and Surface Area

All of the major wetlands in Jandakot are approximately circular in shape and are relatively flat bottomed and steep sided (see Appendix 8 for bathymetry). This results in relationships between volume and surface area with depth similar to those shown in Figure 5.10 for North Lake. The water surface area diminishes rapidly once water levels decrease below the steep sided banks. Further small lowering of water levels results in large areas of mudflats being exposed. Water levels at which the various wetlands are dry and effectively dry are shown in Table 5.5. Note that 'effectively dry' is taken to mean that the water in the wetland has a reasonable surface area but a very low volume.

EPA Bulletin 374 (1990b) defines the 100% level of a wetland as being the highest level where fringing paperbarks and/or pasture are found. Because fringing vegetation is affected by water levels, its location gives some indication of past water levels. However, this is difficult to evaluate for many wetlands. In this PER, the 100% level will be taken to be the highest recorded level in the ten years prior to 1 January, 1989. The 50% level is that level where the surface area is half of that at the 100% level. The 100% and 50% surface area levels are listed in Table 5.5 as well as the range of water levels that vegetation has been subjected to in the last decade.

Water Quality

Seasonal changes in the water quality of Thomsons, Forrestdale, North and Bibra Lakes have been recorded as part of chemical and biological monitoring programmes since 1985. In addition, twice yearly measurements were conducted for a range of wetlands from 1970 to 1986 by the Water Authority. These results have been summarised by Davis (1988) as follows:

> Monthly (1985/86) and subsequent two monthly (1986/87) sampling of water chemistry of four lakes on the Jandakot Mound revealed that two seasonal lakes, Thomsons and Forrestdale, showed highly seasonal changes in conductivity with very high levels being recorded just prior to drying. In contrast North and Bibra were fresher and displayed much lower summer maxima.
>
> All lakes were enriched on the basis of total phosphorus concentrations; levels in Bibra were exceptionally high while Thomsons was the only lake to fall below the level considered to indicate eutrophication (elevated nutrient levels) for part of each year.
>
> Levels of chlorophyll a were higher in the two permanent lakes, North and Bibra, than in the two seasonal lakes, Thomsons and Forrestdale. Levels in excess of 0.2 mg/L (milligrams per litre) appeared to promote chironomid (midge) production at nuisance levels. The three lakes at which these levels or greater were recorded: Bibra, North and Forrestdale, also experienced nuisance midge swarms during the summer months.
>
> Levels of ammonium and nitrate/nitrite were very high at Bibra and North Lake in comparison to the levels recorded at Thomsons and Forrestdale.

Contrary to some previous interpretations, existing data for Jandakot wetlands does not show that seasonality leads to improved water quality, ie lower nutrient content (Davis, 1988; O'Brien, 1988). However, seasonal drying appears to enhance invertebrate diversity (Davis, 1988) and other studies in New South Wales (Briggs *et al.*, 1985; Briggs and Maher, 1985; and Maher and Carpenter, 1984) suggest that the peaks of organic matter which occur after reflooding promote invertebrate and waterfowl productivity. On the relationship between nutrients and water levels, O'Brien (1988) stated:

> It is concluded that there is no first-order dependence of nutrient levels on the variations in average water levels that have occurred since the early 1970s.

However, because of the shallow nature of the Jandakot wetlands, low groundwater levels can affect the nutrient status of wetlands by two mechanisms:

- in summer, evaporation is high compared to groundwater inflow and evapoconcentration of nutrients occurs, and
- groundwater inflow and outflow, and thus nutrient flushing, will be reduced significantly if the water table drops below the level of the relatively impermeable beds found in some wetlands.

At low water volumes wetlands are susceptible to high water temperatures and concentration of nutrients. This can, in some cases, lead to such water quality problems as algal blooms, heavy growth of some macrophtytes, unpleasant odours from decomposing algae, bird deaths from botulism, and plagues of non-biting midges (EPA, 1989c).

Stratification can increase the likelihood of water quality problems. However, because of their shallow nature the wetlands are generally mixed on a regular basis by the wind and a process known as penetrative convection.

5.2.2 Vegetation

The Jandakot Mound area does not form a distinct region for flora. It is part of the Drummond Subdistrict of the Darling Botanical District of the Southwestern Province (Diels, 1906; Beard, 1980). The 'Flora of the Perth Region' (Marchant *et al.*, 1987) describes flora in this part of the Swan Coastal Plain.

General

The native vegetation in the Jandakot Area was summarised by Mattiske using the vegetation complexes of Heddle *et al.* (1980) (see Table 5.6). The dominant complexes are the Bassendean — Central and South and Herdsman. The other two complexes are restricted to the fringes of the Jandakot Mound Area. These are described in detail in Mattiske (1989)(volume 2 of this PER) who concluded that the vegetation in Jandakot was affected by a large number of factors. These included moisture stress, dieback disease (caused by the fungus *Phytophthora cinnamomi*), fire, insects and weeds.

The vegetation complexes are listed and mapped in Appendix 7. Detailed vegetation maps for North, Bibra, Yangebup, Kogolup, Thomsons and Forrestdale Lakes are shown in Appendix 8. Water levels at which paper barks (*Melaleuca* spp.) and bullrushes (*Typha orientalis*) occur are shown in Table 5.5.

With regard to the state of the vegetation on the Jandakot Mound, Mattiske (1988) noted:

> The vast majority of the vegetation on the Jandakot Mound has been cleared, grazed or influenced by urban, industrial, rural, drainage and agricultural activities.

Some wetland vegetation, such as bulrushes, are invasive and can spread rapidly, covering entire wetlands in less than a decade. This is not necessarily a negative impact as it will favour some species of fauna. However, species of waterbirds dependent upon open water will clearly be disadvantaged. In general, lower water levels favour invasive bulrushes, however, the quantity and quality of water required for reed-bed management is not very well understood. The Water Authority and EPA are currently funding a research project which addresses this gap in the present knowledge (see Appendix 2).

Table 5.6 Summary of vegetation complexes in the Jandakot Mound area (from Mattiske, 1988).

Bassendean — Central and South ranges from woodland of Jarrah-Sheoak-*Banksia* on the sand dunes, to a low woodland of *Melaleuca* spp., and sedgelands on the low-lying depressions and swamps. *Banksia attenuata, B. grandis* and *B. menziesii* are common on the upper slopes. *B. ilicifolia, B. littoralis, Melaleuca preissiana* and *M. rhaphiophylla* are common on the low-lying moister soils. Other plant species include *Kunzea ericifolia, Hypocalymma angustifolium, Adenanthos obovatus* and *Verticordia* spp.

Southern River consists of an open-woodland of Marri-Jarrah-*Banksia* on the elevated areas and a fringing woodland of *Eucalyptus rudis-M. rhaphiophylla* along the streams.

Karrakatta — Central and South consists of an open-forest of Tuart-Jarrah-Marri. Common species in the Tuart-Jarrah-Marri open-forest include *B. attenuata, B. menziesii, B. grandis* and *Allocasuarina fraseriana*. Shrub species include *Jacksonia sternbergiana, J. furcellata, Acacia cyclops, A. saligna, Hibbertia* spp., *Allocasuarina humilis, Calothamnus quadrifidus* and *Grevillea thelemanniana*. On the deeper sands the understorey species show changes and include *Hibbertia hypericoides, Conospermum stoechadis, Hovea trisperma* and *Bossiaea eriocarpa*.

Herdsman is dominated by sedgelands and a woodland of *E. rudis-Melaleuca* spp., with other, shrubby species of *Melaleuca* depending on the local drainage and adjacent soils. This vegetation is associated with the series of swamps and small lakes on the Swan Coastal Plain. Other plants include species of *Typha, Baumea, Juncus, Leptocarpus, Isolepis* and *Schoenoplectus*. The vegetation on elevated areas of Herdsman is mainly associated with that of the adjacent landform and soil units.

Rare and Restricted Flora

A review of literature on rare, restricted or poorly collected native plant species in the Jandakot area was undertaken by Mattiske and Koch (1989). Fifteen restricted or poorly collected species were recognised as possibly occurring in the area (see Appendix 6).

Some six of these species belong to the family *Orchidaceae* and generally flower from late August to November. Two of the plants on the list are aquatics (*Hydrocotyle lemnoides* and *Aponogeton hexatepalus*).

Five species of declared rare orchids have been located around the eastern and southern edges of the Jandakot PWSA, these being:

- *Caladenia hueglii*,
- *Diuris purdiei*,
- *Diuris* sp. (Kwinana),
- *Drakaea elastica*, and
- *Drakaea* sp. (south west).

Only the two *Diuris* species occur in seasonally inundated swamps. The other species grow on the drier sands associated with the *Banksia* woodlands (van Leeuwen, CALM, pers. comm., 1989). Orchids generally satisfy their moisture requirements from infiltration of water in the soil profile. In a study on Gnangara Mound it was noted that orchids' tubers were generally within the first 30 centimetres of the soil profile and were only near the water table in swampy areas (van Leeuwen, 1989). However, many species that grow in wet swampy areas appear to grow equally well under drier conditions. CALM is currently undertaking research into the biology of *Diuris purdiei.*

5.2.3 Aquatic invertebrates

Invertebrate fauna forms an essential and significant component of wetland food webs (EPA, 1987b). Higher order predators in these webs include waterfowl and tortoises (a more detailed list of the food web components is contained in Appendix 9). Invertebrates are also valuable as biological indicators of wetland water quality. A loss of species richness (diversity) or changes in the presence or abundance of different trophic groups, for example the predatory invertebrates, often reflects a deterioration in water quality and overall environmental quality of the wetland. In particular, the two important groups Odonata (dragonflies and damselflies) and Coleoptera (water beetles) have been studied in the Jandakot area (EPA, 1987b).

Detailed invertebrate data have been collected in Jandakot wetlands since 1985. The list of aquatic invertebrate species recorded at Thomsons, Forrestdale, North and Bibra Lakes during 1986/87 is given in Davis (1988). A list of species recorded at Yangebup Lake in 1987 is also given. However, this list is less comprehensive than that compiled for the former four lakes because it represents species recorded on only one sampling occasion.

Many of the invertebrates found in Perth wetlands are adapted to cope with seasonal variations in water levels by means of their life history strategies or by their behaviour. For example, many species survive wetland drying by forming desiccation (drying) resistant stages such as eggs or embryos. Some aestivate (bury and lie dormant) in the moist lake bed while others survive as flying adults and so are able to recolonise wetlands as they fill with winter rains.

The two seasonal lakes, Thomsons and Forrestdale, contain a richer fauna than the two permanent lakes, North and Bibra, although species richness in North is also high (Figure 5.11). Examination of data from the Jandakot and Gnangara Mounds shows that seasonal wetlands are generally richer in invertebrate species than the permanent wetlands. This has been attributed to a greater variety of habitats, both in time and space, and lower numbers of predatory mosquitofish (*Gambusia affinis*). Also, in the case of the Jandakot Area, Thomsons and Forrestdale Lakes are located in areas which currently have fewer urban pressures (eg drainage) than lakes such as North and Bibra.

The Water Authority and EPA are currently funding two research projects which are studying aquatic invertebrates. One is looking at life histories of aquatic invertebrates while the other is assessing the biological health and classification of wetlands based on macroinvertebrate community data and water quality (See Appendix 2).

Midges (Chironomids)

High midge numbers are usually associated with warm eutrophic wetlands with partially submerged fringing vegetation. Although the midges are a nuisance in surrounding residential areas they constitute a valuable food supply for many species of waterbirds.

5.2.4 Avian fauna (birds)

This subsection draws largely on the work of Ninox (1988) and EPA (1989a). The material in the bird feeding, breeding and loafing subsections is based on personal communications with Dr S. Halse of CALM (1989).

Most of the avifauna studies in the Jandakot Area have been carried out by the Royal Australasian Ornithologists Union (RAOU). The RAOU defines waterbirds as "birds that get their feet wet". Bushland birds are species other than waterbirds which are not always associated with wetlands, but do make some seasonal use of inundated or damp locations and adjacent upland vegetation. A summary of the number of species of birds observed in the Jandakot Area is given in Table 5.7. Only two birds are gazetted as rare, these being the Freckled Duck (*Stictonetta naevosa*) and the Peregrine Falcon (*Falco peregrinus*).

Table 5.7 Summary of the number of species of birds observed in the Jandakot Area as listed in Ninox (1988). The status of the birds is shown as:
R – rare, U – uncommon, M – moderately common, C – common and ? – unknown.

GROUP	STATUS					TOTAL
	R	U	M	C	?	
waterbirds	1	35	25	11	4	76
bushbirds	1	43	28	14	3	89

Ninox (1988) ranked the wetlands for their importance to waterbirds. The highest ranking wetlands were Forrestdale Lake, Gibbs Road Swamp, Yangebup Lake, Bibra Lake and Thomsons Lake. Apart from the wetlands on the flanks of the mound, the most important of the wetlands appear to be those of the north and east. In effect these are the wetlands south of Jandakot Airport and north of Rowley Road, especially those nearer Forrestdale Lake. These clay based north-eastern areas appear to be less modified than the more highly drained areas to the south-west (Ninox, 1988).

In terms of the way they use the environment, bird activities can be divided into three convenient groups: feeding, breeding and loafing. Loafing refers to activities other than feeding and breeding and includes preening and sleeping.

Bird Feeding Areas

Waders generally feed in 1 to 10 centimetres (cm) of water. The smaller birds use the 1 cm shallows and the larger use the 10 cm deep areas. Avocets feed in up to 15 cm of water while long-legged wading birds (the Heron group) feed in up to 30 cm of water. These birds are generally not affected by seasonally inundated wetlands higher on the mound drying out as they 'move on' to other wetlands.

Birds which use deep open water include the musk ducks (*Biziura lobata*), blue billed ducks (*Oxyura australis*), cormorants (*Phalaccocoracidae* spp.) and darters (*Anhinga melanogaster*). Cormorants and darters will move to an estuarine environment to feed as their wetland habitat is reduced in summer. Waterbirds continue to thrive and are apparently attracted to wetlands as nutrient levels increase (Ninox, 1988) (also see Briggs *et al.*, 1985 and Briggs and Maher, 1985).

Bird Breeding Areas

Adult ducks have a lifespan of 2 to 3 years; there is no significant long term effect if one year's breeding is missed. However, a second season without breeding can result in a decline in numbers. A third consecutive dry year is disastrous for the population if there are no alternative breeding areas. It is expected that most waterbirds have a similar lifecycle to the ducks. Most waders are trans-equatorial migratory birds and only breed in the Northern Hemisphere. Australian waterbirds breed locally in spring and early summer.

It is believed that the larger lakes are not the main breeding areas and that ducks mainly breed in the seasonally inundated wetlands higher on the mound. This is probably true for most other species of waterbirds.

Bird Loafing Areas

Provided that food sources are available nearby, birds are somewhat flexible in the habitats in which they loaf. For example, birds that prefer roosting in inundated paperbarks will roost in most trees.

Alternative Breeding Areas

Most species will travel the 600 kilometres from Jandakot to Esperance if wetland conditions are poor on the Swan Coastal Plain and good in the south-east of Western Australia. Some species, such as crakes and rails, do not travel these distances. In the case of some species there may not be suitable habitats on the south coast. For many species, the main drought refuge areas are on the Swan Coastal Plain. Musk ducks, for example, apparently congregate at Lake Clifton when other lakes become too shallow for diving. Only a limited number of species travel as far as the Kimberleys. A research project, funded by the Water Authority, CALM and EPA, is currently examining the distribution and migration of waterbirds (see Appendix 2).

Individual Lakes

The importance of the major wetlands to waterbirds was summarised in EPA (1989a), RAOU (1988) and CALM (1987) as:

NORTH LAKE appears to be important for breeding of ducks.

BIBRA LAKE has exceptionally large numbers of Hoary-headed Grebe (*Poliocephalus poliocephalus*), possibly being the largest number in the state and has a high diversity of species.

YANGEBUP LAKE has the highest numbers of Pink-eared Ducks (*Malacorhynchus* *membranaceus*) and Blue-billed Ducks (*Oxyura australis*) of any wetland in the south-west of Western Australia.

KOGOLUP LAKE shows a high potential for breeding with a moderately high number of species and breeding species. The scrub thickets in the south-east corner are not found elsewhere in the chain and provide a potential breeding area for the Little Bittern (*Ixobrychus minutus*).

THOMSONS LAKE shows a very high diversity of bird species and is important for breeding. Substantial numbers of migratory waders are regularly recorded including rare species and the wetland is a remnant breeding area for Marsh Harriers (*Circus aeruginosus*) and Australasian Bitterns (*Botaurus poiciboptilus*) in the metropolitan area. A guide to the birds found on Thomsons Lake has been compiled by Clay *et al.* (unpublished).

FORRESTDALE LAKE is the most important reserve for the Long-toed Stint (*Calidris subminuta*) in Australia. The lake supports large numbers of Pacific Black Ducks (*Anas superciliosa*), Australasian Shovelers (*A. rynchotis*) and Clamorous Reed-Warblers (*Acrocephalus stentoreus*) and is the only reserve in the region to have been used by the Little Ringed Plover (*Charadrius leschenaultii*) and Little Stint (*Calidris minuta*), both species considered uncommon in Australia. The reserve is important for the breeding of the Hardhead (*Aythya australis*), Purple Swamphen (*Porphyrio porphyrio*), Dusky Moorhen (*Gallinula ventralis*) and Clamorous Reed-Warbler.

Both Thomsons and Forrestdale Lake are listed, as a single unit, as wetlands of international importance under the International Union for the Conservation of Nature and Natural Resources (Ramsar Convention). Both Lakes are 'A' Class nature reserves, vested in the National Parks and Nature Conservation Authority, and managed by CALM.

5.2.5 Non-avian vertebrate fauna

A list of vertebrates either recorded in or likely to occur in the Jandakot Area is given in Ninox (1988). A summary of this list is given in Table 5.8. Two mammals and three reptiles/frogs were identified as being rare in the Jandakot area, these being the chuditch (*Dasyurus geoffroii*), numbat (*Myrmecobius fasciatus*), turtle frog (*Myobatrachus gouldii*), western blue tongue skink (*Tiliqua occipitalis*) and monitor (*Varanus tristis*). The numbat and the chuditch are gazetted rare species. Gazetted rare reptiles found in the Jandakot area are the lined skink (*Lerista lineata*), python (*Morelia spilota imbricata*), and the burrowing snake (*Vermicella calonotos*).

Table 5.8 Summary of number of species of mammals, reptiles and amphibians, either recorded or likely to occur in the Jandkot Area, as listed in Ninox (1988). Their status is shown as:

R – rare, U – uncommon, M – moderately common, C – common and ? – unknown.

GROUP	STATUS R	U	M	C	?	TOTAL
mammals	2	2	2	4	20	30
amphibians and reptiles	3	14	4	24	7	52

5.3 CURRENT MANAGEMENT OF WETLANDS

5.3.1 Current management objectives

This subsection is largely drawn from the document 'A Guide to Identifying Wetland Management Objectives in the Perth Metropolitan Area' (EPA, 1990b).

EPA Categories for Wetlands

The EPA published Bulletin 227 'Draft Guidelines for Wetland Conservation in the Perth Metropolitan Area' (DCE, 1986) which gives management objectives for some of the larger wetlands in the Jandakot area. This report states:

> The Environmental Protection Authority intends that the Guidelines should be adopted by individuals and organisations concerned with developments and land uses which impinge on wetlands and the water supply of wetlands.

Bulletin 227 was subsequently revised and is available as Bulletin 374 (EPA, 1990b). Recommendations for specific wetlands may also be found in the report of the EPA for System Six (DCE, 1983).

Bulletin 374 places wetlands into one of five broad management categories by using a system which scores the "naturalness" and "human use" of the wetland (for a full discussion of wetland attributes see Middle, 1988). These categories were listed in EPA (1990b) as:

Category H — high priority conservation areas

These wetlands possess a high degree of naturalness and there is a high level of interest in using the wetlands for various human purposes. This category is recognised as having the highest priority for establishment and implementation as regional park wetlands.

Management objectives:

- active management to maintain and enhance the wetland attributes, particularly natural attributes. Where there is no active management at present it should be put in place as a matter of highest priority.

Category C — Conservation

These wetlands possess a high degree of naturalness.

Management objectives:

- to maintain and enhance natural attributes and functions.

Category O — Conservation and recreation

These wetlands have been modified but are considered to play important roles in their urban and/or rural settings.

Management objectives:

- to provide for human uses whilst maintaining and enhancing natural attributes and functions.

Category R — Resource enhancement

These wetlands have been modified and/or do not have clearly recognised human uses in their urban or rural settings.

Management objectives:

- to maintain and enhance the existing ecological functions

Category M — Multiple use

Wetlands in this category are significantly degraded, possessing few natural attributes and limited human use interest.

Management objectives:

- should be considered in the context of catchment and land use planning (especially drainage, nutrient enrichment, surface and groundwater pollution), in terms of the current value of the wetlands and the potential value to the community if rehabilitated.

Table 5.9 shows the management categories determined from the revised guidelines for the East Beeliar wetlands.

Beeliar Regional Park

In 1983, the System 6 Report (DCE, 1983) recommended that the area M93 (North Lake to Banganup Lake) be designated as a regional park. In July 1986, after considering a comprehensive submission from the Wetlands Conservation Society, the government announced plans to form the Beeliar Regional Park, to include the eastern and western chains of lakes in Cockburn (System 6 areas M91, M92, M93 — see Figure 5.5). The Beeliar Regional Park Consultative Committee (BRPCC) was then formed to undertake a planning study and provide advice to the Department of Planning and Urban Development (DPUD) on the proposal for the establishment of the Regional Park.

Table 5.9 Management objectives and preferred uses for individual wetlands. Information drawn from Bulletin 374 (EPA, 1990b) Where a lake was not listed in EPA Bulletin 374 its category was determined from EPA Bulletin 371.

WETLAND	MANAGEMENT CATEGORY
North Lake	O
Bibra Lake	C
Lower Swamp	R
Roe Swamp	O
South Lake	R
Little Rush Lake	C
Yangebup Lake	C
Kogolup Lake	C
Thomsons Lake	H
Hird Rd Swamp	R
Branch Circus Swamp	R
Copulup Swamp	M
Banganup Swamp	C
The Spectacles	O
Forrestdale Lake	C

The recommended land uses detailed in DPUD's Beeliar Regional Park proposal (DPUD, 1990b) range from promoting recreation, leisure and sport in the Park (eg Bibra Lake West) to restricted public access (eg Banganup Lake Marsupial Research Station).

In general, the DPUD's objectives/preferred uses for individual wetlands are consistent with those of Bulletin 374.

In April 1990, the Government formally approved the establishment of the Beeliar Regional Park. The Park will be managed jointly by CALM, the City of Cockburn and the Town of Kwinana through a joint management agreement.

5.3.2 Existing management plans

There are three published management plans or proposals for wetlands in Jandakot which are particularly relevant to this report. These are for the two 'A' Class nature reserves — 'Forrestdale Lake Nature Reserve Management Plan 1987-1992' (CALM, 1987), 'Thomsons Lake Nature

Reserve Management Plan — No. 2' (Department of Fisheries and Wildlife, 1981) and Management Proposal for Yangebup Lake' (Murdoch University, 1988).

Forrestdale Lake

CALM (1987) stated the following:

> The primary objective of management of Forrestdale Lake Nature Reserve is to protect and enhance the area as a waterbird habitat for the range of species presently using the Lake. Consideration must therefore be given to the requirements of the various species ranging from diving ducks to waders, and including several rare species. Secondary objectives include the following: retaining the area as a representative example of Swan Coastal Plain Wetlands; ensuring the continued presence of a diversity of native flora and fauna; ...

With regard to water levels, this report stated:

> An annual pattern of water levels, suitable for the needs of the full range of waterbirds currently using the Lake, should be maintained. There should be at least 0.9 metre of water in late spring of each year.

Bulrushes (*Typha*) should be managed for the benefit of the waterbirds and to prevent the Lake from becoming a *Typha* lake.

Thomsons Lake

The Department of Fisheries and Wildlife (1981) included amongst their management objectives:

> To maintain Thomsons Lake as a waterbird habitat, continuing to monitor lake levels and changes in lake levels, in co-operation with the Metropolitan Water Supply, Sewerage and Drainage Board (now the Water Authority).

Yangebup (and Little Rush) Lake

Murdoch University (1988) stated:

> The management objectives ... are conservation for Little Rush Lake and conservation and recreation for Yangebup Lake. These objectives were determined by the importance of the wetlands as a wildlife habitat and drought refuge, the relative environmental condition of both lakes and by the recreation opportunities available at Yangebup Lake.

The report, which is not a gazetted plan (ie, not part of any town planning scheme), made thirty-three recommendations, one of which related to water levels; this was:

The Water Authority should ensure that the water level of Yangebup Lake is maintained between 13.9 m AHD and 18 m AHD with the following constraints:

(i) the lake level must not exceed 17 m AHD for more than 3 months in any 12 month period;

(ii) the lake should be allowed to follow its natural seasonal fluctuations within these limits.

Other Management Plans

Other management plans which cover the Jandakot wetlands include 'North Lake Draft Management Plan' (Murdoch, 1986), 'North and Bibra Lakes — An Environmental Study' (Murdoch, 1979) and 'Bibra Lake — Concept and Management Plan' (Riggert, 1982).

5.4 REGIONAL SOCIAL ENVIRONMENT

5.4.1 Population

The population of Perth is growing rapidly. At June 30, 1986 the population of the Perth Statistical Division was estimated to be 1 050 350. A year later the population was estimated at 1 083 449, an increase of 33 099 or 3.15%. The preliminary population figure for June 30, 1988 is 1 118 131, a further increase of 34 682 or 3.20% (Australian Bureau of Statistics, 1989).

Residential development has progressed rapidly in the Jandakot area in recent years. The Review Group to the then State Planning Commission (1987) noted that this was particularly so in the City of Cockburn as far south as Yangebup Road. The Review Group recognised the potential for the land south of Yangebup Road and east of Thomsons Lake, then zoned Rural, to accommodate over 30,000 people. This is around one year's growth in population for Perth.

5.4.2 Land use, tenure and zoning

Underground Water Pollution Control Area (UWPCA), Public Water Supply Area (PWSA) and Groundwater Areas.

The UWPCA, which has the same boundaries as the PWSA (Figure 1.1), was proclaimed to protect the quality of water in the surface aquifer from the activities of land and water users. However, groundwater flow extends beyond the UWPCA (and the PWSA) in all directions (Figure 5.3). Thus, activities and land uses within the UWPCA can have significant impacts beyond the boundaries of the UWPCA.

The PWSA was proclaimed to provide for licensing of private use of groundwater. The surrounding Groundwater Areas of Perth, Cockburn and Serpentine were proclaimed for similar reasons (see Figure 8.14).

Local Authorities

The Jandakot Area comes under the jurisdiction of six local government authorities. The majority of the area is within the City of Cockburn. Smaller areas fall within the boundaries of the Town of Kwinana to the south, the Shire of Serpentine-Jarrahdale to the south-east, the City of Armadale along the eastern flank, the City of Melville to the north and the City of Canning to the north-east.

Current Land Zoning and Use

Current Local Authority land zoning, as identified in Town Planning Schemes, is shown in Figure 5.12. Current land use is shown in Figure 5.13. Note that both these figures use the boundary being applied to the Jandakot Land Use and Water Management Strategy (see Section 10.5.3) rather than the boundary of the Jandakot Area. Land use chiefly consists of privately owned rural land, of which approximately 25 percent is uncleared. This includes a significant proportion of special rural lots. Other land uses include industry, commercial enterprises, institutions, private residences and reserves for recreation and conservation.

South Jandakot Urban Development

A framework has been provided for the extension of urban development south of Yangebup Road. In particular, the SPC published a planning study of the South Jandakot (Thomsons Lake) locality in October 1986. This study recommended that 1300 hectares of land, mostly within the PWSA, be rezoned for residential purposes. Recommendations were also put forward to protect the groundwater resource and wetlands. These included the preparation of a Water Resources Management Plan.

The EPA assessed the proposed South Jandakot urbanisation proposal as environmentally acceptable subject to a number of recommendations (EPA, 1987).

The DPUD then advertised the MRS amendment to rezone the land in South Jandakot for urban development and an initial drainage management plan for the area was assessed by the EPA to establish whether it complied with the ministerial conditions set for rezoning.

The EPA's Report and Recommendations as to whether the Minister's conditions were satisfied, were published as Bulletin 388 (EPA, 1989b). The EPA concluded that the proponent had not demonstrated an acceptable drainage management proposal.

A revised drainage management plan was prepared for DPUD by Consulting Engineers G B Hill and Partners in association with the Water Authority (DPUD, 1990a), in an endeavour to produce a plan which adequately addressed water management and environmental concerns.

In April 1990, the EPA released a report (EPA, 1990c) advising that the ministerial conditions relating to drainage proposals for the development had been satisfied, subject to a number of recommendations. Following the resolution of other ministerial conditions relating to buffer requirements around the Jandakot treatment plant, the MRS amendment to rezone the land may proceed.

The boundary of the total area proposed by the SPC (now DPUD) for the South Jandakot Urban Development is shown in Figure 5.13.

Conservation and Recreation Reserves

Five areas (M93, M94, M95, M97 and M99) subject to System Six Conservation Recommendations (DCE, 1983) occur within the Jandakot Area (Figure 5.5). A further two (M98 and M100) are located immediately to the south.

Of the four principal areas, three (M93, M95 and M97) are focused on wetland reserves, while the fourth area (M94) consists mainly of *Banksia* woodland on Commonwealth land surrounding Jandakot airport.

A detailed account of these areas can be found in the System Six Report (DCE, 1983).

As already indicated in section 5.3.1, the Government has given approval to the establishment of the Beeliar Regional Park which is centred on System Six areas M91, M92, and M93.

The Government has also announced plans to establish the Jandakot Botanical Park with the objective of preserving much of the remaining *Banksia* woodland in the south of Perth region. At this stage, CALM and DPUD are jointly determining the boundaries of the Park. The Water Authority considers that, together with the Beeliar Regional Park, the Jandakot Botanical Park is an integral component of an overall management strategy for the Jandakot area and is strongly supportive, in principle, of the proposal. As such, the Authority believes that the relevant government agencies should resolve the boundaries and management issues associated with the proposal by the earliest possible date.

Future Landuse

Future landuses in the Jandakot PWSA were examined in WAWRC (1986) and WAWA (1987a). Since that time, the situation regarding the South Jandakot Urban Development has been clarified (see above). The boundaries of the Beeliar Regional Park have also been identified while those of the proposed Jandakot Botanical Park have not yet been set.

In April 1990, DPUD released a draft report known as 'Metroplan — A Strategic Plan for the Perth Metropolitan Region'(1990c). This document shows conceptually the parts of the Jandakot Area which DPUD consider are suitable for urban development. It also shows new areas which have been identified for use as Regional Open Space including Landscape Protection Areas.

More detailed recommendations on future land uses will form part of the Jandakot Land Use and Water Management Strategy, which is being developed by DPUD and the Water Authority (see Section 10.5.3) and the Jandakot Environmental Protection Policy being developed by the EPA. In general, they are likely to consist of areas of urban development in the west, conservation and recreation reserves in the west and east, with the residual land being mainly for special rural and rural purposes.

5.4.3 Heritage features

A number of early settler cottages are located in the general vicinity of the Jandakot Mound. However, none of these are situated near any areas where civil works are likely (O'Brien, 1988).

Investigations undertaken for the Water Authority (O'Connor *et al.*, 1989) did not reveal any Aboriginal archaeological sites within the areas of direct physical impact. The Consultants reported that the survey strategy was such that, had any major archaeological site been present, they believed that it would have been discovered. The Consultant's report has been provided to the Department of Aboriginal Sites, Western Australian Museum.

There are six known ethnographic sites in the Jandakot Area (O'Connor *et al.*, 1989). Consistent with normal practice in these matters, O'Connor *et al.*, (1989) is not published here because it contains information which might be considered by Aboriginal people to be of a confidential nature. Four existing sites of ethnographic significance were identified from the Register of Aboriginal Sites. Two new sites were identified from consultation with Aboriginal people with local knowledge. These new sites have been reported to the Registrar of Aboriginal Sites, Western Australian Museum.

5.4.4 Community attitudes

This sub-section draws on the work of Macpherson and Syme (1989a; 1989b) and Syme and Macpherson (1988).

The main community interests regarding groundwater in the Jandakot Area are water allocation and wetlands.

Water Allocation

The community has a positive attitude towards water allocation to market gardening and primary industry in general. There is also strong support for environmental protection to be considered in water allocation problems. The lowest priority areas appear to be industry and parks. The attitudes towards public supply and private wells seem to be somewhat divided in the community with substantial proportions of people both for and against allocation in these areas.

Environmental Awareness

There is clearly a high level of environmental awareness and concern in the community. For example, 97% of residents surveyed by Syme and MacPherson (1988) support conservation of the surrounding environment. However, these same residents have many different levels of understanding and interpretations of conservation. For example, 22% of residents agreed that clearing to the water's edge achieves the best appearance while 37% believed that clearing should not be allowed.

Wetlands

Wetlands are a particularly valued component of the environment. This is evident from the unanimous support for the Beeliar Regional Park and the maintenance of 'healthy' lakes. A strong desire was expressed for the management of the wetlands to maintain wildlife. Some concern was expressed for the current health of the wetlands. There appears to be considerable concern about the future conflict between further urbanisation and wetland maintenance. There is also a generally held view that industry should not be permitted near housing or wetlands.

Expectations

There are three elements of community attitudes to wetlands; these being aesthetic, altruistic (conservation) and personal well being.

In terms of wetland management the local community's expectations are:

- aesthetics
  - — the preservation of open water landscape,
  - — the clearing of vegetation to maintain views, without disadvantaging wildlife,
  - — the maintenance of high water levels unless there are compelling reasons for lower levels,
  - — the creation of open water bodies using drainage water,
- conservation
  - — the conservation of wetlands, flora and fauna,
  - — the prevention of development close to the wetlands,
  - — the strict control of pollution,
- personal well being
  - — the maintenance of property values associated with the proximity and view of wetlands,
  - — the maintenance of the range of passive and active recreational opportunities around the wetlands, and
  - — the control of midges and flooding.

A more detailed discussion of community attitudes is contained in Macpherson and Syme (1989a) and Syme and Macpherson (1988). The latter report is reproduced in the supporting volume to this PER.

A Basis for Management

From their research Syme and Macpherson (1988) reasoned that:

- the wetland water levels over the past ten to fifteen years represented an acceptable range to the community and should only be changed slowly,
- satisfaction of aesthetic expectations, without increasing flood risk, is more important in the urbanised northern end of the Beeliar Wetland chain,
- management of the wetlands for conservation is likely to be more acceptable in the more remote southern part of the Beeliar chain, although this acceptance may change with future urbanisation,
- less is known by the community about the seasonal wetlands high on the Mound than the larger wetlands on the flanks. Therefore expectations for management of the larger wetlands is greater, and
- artificially recharged wetlands may provide alternative sites for the pursuit of active recreation less suited to natural wetlands.

5.4.5 Recreation

A large proportion of outdoor recreational activity is based around water (ie, beaches, rivers, wetlands) (Department of Youth Sport and Recreation, 1977). Therefore, it is expected that most outdoor recreation in the Jandakot Area will focus on the wetlands. Table 5.9 indicates which Jandakot wetlands are considered suitable for recreation.

The report 'Recreational Opportunities of Rivers and Wetlands in the Perth to Bunbury Region' (WAWRC, 1987b) lists 31 water related activities which can be divided into 19 water oriented activities and 12 water dependent activities. Unlike the water dependent activities, the water oriented activities do not require minimum water depths in the wetlands. For Jandakot wetlands, most, if not effectively all, recreational activities are water oriented as opposed to water dependent (Murdoch, 1979; Syme and McPherson, 1988).

6 The Philosophy Behind Environmental Criteria

Criteria are 'principles or standards that things are judged by' (OED, 1976).

This section discusses the philosophy behind setting environmental criteria for the Jandakot GWS Stage 2 development. These criteria are needed to protect the environment and must be satisfied for the total groundwater abstraction, both private and public. The criteria presented in this report are proposed criteria and are not statutory unless incorporated into the conditions set by the Minister for Environment.

This section covers how environmental criteria:

- are used to ensure that management objectives are met for areas likely to be impacted by groundwater use,
- often need to be complex,
- need to be flexible,
- are largely determined by our current state of knowledge, and
- are shorter lived than the philosophy behind them.

6.1 BACKGROUND

Groundwater is a particularly valuable water source because of its closeness to consumers and its availability in the hot dry summer months when water demand is highest. These consumers are private and public water supply and the environment.

If abstraction from the Jandakot Mound was allowed to grow without active management, the groundwater resource would eventually be depleted. This would result in major changes to the environment and cause hardship amongst private and public users.

However, the Water Authority manages the total groundwater resource using the concept of sustainable yield. As a consequence abstraction is kept at levels that will never lead to unacceptable effects on the major beneficial users of the resource. In this case, the major beneficial users are private and public users and the environment.

The sustainable yield of an aquifer can be used to determine an *average annual quota*. However, the amount of water that can be drawn in any given year, the *annual draw*, may vary depending on the net recharge to the aquifer during the period prior to the given year. In turn, this depends on factors such as rainfall and evaporation which vary from year to year. Therefore it is not possible to predict what the exact annual draw will be for the forthcoming year. However, the average annual quota necessary to ensure sustainability over a number of years can be predicted with much better accuracy.

6.1.1 The role of the Water Authority in recommending criteria

The criteria discussed here relate only to those aspects of the environment which might be significantly affected by groundwater use. The criteria themselves do not form an exhaustive set of guidelines for balanced management of the Jandakot Area. This responsibility rests primarily with other Government agencies.

6.2 LIFESPAN OF CRITERIA

The criteria recommended in this PER govern both the design and management of the Jandakot GWS Stage 2 development and apply to all phases of the development from preliminary design through to full operation.

The philosophy outlined in this section is particularly important as it provides a basis for determining present and future criteria. The criteria themselves will almost certainly change as:

- more hydrological information becomes available from the operation of the scheme,
- ongoing research projects provide a better understanding of the environment being managed, and
- other statutory management agencies determine broader or more detailed management objectives and criteria for the area.

For this reason they are viewed as interim criteria for the purpose of the design of the scheme and the initial operation.

6.3 COVERAGE OF THE CRITERIA

Criteria are needed to cover the area where groundwater impacts (ie water table changes) are likely to occur. These changes can be predicted with reasonable confidence using a computer model of the groundwater and wetland system (see Appendix 11). It is predicted from modelling that the impacts of Jandakot GWS will generally be contained within the area bounded by Thomsons Lake to the west, Forrestdale Lake to the east, North Lake to the north and The Spectacles to the south. It is this area, previously referred to as the "Jandakot Area", that the criteria are intended to protect.

It is not possible to set criteria to cover every aspect of the environment of the Jandakot Area. This is partly due to a lack of data which is dealt with further in section 6.7. However, given the nature of the groundwater system, satisfying a limited but carefully chosen set of criteria will provide comprehensive protection. Similar logic was used by the EPA when recommending criteria for the Gnangara Mound Groundwater Resources ERMP (EPA, 1987c). The EPA assumed that appropriate protection of the wetlands from regional-scale drawdown would protect much of the surrounding vegetation, the associated fauna and other environmental values.

Wetlands

Of the natural environment in the Jandakot Area, this PER concentrates on the wetlands because:

- they are a sensitive part of the total environment. The protection of which will, to a large degree, protect the surrounding environs,
- of their important role in the life cycle of fauna, particularly as breeding grounds,
- they provide natural drainage systems, recreational and educational opportunities, and
- of the relative wealth of data on wetlands. This allows the development of realistic and practical criteria.

Terrestrial Environment

Little is known of the water needs of the dry land vegetation of the Jandakot Area. Research is underway to provide the information necessary for future management. In the interim, conservative criteria will be used to protect known areas of important vegetation. This will also protect the associated components of the terrestrial environment.

6.4 CHARACTERISTICS OF CRITERIA

In practice environmental criteria often need to be complex and are largely determined by our current state of knowledge. Environmental criteria must:

- ensure that the objectives are met,

and should, where possible:

- be easily applied,
- be simply tested,
- be understood by the general public,
- allow management flexibility, and
- be able to be modified as better information becomes available.

Environmental criteria are standards to be used to ensure that environmental objectives or aims are met. There is little to be gained by satisfying criteria which do not do this. These objectives are outlined in the following section.

It is also important that the criteria can be easily applied. This means that they must be readily measurable. For example: 'the minimum water level in Hypothetical Lake is 5.0 metres above AHD. Also, it is preferable once the scheme is operational that compliance with the criteria can be checked without complicated equipment so that the general public can check compliance for themselves.

Criteria need to be readily understood by the public. This allows the public to critically examine the criteria on which the scheme is based. In turn, they can assess the likely environmental impacts of the scheme.

Criteria that allow some management flexibility give a greater opportunity for the groundwater resource to be used efficiently. Criteria that do this are referred to as 'flexible criteria' in this PER and are discussed further in section 6.5.1.

As already stressed in this PER, criteria will change. Most criteria consist of 'what', 'where', 'when' and 'how much'. Take the following example:

what	where
The minimum water level	in Hypothetical Lake

is 5 metres above AHD.
how much

Note that the 'when' in this example is anytime. When a criterion is changed it is usually the value (the 'how much') and the 'when' that are altered. If either the 'what' or 'where' is altered this would probably constitute a new criterion. It is acknowledged that any of the above changes may be required to the interim criteria presented in this PER.

6.5 OBJECTIVES BEHIND THE CRITERIA

Objectives can be set on many different levels. There are objectives which apply to the entire geographic area or system under consideration, these are termed 'system objectives' in this PER. Similarly, objectives which apply to sub-areas or components of the system, such as individual wetlands, are referred to as 'local objectives'.

When selecting environmental criteria it is important to recognise the fundamental environmental management objective. In this case, it is the conservation, including where feasible, enhancement, of the present environmental values, and includes the retention of the diversity of wetlands. This is consistent with the System Six Study (DCE, 1983) recommendations for the area and more generally the State Conservation Strategy for Western Australia (DCE, 1987).

The World Conservation Strategy (International Union of Conservation of Nature and Natural Resources, 1980) defined conservation as:

> The management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations. Thus conservation is positive, embracing preservation, maintenance, sustainable utilisation, restoration, and enhancement of the natural environment. Living resource conservation is specifically concerned with plants, animals and micro-organisms, and with those non-living elements of the environment on which they depend. Living resources have two important properties the combination of which distinguishes them from non-living resources: they are renewable if conserved; and they are destructible if not.

Managers of groundwater abstraction must recognise that conservation and sustainable development are fundamentally linked by their dependence on living resources (EPA, 1990b). However, groundwater abstraction is only one of many factors which influence the groundwater resource and dependent living resources. Management of groundwater alone will not ensure that all of the objectives of conservation are met.

Conservation of the living resources will require integrated management by the responsible Government agencies.

It is important to ensure that management of groundwater use is consistent with the broader conservation objectives of integrated management.

The environment of the Jandakot Area will continue to change as a result of both natural and artificial processes, as discussed by Ninox (1988):

> There is no place for fixed philosophical or radical stances; the Jandakot wetlands and their wildlife will change and potentially degrade even without the planned housing development or the proposed extensions to the Jandakot groundwater scheme.

The management criteria proposed in this report need to be flexible enough to accommodate such changes in the environment. Accordingly they are proposed as interim criteria and are likely to be frequently reviewed when compared to the lifetime of the wetlands. These reviews will occur as knowledge of the components and function of the natural systems of the Jandakot Area improve and the community's expectations evolve.

To optimise the use of the resource it is necessary to have a flexible operating strategy coupled with criteria to protect a dynamic environment. This generally leads to a complex set of criteria being required. One case where criteria are relatively simple is when aesthetic considerations dominate the management objectives.

The above assertion that detailed and, unfortunately, complex criteria are often required is supported by Research Group on Groundwater Management (RGGM, (1989) who stated:

> ... for individual wetlands, simplistic rules regarding water levels run the risk of simplifying the biota compared to that which has evolved under a more natural variable regime, reducing both the value and the resilience of the wetland.

6.5.1 System objectives

Private and Public Use

Private and public users of groundwater generally want to regularly abstract similar quantities of water on an annual basis. Such security of supply allows advance planning which results in more efficient use of the groundwater resource. However, several facts confront the groundwater manager who wishes to abstract a regular quantity of groundwater within the concept of sustainable yield:

- the level of the water table at the end of the abstraction period (currently around May) has a dependence upon the level at the beginning of summer,
- it is not possible to predict what the exact annual draw will be for any particular year; or alternatively, given the water table level at the beginning of a year and the volume of water to be extracted, it is not possible to predict the exact end of year level,
- the average annual quota can be predicted with reasonable accuracy for longer periods (ie several years), and
- the annual draw for any single year is likely to vary far more than the average annual quota based on the sustainable yield over several years.

Given these facts, it is practical to annually abstract a uniform quantity of groundwater based on the average annual quota. This would result in minimum water table levels which vary from year to year. Because end of year water table levels vary and can not be predicted exactly, operating strategies based on criteria with flexible minimum water levels are required. When compared to fixed or rigid criteria, flexible criteria allow more efficient use of the groundwater resource. This does not mean that protection of the environment has to be compromised.

The period over which the average annual quota is calculated will vary. As a general rule, 'the period' will be as long as possible but shorter than the time over which significant climate and land use changes in areas affecting the aquifer occur.

Environmental Use

The *primary environmental objectives* are:

- the maintenance of essential ecological processes,
- the preservation of genetic diversity, and
- the optimisation of the quality of life for Western Australians.

The first two are consistent with the aims of the World Conservation Strategy (International Union of Conservation of Nature and Natural Resources, 1980) and National Conservation Strategy (Department of Home Affairs and Environment, 1984). The third is from the State Conservation Strategy (DCE, 1987).

Biological diversity conventions and strategies are discussed in 'Save the Bush' (Department of Arts, Sport, the Environment, Tourism and Territories, 1989).

In determining criteria a number of important assumptions are made:

- that genetic diversity is expressed at the species level as species diversity, and
- that habitat diversity is essential for and a good indicator of species diversity (MacMillan, 1986). To evaluate the latter criterion it is necessary to have an accepted list of wetland habitat types requiring maintenance.

On the subject of diversity the Research Group on Groundwater Management (RGGM, 1989) stated:

> ... much of the ecological value of the wetlands lies in their diversity, and this diversity gives the regional wetland system as a whole a greater resilience to withstand and recover from stresses than a more uniform system. However, management of the groundwater according to uniform rules which do not reflect the differences between wetlands would tend over time to produce greater uniformity.

Therefore rigid criteria which impose uniformity are not compatible with the aim of maintaining genetic diversity.

The *secondary objective* is:

- the maintenance of species abundance.

The maintenance of abundance requires a more detailed management programme than to maintain genetic diversity. Given the current lack of biological data it is not feasible to try and determine criteria for such a programme. To compensate for this, regular feedback on abundance must be provided via monitoring and criteria modified as necessary.

Criteria for Private, Public and Environmental Use Objectives

Inflexible environmental criteria which impose uniformity are not consistent with the objectives of public and private users and the environment.

The objectives of the environment and public and private users can be best achieved if criteria (eg preferred minimum water levels) result in hydrological regimes which mimic nature. For example, preferred minimum water levels would be lower in dry years when water levels would naturally have been lower.

To ensure the maintenance and sustained use of the system as a whole it is necessary to put bounds on the 'mimicking'. This could be, for example, in the form of fixed absolute minimum levels.

To meet the secondary objective of abundance, a monitoring programme must be set up to provide regular feedback. Criteria need to be modified as necessary based on the results. Monitoring will also need to be used to check diversity.

6.5.2 Local objectives

Specific management objectives for a number of wetlands have been reported in section 5.3.1. In planning the Stage 2 abstraction scheme the Water Authority has adopted those objectives as a starting point for management.

6.6 SPECIFIC FACTORS

Some specific factors which should be considered when setting criteria for individual wetlands are:

Seasonality (Drying Out)

Seasonal wetlands form a valuable part of the Jandakot Area environment because of their high species diversity. However, maximum species diversity also requires permanent water bodies. Therefore a conservative approach is to ensure the maintenance of a range of wetlands from permanent to seasonal.

Invasive Vegetation

Invasive vegetation, such as bulrushes, provide habitats for some fauna species, however they can spread rapidly at the expense of other habitats. Large changes in the area of bulrushes are undesirable if the current values of the system are to be preserved. Note that this is considered to be more of a problem for *Typha* spp. than *Baumea* spp.

Paperbarks and Flooded Gums

Paperbarks (*Melaleuca* spp.) and flooded gums (*Eucalyptus rudis*) require moist soil conditions and when inundated provide ideal habitats for waterbird nesting and loafing. They should be periodically inundated where possible.

Banksias (and Other Trees)

Banksias form important woodlands in the Jandakot Area. Studies on the Gnangara Mound indicate that deaths of phreatophytic trees (ie, roots into the water table) occur when the water table drawdown reaches around two metres over a relatively short period (Dr E Mattiske, pers. comm. 1989). This is a guide to the maximum water table drawdown that can be tolerated in a short period (ie, one year).

Historical Water Levels

The existing vegetation distribution has occurred in response to past water levels, particularly over the last few decades (Alpin, 1975; Mattiske, 1988), and can be used to provide an indication of those levels. The system should be managed so that water levels are close to past levels where possible. This is discussed further in section 6.8.1 and is the subject of several research projects (Appendix 2).

Aesthetics

Local residents expect aesthetic criteria to maintain high water levels unless there is some clear reason to the contrary. This is particularly so for wetlands sited closer to residential areas.

The Public

The diversity of social values within the system should be maximised. Residents in Jandakot expect environmental criteria to preserve wetlands, flora and fauna. Equally, residents wish to be able to draw groundwater for their own use and to have access to a public water supply system.

Recreation

A wide variety of wetlands are required to meet the full spectrum of recreational uses. Bibra Lake is the focus for more structured leisure activities involving formal picnic and children's play facilities. The aesthetic values of this group of users, such as presence of open water, are particularly important at such lakes. In addition, recreational facilities such as cycle paths and picnic areas should preferably not be flooded.

Tenure

The tenure, vesting, the condition of a wetland and its potential for disturbance need to be considered when determining the priority uses for each wetland. This has already been taken into account for the wetlands listed in Table 6.1.

Development

Wetlands close to existing residential developments generally have higher nutrient loadings, less buffer vegetation and raised water levels due to increased recharge and runoff. The proposed South Jandakot urban development (SPC, 1986), if proceeded with, will change the surrounding water balance and impose further impacts on the system which need to be taken into account. Measures to mitigate these impacts are currently under consideration by DPUD.

Midges

For lakes such as Yangebup, Forrestdale, Bibra and North, a reduction in midge numbers would be considered to be desirable. However, the only effective way of controlling midges by water level changes is to dry the lake out completely (Davis *et al.*, 1988). With the exception of Forrestdale Lake, this is not consistent with the other objectives contained in this PER.

Flooding

Flooding, or for that matter a perceived threat of flooding, is unacceptable to residents. However, groundwater abstraction by the Jandakot GWS will not provide a mechanism for flood control. The Technical Advisory Group's report to the EPA (EPA, 1989a) stated:

> ... compared to the peak flows generated by a significant storm, the pumping rates attainable by bores linked to the public supply are quite low. Furthermore, due to ground conditions it may be many weeks before the water table over the wide area responds to any pumping initiative. Therefore, irrespective of the economic argument of whether or not dam storages should be used in preference to groundwater resources in winter, the operation of a public water supply borefield cannot be considered as an acceptable "drainage" strategy for coping with extreme rainfall events ...

Alternative Bird Habitats

A knowledge of alternative habitats assists in putting the importance of the Jandakot wetlands into a regional context. Also, some alternative habitats can have populations from which recolonisation can occur, thus the reversibility of the groundwater scheme impacts can be evaluated.

Nutrients

As discussed in section 5.2.1 of this report, in general, water levels do not influence the 'average' nutrient status of wetlands to any detectable degree (O'Brien, 1988). Therefore, in relation to this project, it is not considered necessary to incorporate criteria for the general management of nutrients. The exception to this is specific wetland situations in which significant increases in nutrient concentrations result from evaporation of shallow water. This is discussed further in section 6.8.2

Food Chains

Food chains are discussed in section 6.8.3.

6.7 SUMMARY OF AVAILABLE DATA AND EXISTING CRITERIA

Because of the complexity of biological systems, including wetlands, and the scarcity of data on them, it is the available data that largely determines the type of criteria that can realistically be set.

There are vegetation, water level and bathymetric data for North, Bibra, Yangebup, Kogolup, Thomsons and Forrestdale Lakes. CALM are the managers of the 'A' class reserves — Thomsons and Forrestdale Lakes, and have established criteria for these lakes. The Spectacles and Banganup Lakes are also important wetlands for which there is some water level information and the deepest points are known. Little is known of the seasonally inundated wetlands higher on the mound. System Six areas in or near Jandakot are M93 (Cockburn Wetlands — Eastern Chain), M94 (Jandakot Airport), M95 (Forrestdale Lake), and M97 (Wandi) (see Figure 5.5). Other areas of possible significance include (LeProvost *et al.*, 1987b):

- Bartram Road Complex,
- Beenyup Road Swamp,
- Twin Bartram Swamp,
- Solomon Road Wetland, and
- the area enclosed by Lyon, Gibbs, Beenyup and Gaebler Roads

The availability of data on wetlands is summarised in Table 6.1

The ecological function of the wetlands, individually and as a system, is complex. A number of components of the ecosystem are better understood than others and are believed to represent good indicators of system function. These components are:

- the water regime, (see Winter, 1988; Townley and Davidson, 1988), which is clearly fundamental to the wetlands existence,
- vegetation, which performs many functions, including its habitat value for fauna (see Carter *et al.*, 1978),

Table 6.1 Available or currently being assessed (A), limited (L), and required (R) data for wetlands as drawn from O'Brien (1988) and the Water Authority (1988).

LAKE	WATER	BATHYM.	VEGETN.	FAUNA		QUALITY	
	Levels	Bottom		W.birds	Aquat.	Nut.	Chem
NORTH	A	A	A	A	A	A	A
BIBRA	A	A	A	A	A	A	A
SOUTH			A	A			
LITTLE RUSH	A		A	A	R	R	R
YANGEBUP	A	A	L	A	A	A	A
KOGOLUP (S)	A	A	L	R	A	A	A
THOMSONS	A	A	A	A	A	A	A
BANGANUP	A	L	A	R	A	A	A
WATTLEUP	A	R	L	R	A	A	A
SPECTACLES	L	L	L	R	A	A	A
FORRESTDALE	A	A	A	A	A	A	A
HIRD RD			L	R			
TWIN BARTRAM			L	R			
BARTRAM	L	R	L	R	A	A	A
SOLOMON			L	R			
RUSSELL			L	R			
GAEBLER			L	R			
BEENYUP			L	R			
BRANCH RD			L	R			
MATHER RES.	L	R	R	R	L	L	R
BORONIA RD SWAMP			R	R			
COPULUP			R	A			

- water birds, which are the most frequently and readily monitored high order consumers (see DWRV, 1988; Weller, 1988), and
- macroinvertebrates, which are recognised as a very important element of wetland food chains(see EPA, 1987c and Appendix 2).

Together these components present a broad picture of the wetlands status and function. As such they are believed to represent good indicators for system monitoring and management of groundwater abstraction.

6.8 SOME PRACTICAL CONSIDERATIONS

This section contains information and conclusions which need to be taken into account when setting criteria for the Jandakot GWS Stage 2 development.

6.8.1 Water levels

The present condition of the environment is a highly valued one and should be used as a guide to determining criteria (O'Brien, 1988). However, due to variations between lakes it is difficult to determine a representative period for water levels. As a guide, and consistent with the earlier definition of conservation, a water level range that is representative of the levels to which the vegetation has been subject (ie adapted) in the last few decades should be used. However, artificially rising water levels in some northern lakes need to be accounted for.

6.8.2 Water quality

As discussed in section 5.2.1 of this report, water levels do not influence the 'average' nutrient status of wetlands to any detectable degree (O'Brien, 1988). It can be shown that dissolved ion concentrations can increase by up to five fold just prior to a wetland drying out. The same concentrating effect will apply to nutrients such as phosphorus and nitrogen, however, this will be modified by the wetland biota and assimilation and release from sediments (McComb and Lukatelich, 1986; Gachter, 1987).

Other water quality issues will be addressed in an Environmental Protection Policy (EPP) which the EPA is preparing for the Jandakot Mound. Water quality criteria, which the EPA propose to develop for freshwater systems, will provide guidance for land managers to ensure the protection of wetlands from pollution.

6.8.3 Food chains

A food chain or web is an energy path or sequence of links that shows who eats whom or what (see Appendix 9). However, it is difficult to measure the exact sources and quantities in a food chain and to document the functional relationships within food chains (Preston and Bedford, 1988). A further complication is that food chains are influenced by changes in the physical environment other than those due to the groundwater abstraction (see Klopatek, 1988). Because of these difficulties, it is not possible to accurately predict, at present, the impacts on food chains due to groundwater abstraction. However, several indicator groups can be used to monitor the 'health' of the wetland food chains. This is discussed further in section 10.6.3.

6.8.4 Climatic variability

Both short-term variability and long-term changes in the climate need to be considered.

CALM recognises climatic variability by using the wettest 10%, middle 80% and driest 10% of years on record as a basis for setting criteria. For example, if the last year was in the 10% wettest on record, the minimum allowed water level in Hypothetical Lake might be 10.0 metres AHD, however, if the last year was in the driest 10% on record the minimum allowed water level might be 9.5 metres AHD. This is consistent with mimicking natural variation. A similar approach is used in this PER (see section 7.1.4), although that used here is based on a 75 year climatic record while CALM's classification of rainfall years is based on a 10 year period.

Possible long-term changes, such as those which may be associated with the 'greenhouse effect', will need be taken into account in the future. However, there is little point in allowing for these effects in the interim criteria in this PER because of the criteria's short-term nature. This may be more appropriate once the research projects listed in Appendix 2 are completed.

6.8.5 Aquifer response

It is difficult to predict the behaviour of an aquifer for any particular year because of variability in factors such as the amount of rainfall and evapotranspiration.

This is further compounded by the 'lagging' of impacts on the aquifers. This refers to changes (eg in rainfall) that have already occurred but whose impacts persist for some time. For example it may take many years of average rainfall for water table levels to recover after a period of below average rainfall years.

Lagging also applies to artificial changes such as pumping. Should water levels decline in wetlands, stopping abstraction from wells other than those situated very close to the affected wetlands, will have little effect in the short-term. Thus careful management and planning are of paramount importance.

6.8.6 Artificial maintenance of wetland water levels

During low rainfall sequences, environmental criteria may not be satisfied without active management in some areas, particularly wetlands. In such cases it is often economic to artificially maintain water levels in the wetland to meet environmental criteria. This has already been done on the Gnangara Mound by adding groundwater to Lake Nowergup and Lake Jandabup.

Adding water to a freshwater system can have a number of effects, including:

- changes to the water quality,
- alteration of the temperature, and
- formation of an intrusive bottom layer by recharge water.

Since most dynamic processes in shallow water bodies are driven by energy fluxes through the surface (ie wind and sun) the amount of mixing in wetlands of similar depths will be the same. Therefore, detailed measurements on the mixing behaviour in North Lake can be applied to other wetlands in the Jandakot Area. The expected behaviour is as follows:

> When the wetland is thermally stratified, recharge water flowing into the wetland will reside on the bottom. On a hot summer day the stratification may be up to 2°C m^{-1}. The wetland will probably mix over its full depth once or twice a day under typical conditions.
>
> For typical artificial recharge rates, the addition of water will not alter the temperature differential from top to bottom since the bottom layer would consist of cooler groundwater. However, a marginally thicker layer of 'cool' water will form in the bottom of the wetland during the stratification phase. Once the lake mixes, the temperature of the lake may be up to 0.1°C lower than it would have been without the addition of recharge water. The marginal cooling effect from the groundwater is considered to be minor compared to the magnitude of other heat inputs.
>
> Given the high nutrient levels in most wetlands in the Jandakot Area, artificial maintenance is likely to lead to reduced concentrations of nutrients such as nitrogen and phosphorus. However, any recharge water that contains even small amounts of nutrients will add to the overall nutrient loading of a wetland. Therefore, it is important that only groundwater of a suitably high quality is used.

The five major wetland research projects currently underway (see Appendix 2) will provide effective monitoring of artificial maintenance on the Gnangara Mound. This information will assist in designing and operating artificial maintenance schemes in the Jandakot Area. A primary consideration will be that artificial maintenance regimes mimic natural water level fluctuations of wetlands.

6.9 MANAGEMENT/MONITORING

Changes in water levels should be imposed gradually in environmentally sensitive areas. At present the Water Authority is conducting trials involving phasing-in well production over three years in an area of Banksia woodland on the Gnangara Mound. This is to allow the woodland to adapt to the new water level regime without undue stress.

Active management of wetland water levels must be considered as an option. This could be for two foreseeable purposes:

i) artificial recharge of a particularly sensitive local area so that, overall, more water can be drawn from the surrounding aquifer, or
ii) artificial recharge to maintain critical aspects of a wetland in a drought period, despite pumping from wells having been suspended.

It is important that the reliability of such methods is addressed, and the responsibilities of the various Government agencies, identified.

Monitoring of criteria compliance needs to be undertaken to ensure that objectives are being achieved. If monitoring reveals that criteria are not being satisfied, and the Water Authority wants to continue operating the abstraction scheme it is recommended that it must either:

- demonstrate to the satisfaction of the EPA that the breach of criterion is caused by a factor unrelated to groundwater abstraction and water levels, or
- show to the satisfaction of the EPA that the breach of criterion is a transient phenomenon and that the situation will be restored to its pre-existing condition within an agreed period (ie the effect is temporary and reversible). For example, numbers of a particular waterbird species may decrease in the Jandakot Area but may exist in sufficient numbers in other areas and be able to recolonise, or
- if neither of the above is acceptable to the EPA, take the agreed action listed against the

relevant critical level in section 7 of this PER or as determined by the Minister for Environment in the conditions for the implementation of the project.

If in the course of time it is shown that a critical level and/or its associated action does not adequately serve its purpose as stated in the Minister's conditions, then a review would be appropriate.

6.10 THE APPROACH TO RECOMMENDING CRITERIA

The multivariate approach so often used for ranking wetlands does not necessarily highlight special features that a site possesses. Equally, considering the components of the system separately can lead to an integral part of the system being neglected. This is demonstrated by the following analogy (Preston and Bedford, 1988):

> Imagine a Renaissance mosaic of mother and child, composed of tiles of various shapes and colours. If conventional environmental assessment strategies were used, the tiles would be evaluated in terms of their individual intrinsic value. This strategy would not preserve the image of the mother and child. Yet the image is the feature making the mosaic more valuable than the sum of the values of its component tiles. If the image in the mosaic is to be preserved, the value of each tile must be determined by its importance in conveying the central image of the mosaic.

Therefore, a combination of these two methods should be the most effective means of achieving the desired conservation goals (this is discussed in Environmental Management, 1988). In the 'A' Class nature reserves the criteria set by CALM will be adhered to. Criteria are recommended for the major wetlands and all System 6 areas. Elsewhere the emphasis is on maintaining habitat diversity within the wetland system. The impact on seasonally inundated wetlands higher on the mound is examined although there is some doubt as to future land use over much of this area.

The Procedure

The broad procedure or algorithm for determining acceptable groundwater scenarios is as follows:

1. Set environmental criteria (see section 7) based on the philosophy described in the above section.
2. Select an operating strategy and use a computer model to predict the likely water regime (see section 8).
3. Check that the model predictions satisfy the criteria and examine impacts (see sections 8 and 9). Run other strategies if necessary.
4. Implement the selected operating strategy and monitor the actual impacts (see section 10). Change the strategy and refine the computer model if necessary.

7 Environmental Criteria

The aim of the environmental criteria presented in this section is to protect those aspects of the environment which might otherwise be unacceptably affected by groundwater use. These criteria are based on the philosophy expressed in section 6.

The criteria are intended to protect the valued attributes of wetlands, their function as a system and the remnant native vegetation in the Jandakot Area. As discussed in section 6, it is expected that these criteria are sufficient to protect most unspecified components of the environment (eg the smaller wetlands which are not specifically addressed in the PER such as South and Little Rush Lakes). Criteria are recommended for protection of the following:

- terrestrial habitats,
- Thomsons and Forrestdale Lakes,
- other major wetlands,
- the wetlands as a system, and
- air quality.

7.1 INTRODUCTION

7.1.1 Types of criteria

To make maximum use of the groundwater resource it is important that the criteria are used as a basis for both the design and operation of the groundwater scheme. For example, if public abstraction wells are not appropriately located, environmental constraints may limit the amount of water that can be abstracted. Poor design or planning could be expensive to correct once the scheme is operational.

To this end some criteria are only intended to be applied at the early planning and design stages. These are referred to here as *'design criteria'*. Other types used here are *'operational criteria'* and *'action criteria'*. Operational criteria help define targets for the operation of the scheme and are used at both the design and operational stages. However, due largely to factors outside the Water Authority's control, it will not always be possible to satisfy the operational criteria. On these rare occasions, action criteria ensure that the environment is protected. They specify when corrective action must be taken and may specify what action will be taken. Hypothetical examples of these criteria are given in Table 7.1.

Table 7.1 Types of environmental criteria.

TYPE	EXAMPLE
DESIGN	Wells shall not be placed closer than 150 m to "Hypothetical Lake".
OPERATIONAL	Minimum water levels in "Hypothetical Lake" shall preferably be between 11.0 and 11.2 metres AHD.
ACTION	Water levels in "Hypothetical Lake" must not go below 10.8 metres AHD.
	associated action — artificial recharge of "Hypothetical Lake" to maintain a minimum water level of 10.8 metres AHD.

7.1.2 Compliance with criteria

Guides and Rules

Criteria can be divided into those that are a guide for managers and those that are rules and must be followed. Guiding criteria use wording such as: 'preferred' and 'should'. Criteria that are rules use wording such as: 'absolute' and 'shall'. Most operational and design criteria are guides, but all action criteria are rules.

In Practice

A computer model is used to assess alternative strategies. Guiding criteria are then applied, as follows, to determine acceptability of operating strategies:

- in the case of minimum water level ranges (except for Thomsons Lake) — minimum water level predictions from the computer model must fall within the specified range at least 95% as often as they currently do (see Table 8.3), and
- in the case of water table drawdown over large areas — drawdown predictions from the computer model must be less than the specified drawdown for at least 95% of the area (drawdown cones excluded).

Allowing guiding criteria to be breached for 5% of years or 5% of area allows a lot more water to be drawn with minimal 'additional' impact on the environment.

Operational criteria for maximum water levels are included because the groundwater scheme will help reduce high water levels in some areas. These are not action criteria because the scheme cannot be used to directly manage high water levels.

7.1.3 The Baseline

For the purpose of criteria relating to changes in water table level, the changes are relative to the current situation. The predicted changes in water levels shown in this report represent the average change in annual minimum water level based on a computer simulation that used climatic data recorded for Perth over the last 75 years.

7.1.4 Effective Rainfall

As discussed in section 6.8.5, the aquifer has a lagged response to rainfall. This can result in, for example, low water levels following a very wet year if the preceding years were drier than average. An 'effective rainfall' which takes into account the rainfall over several years can be calculated from:

$$\text{effective rainfall} = \frac{4 \times YR1 + 3 \times YR2 + 2 \times YR3 + YR4}{10}$$

where YR1 is the rainfall this year, YR2 is the preceding year's rainfall, YR3 is the rainfall for the year before that etcetera.

When criteria in this PER are based on rainfall it is the effective rainfall that is used.

A 'wet year' is when the effective rainfall is in the 10% of wettest years on record, a 'dry year' is when the effective rainfall is in the 10% of driest years on record and a 'medium year' is for the other 80%. An analysis of Perth's rainfall records (see Figure 7.1) shows that it is a 'dry year' when the effective rainfall is less than 750 millimetres and a 'wet year' when it is greater than 1,010 millimetres.

7.2 TERRESTRIAL CRITERIA

The terrestrial criteria recommended in this section are designed to minimise the impact of the GWS on remnant areas of native vegetation and seasonally inundated wetlands higher on the mound which are identified as being environmentally sensitive.

7.2.1 Drawdown cones

Of the local effects which need to be taken into account when designing the scheme, the most obvious is the drawdown cone surrounding each well. Experience on the Swan Coastal Plain has shown that these typically extend more than 1 km, from the well, however the bulk of the cone is within 500 metres. In addition, drawdowns of 2 metres in a year can lead to phreatophytic vegetation dying (see section 6.6). Based on this, the following criteria are designed to minimise the impact on the terrestrial habitat from drawdown cones:

- as a design criterion, wells should not be placed closer than 300 metres to natural non-degraded sumplands (seasonally inundated wetlands) and preferably not closer than 500 metres. Note that this is based on the "core area" of the wetland as determined by Middle (1988) and LeProvost *et al.* (1987). Pump testing will provide further details as to the nature of the drawdown cone.
- Wells shall not be placed closer than 200 metres to System Six area M94 and preferably not closer than 400 metres as a design criterion.
- Any well whose drawdown cone is estimated to be greater than 1.5 metres deep in environmentally sensitive areas will have its draw phased in evenly over a three year period. Estimates will be based on the results from pump tests. For the purpose of this criterion, environmentally sensitive areas include:
  - System 6 areas,
  - the potentially significant wetlands between Thomsons Lake and Forrestdale Lake in the South Jandakot Urban Development area as identified by LeProvost *et al.* (1987) (see Table 5.4), and
  - the *Banksia* woodland vegetation bounded by Lyons, Gibbs, Gaebler and Beenyup Roads.

The above criteria mean that damplands, which are waterlogged as opposed to seasonally inundated with water, are not specifically addressed by these criteria. However, their vegetation is generally protected by the criteria given in the following section.

7.2.2 General drawdown

Water table drawdowns of around 2 metres are believed to have led to the deaths of phreatophytic trees on the Gnangara Mound (E. Mattiske, pers. comm., 1989). Further, CALM have stated that they do not support water table drawdowns in excess of 1 metre in areas of Banksia woodland vegetation. Therefore, to maintain native vegetation:

- as a design criterion, drawdowns must not exceed 1 metre in areas of phreatophytic native vegetation.

As already mentioned, design can only be based on average values. However, in practice, water levels may be less than or greater than the predicted value due to local anomalies in the aquifer. The following criterion allows for some of the effects of these anomalies while protecting the native vegetation from extreme drawdown:

- actual drawdowns should be less than 1 metre in areas of phreatophytic native vegetation and in no case shall exceed 1.5 metres.

For the purpose of this criterion, phreatophytic vegetation is assumed to only occur where the depth to the water table is less than 5 metres. The areas specifically protected by the criteria are shown in Appendix 7 and Figure A7.2.

7.2.3 Rare flora

Five declared rare species of orchids have been found around the eastern and southern boundaries of the Jandakot PWSA. Van Leeuwen (1989) stated "orchids will not be directly affected by the drawdown of the existing water table levels ..." However, the orchid assemblage may be affected by changes in the surrounding vegetation. To ensure the maintenance of vegetation composition in areas where rare orchids grow:

- in areas where rare species of orchids are known to occur, drawdowns should be less than 0.5 metres and must be less than 1.0 metres.

Liaison will be maintained with CALM regarding the location of rare flora.

7.2.4 Seasonal wetlands of potential significance

Very little is known about the seasonal wetlands higher on the mound. However, it is known that some of these wetlands play an important role in the breeding of waterbirds. Based on the information presented in sections 5.2.1 and 5.2.4, the following operational criterion is designed to maintain the breeding role of these wetlands:

- The Bartram Road Wetland Complex and Twin Bartram Swamp should preferably contain water until the end of January.

Beenyup Road Wetland and Solomon Road Wetland are significant for non-aquatic species of vertebrate. Such wetlands can tolerate larger changes in water level than those used by waterbirds for breeding. LeProvost *et al.* (1987) listed four categories of possible change in wetland vegetation. However, they did not indicate the corresponding water level changes which result in these categories. From their conclusions it appears that they believe a drawdown of around 0.4 metres will result in partial death of wetland vegetation and adjustment of remaining vegetation. Therefore, to maintain non-aquatic vertebrate habitat:

- Water table drawdown in Beenyup Road Wetland and Solomon Road Wetland should preferably be less than 0.3 metres.

7.3 THOMSONS AND FORRESTDALE LAKES

Both Thomsons and Forrestdale Lakes are 'A' Class reserves which are managed by the Department of Conservation and Land Management. Accordingly, existing criteria set by CALM are used here as a basis for recommended criteria.

7.3.1 Thomsons Lake

CALM's original criteria for Thomsons Lake are listed in EPA Bulletin 371 (EPA, 1989a). However, in a letter dated February 1, 1990, and at the Water Authority's request, CALM clarified these criteria and reconfirmed their objectives for lake management. In part this letter states:

> The objective is to protect the ecological character of the lake and, in particular, its importance as a waterbird habitat.
>
> *Strategies*
>
> 1. Lake levels must remain linked to the natural course of events associated with the environmental attributes of the catchment. The main determinant of this process is that the link between lake levels and the natural rainfall patterns must be maintained.
> 2. Lake levels must reflect the natural seasonal patterns. That is highest in winter, dropping over summer and lowest, usually dry, in late summer or autumn. Water levels are not to be held at an artificial and constant level.
> 3. To minimise sudden rises in water levels due to artificial sources of water. If such rises are in conflict with either 1 or 2 above, the excess water shall be removed as soon as possible.
> 4. To prevent any increases in nutrient input into the lake and where possible reduce nutrient input.

CALM's water level criteria are shown in Table 7.2.

Table 7.2 CALM's criteria for water levels in Thomsons Lake. All water levels are in metres AHD.

	WINTER/ SPRING MAX.	SUMMER/ AUTUMN MIN.	VISUAL IMPACT	%FREQUENCY
wet years	> 13.3	> 11.8	Lake does not dry	10
medium years	12.8 (approx)	11.3-11.8	Lake dries out between January and April	80
dry years	> 12.3	10.8-11.3	Lake dry by January	10
never		< 10.8		0

(note: deepest point is at 11.8 metres AHD)

While recognising the difficulties in meeting these criteria precisely, CALM recommended that the above levels be met 80 percent of the time.

For the purposes of managing the impacts of groundwater abstraction on the lake only the lower end of the minimum water level ranges need to be considered. These levels are currently satisfied in 30% of years (Table 7.3). The figure of 30% was derived from a computer simulation based on current land use and groundwater abstraction and using climatic data for the 75 years from 1912 to 1987.

Table 7.3 Current performance of Thomsons Lake compared to CALM's recommended criteria (in brackets). Values are frequency of occurrence.

Rainfall	Minimum Water Levels (metres AHD)				
	<10.8	10.8-11.3	11.3-11.8	>11.8	
wet	0 (0)	0 (0)	0 (0)	11 (10)	
medium	0 (0)	1 (0)	11 (80)	67 (0)	
dry	0 (0)	9 (10)	1 (0)	0 (0)	
TOTAL	0 (0)	10 (10)	12 (80)	78 (10)	= 100

Clearly, the aim of the CALM criteria is to protect the ecological character of the lake, in particular its value as a waterbird habitat. On the basis of the Water Authority's modelling, this would require having lower water levels than the lake would experience under current land use and abstraction, particularly in medium rainfall years. The modelling would suggest, however, that CALM's criteria cannot be met for 80% of the time without active management to lower water levels in the lake. As such, the Water Authority proposes that the CALM criteria be used as a goal for current and proposed management. An appropriate criterion for Thomsons Lake which is consistent with this aim is:

- as a design criterion, water levels in Thomsons Lake must satisfy those given in Table 7.2 for at least 30% of years (this will be an improvement on the present situation and moves towards CALM's objectives in managing the lake).

As a design criterion, the acceptability of a particular scheme operating strategy can be evaluated over a 75 year computer simulation. However, it is not feasible to test for this criteria over a period of a few years or even over a decade. For this reason, management of water levels in Thomsons Lake will need to rely on the design criteria, and the model simulation which shows that these criteria will be satisfied. In line with this, actual water levels will be compared to the predicted water levels from the model simulation to detect any deviations away from the 'accepted' scenario. The annual deviations will be averaged over a four year period to determine whether they are significant or not. In addition, there will be a maximum allowable deviation in any one year.

Operational and action criteria are then as follows:

- the average annual deviation over a four year period from the predicted water levels in Thomsons Lake must not be greater than 0.1 metres. This will be calculated as per the following example:

	Year 1	Year 2	Year 3	Year 4
actual water level	11.2	11.6	11.1	12.2
predicted water level	11.0	11.8	11.2	12.3
difference	0.2	−0.2	0.1	0.1

average deviation = (0.2 − 0.2 + 0.1 + 0.1) / 4 = 0.05

- should the deviation between the actual and predicted minimum water level in Thomsons Lake exceed 0.25 metres in any one year, this must be reported to the EPA as soon as possible, and
- the minimum water level at Thomsons Lake must never go below 10.8 metres AHD.

The validity of the computer simulations with regard to Thomsons Lake will be reviewed and reported to the EPA on a triennial basis.

7.3.2 Forrestdale Lake

CALM's criteria for Forrestdale Lake are:

- at least 0.9 metre of water in the lake when water levels are at their annual maximum (the deepest point is at 21.6 metres AHD), and
- a natural cycle of filling and drying should be allowed to continue.

Additional environmental criteria are recommended here to ensure that the 'natural cycle' continues. Based on water levels over the last decade (i.e. 1978-1988) these criteria are:

- minimum water levels should be in the range 21.2-21.6 metres AHD,
- minimum water levels shall be greater than 21.1 metres AHD, and
- the preferred times of (earliest) drying are:
  WET YEARS dry by April
  MEDIUM YEARS dry by February-March
  DRY YEARS dry by January.

7.4 MAJOR WETLANDS

The major wetlands, for the purposes of this document, other than Thomsons and Forrestdale lakes, are North Lake, Bibra Lake, Yangebup Lake and Kogolup Lake. The term 'major' is not necessarily indicative of a level of importance.

Although they are recognised as very important wetlands, similar rigorous criteria have not been recommended for Banganup Lake and The Spectacles, as detailed bathymetry is not available. These lakes are therefore dealt with separately in section 7.4.3

7.4.1 Primary objectives

The primary objectives for the major wetlands are listed in Table 5.9. More detailed objectives on which criteria can be based and which are consistent with the primary objectives, are listed in Table 7.4.

Table 7.4 Detailed objectives for North, Bibra, Yangebup and Kogalup Lakes.

LAKE	DETAILED OBJECTIVE
NORTH	• have *Melaleuca* spp. periodically inundated
	• stay within historical water level range
	• maintain aesthetics
BIBRA	• limit *Typha* spread
	• have *Melaleuca* spp. and mudflats periodically inundated
	• stay within historical water level range
	• maintain aesthetics
	• maintain access to recreation areas (avoid flooding)
	• maintain as a summer refuge for waterbirds
YANGEBUP	• limit *Typha* spread
	• have *Eucalyptus rudis* (flooded gums) periodically inundated
	• stay within historical water level range
	• maintain aesthetics
	• avoid flooding
	• maintain as a summer refuge for waterbirds
KOGOLUP	• stay within historical water level range
	• have *Melaleuca* spp. periodically inundated

7.4.2 Criteria

The criteria for the major lakes are given in Table 7.5. These criteria were derived based on the detailed objectives in Table 7.4 and the data summarised in Table 5.9. The recommended maximum water table levels are taken from EPA (1989a).

Evapoconcentration of nutrients is not considered when setting criteria because the effect is temporary. Also, with the 'elevated' water levels in some Jandakot wetlands, evapoconcentration of nutrients probably occurs to a lesser degree than in the past. Nonetheless, the potential impacts of evapoconcentration on water quality are considered in section 9.

Table 7.5 Water level criteria for North, Bibra, Yangebup and Kogalup Lakes.

Lake	Recommended Maxima	Operational Minima	Action Minima
North	< 14.9	13.0-13.5	12.7
Bibra	< 15.0	13.6-14.2	13.6
Yangebup	< 16.5	13.9-15.5	13.8
Kogolup	< 14.8	13.1-14.0	13.1

Note that "<" is an abbreviation for 'less than'.

Recommended maxima are mainly to prevent flooding of recreation areas and fringing vegetation. As previously stated however, flooding cannot be controlled by groundwater abstraction (see Section 6.6). When water level predictions indicate that, without active short term management, the action minima will be reached, one or a combination of the following strategies will be employed:

- modify pumping from any well where such changes can have a measurable effect (say raise water levels 1 centimetre or more in the wetland), except in extenuating circumstances such as where significant economic hardship would occur to water consumers, or CALM declare that low water levels would be beneficial to the wetland,
- the wetland will be artificially maintained by adding water, and
- a short-term detailed monitoring programme will be implemented to monitor the condition of agreed strategic species. Baseline monitoring is already in place, and will be continued, for these lakes to provide an historical comparison to the short-term monitoring. The baseline monitoring is detailed in Section 10.

The combination of strategies applied would be determined in consultation with the EPA. Prediction of water levels is covered in section 8 and frequency of monitoring of water levels in section 10.

7.4.3 Banganup Lake and The Spectacles

Banganup Lake is probably the least disturbed wetland in the eastern chain of Beeliar wetlands, forming part of the University of WA's Marsupial Research Station. Because of its proximity to Thomsons Lake, the wetland will be affected by groundwater management aimed at keeping water levels in that lake low for waterbird habitat. Banganup Lake is currently often dry for 10-11 months of the year. *Baumea* and *Eucalyptus rudis* are encroaching into the wetland area. The lake is not used significantly by waterbirds but the *Baumea* stands are believed to be an important habitat for some marsupials during breeding. (P. Clay pers. comm.).

It is therefore important that the wetland area be maintained. To achieve this, the water level should preferably not go below 11.5 m AHD. This equates to the minimum recorded level for the lake. The Water Authority will investigate the feasibility of maintaining water levels at, or above, this level (see section 9.5.1).

Although at one time apparently cleared for agriculture, The Spectacles now has a very good example of a closed *Melaleuca* woodland and is recognised as a valuable wetland. It is proposed that The Spectacles be included in the Beeliar Regional Park. Water levels in The Spectacles are likely to have been artificially elevated due to flow from the Peel Main Drain.

The Water Authority has been recording water levels in The Spectacles since November 1988. It is considered that this does not provide sufficient water level data to set criteria for the lake. However, there is clearly some opportunity to provide control over water levels by manipulating the flow in the drain.

7.5 THE WETLAND SYSTEM

This sub-section recommends criteria which are designed to maintain the value of the wetlands as a system. This should ensure that the many complex interactions within the ecosystem will be maintained.

7.5.1 Background

As stated in section 5, water levels affect vegetation which in turn affects the value of the habitat to wildlife. Of the wildlife, waterbirds have been selected as suitable indicators because they are higher order consumers whose numbers are readily monitored.

Assumptions

Some assumptions which can be made about the relationship between waterbirds and the environment are:

- in a wetland system, waterbird numbers correlate reasonably well with habitat area although this does not hold very well for individual wetlands,
- vegetation largely determines which waterbird species are found in the various habitat types although tannin stained lakes do not readily support birdlife,
- under most conditions water quality has very little bearing, with the exception of salinity. However, the variation of salinity within Jandakot wetlands is negligible, and
- the correlation between waterbird species and habitat types is better for the common species and is accurate in approximately 60% of instances for less common species (S. Halse, CALM, pers. comm.).

Habitat Types

The habitat types chosen for use in examining the relationship between waterbirds and habitat are based on those discussed in section 5 and are listed in Table 7.6.

Table 7.6 Habitats used by waterbirds in the Jandakot Area. No. represents a nominal habitat reference number, while CLASS represents a habitat grouping which is explained in section 7.5.4.

No.	Class	Description
1		Open forest and woodlands of Tuart (*Eucalyptus gomphocephala*)
2		Low open forest, woodlands of *Banksia attenuata* and B. *menziesii*. B. *ilicifolia* and Jarrah on moister lower slopes
3		Fringing woodlands of paperbarks, flooded gums and B. *littoralis*
4		Low open woodlands of *Melaleuca preissiana* with a very dense shrub-layer of seasonally inundated heath species, ie dampland or sumpland
5	II	Fringing and intrusive wet sedgelands and reedbeds
6	I	Bare shorelines and mudflats with up to 0.15 m of water
7	II	Inundated woodlands of *Melaleuca rhaphiophylla* and shrubs
8	II	Open shallow expanses of water (< 0.5 m deep)
9	III	Open deep expanses of water (> 0.5 m deep)
10	IV	Pastures, grassed areas and farmland with relic stands of paperbarks (*Melaleuca* spp.) and eucalypts (*Eucalyptus* spp.)
11	I	Water pastures and flooded grasslands
12	III	Non living roosts
13	IV	Non living nest sites

The habitats listed in Table 7.6 often do not form distinct units, rather, there is often a gradation of habitats. When water table levels change, shifts occur between the different habitats. Some will be reduced in area or extent while others will increase. For example, decreasing water levels may lead to an increase in the area of mudflats but a decrease in the area of inundated trees and shrubs.

The timing of the habitat shifts will vary. For example, decreasing water levels may lead to:

- mud flats being exposed immediately,
- rushes and hedges spreading over a period of several years, and
- paperbarks being established further downslope over tens of years.

Also compounding these shifts are those that occur naturally due to the vagaries of climate. This is discussed further in section 7.5.4.

7.5.2 Waterbirds and habitats

Waterbirds, depending upon their species, require a variety of habitats for feeding, breeding and loafing (e.g. preening, sleeping etc.) (Maher, 1986). We can consider the above example where the area of mudflats increases and the area of inundated trees and shrubs is reduced. In this case, waders that feed on mudflats are advantaged while waterbirds that nest in inundated trees and shrubs will be disadvantaged. Such advantages and disadvantages can be examined methodically by using a technique known as a sensitivity analysis.

Sensitivity Analysis

A sensitivity analysis was carried out by the Water Authority for waterbirds by calculating a Habitat Suitability Index (HSI) for each species. The HSI provides a measure of how much of the habitats a species currently uses will exist in a future scenario (DWRV, 1988; Weller, 1988). This allows predictions to be made about the overall advantages and disadvantages for the waterbirds from which the relative impacts of various scenarios can be judged.

To calculate an HSI, each habitat is initially given the value 1 (i.e. 100%). If a habitat is reduced by, say 10%, it then has the value of 0.9. For example, if a bird typically feeds in habitats types 1, 2 and 5 and 10% of habitat 5 is converted to another habitat type, other than 1 or 2, then the HSI for feeding for this bird is:

$$HSI_{feeding} = \frac{\text{actual habitat used}}{\text{max. possible}} = \frac{1 + 1 + 0.9}{1 + 1 + 1} = .97$$

Habitat Suitability Index Calculations

The average HSI for all birds and for restricted species was calculated for feeding, loafing and nesting (Appendix 10 lists the bird species and the habitat types they use for feeding nesting and loafing).

In addition, an overall index was evaluated using the following formula:

$$HSI_{overall} = [\ 3 \times HSI_{feeding} + 2 \times HSI_{nesting} + HSI_{loafing}\ ] \ / \ 6$$

This formula states that feeding and nesting are respectively three and two times more important than loafing. This was derived on the basis that birds need to feed every year, that they need to nest most years and that they are relatively flexible about their loafing habitats. Therefore, occasional and temporary loss of loafing habitat will not be as critical to the survival of a species as the loss of feeding habitat.

7.5.3 Comments on the sensitivity analysis

The sensitivity analysis or HSI provides a useful guide for determining operating scenarios that will have the least impact on waterbirds and more generally ensures that the carrying capacity of the environment is maintained in the short term. This is a conservative approach since instantaneous population size and short term trends are not necessarily good indicators of management success because of natural variability. However, it should be noted that the HSI:

- assumes that each habitat has the same carrying capacity,
- assumes that the population size of the species of interest is determined by, or directly related to, available habitat, and
- while not very accurate quantitatively, such a technique gives an indication of which species will be advantaged and which will be disadvantaged when a shift in habitat occurs. Also it allows the relative impacts of habitat shifts to be assessed or ranked.

7.5.4 Results of the sensitivity analysis

The sensitivity analysis was used to rank the various habitats into classes according to how sensitive waterbirds are to changes in those habitats (see Table 7.6). Four classes of sensitivity proved to be convenient for grouping common species together and likewise for restricted species. These ranged from Class I (most sensitive) to Class IV (least sensitive). Therefore, reductions in the area of Class I habitats are less desirable than comparable reductions in Class IV habitats.

Maximum Habitat Shifts

There have been shifts between the various habitat types due to climate variability and the impact of urbanisation. The abstraction of groundwater, both private and public, will compound these shifts.

The degree to which a wetland habitat can be permitted to shift needs to incorporate the classes of habitat sensitivity and climatic variability as outlined above. Consistent with CALM's criteria, and section 7.1.4, wet, medium and dry years were used to describe climatic variability. To determine acceptable habitat shifts in percentages, relative to the baseline distribution, it was necessary to select three 'reference points' and then interpolate between these. Following consultation with CALM the following were used:

- 5% was recommended as the maximum reduction, relative to the baseline, for a Class I habitat in a wet year
- from a dry to a wet year the maximum reduction of habitat relative to the baseline can increase by 10% within a Class
- from Class I to Class IV the reduction of habitat allowed can increase by 10% within any rainfall group.

This results in the action criteria given in Table 7.7 (see Department of Water Resources Victoria, 1988 for a comparison with stream habitat shifts).

Table 7.7 Maximum allowable habitat reductions (in area) for the Jandakot Area (Thomsons Lake excluded)

Habitat Type	Wet Year	Medium Year	Dry Year
I	5 %	10	15
II	8	13	18
III	12	17	22
IV	15	20	25

Increases of habitat shall be no more than 5% greater than the values given in the above table. This is to ensure that no species gains a competitive advantage leading to a reduction in other species.

Thomsons Lake is not considered for the purposes of determining habitat shifts. This is because shifts will occur as a direct result of CALM's criteria for Thomsons Lake.

Note that the baseline habitats will be as per the vegetation maps (dated 1984-1985) contained in the draft version of EPA Bulletin 266 "Notes on Perth Wetlands".

Sensitive Habitats

Some habitats were found to be particularly sensitive for a specific waterbird activity (eg feeding, nesting or loafing). These habitats are listed in Table 7.8.

Table 7.8 Habitats which waterbirds are particularly sensitive to changes in.

Habitat No.	Sensitivity
11	Feeding for both common and restricted species
7	Nesting for common species
9	Feeding for common species

It is important that these habitats are maintained and to this end a 'refuge' be provided in summer. This is satisfied by the following criteria:

- Bibra Lake must not dry out for more than 2 years in any 3 year period, and preferably not more than 1 in 3.
- Either Bibra or Yangebup Lake must contain 0.3 metre of water and preferably 0.5 metre.

These criteria will be complied with by adopting the action criteria of 13.6 m AHD as the minimum water level for Bibra Lake.

If it is clear that, without active short term management, maximum habitat shifts or sensitive habitat criteria will be breached, one or both of the following strategies will be employed:

- modify pumping from any wells where such changes can have a measurable effect (say raise water levels 1 centimetre or more in the wetland), except in extenuating circumstances such as where significant economic hardship would occur, and
- a more detailed short-term monitoring programme will be implemented to monitor the condition of agreed strategic species.

Note that monitoring programmes are discussed further in section 10.

7.6 AIR QUALITY

There are two potential sources of air pollution from the treatment plant. These are from hydrogen sulphide and chlorine.

7.6.1 Chlorine

Chlorine, at ordinary temperatures and pressures, is a gas approximately 2.5 times as dense as air. As a result, chlorine flows downhill, collecting in low spots. However, strong winds and thermal gradients in the atmosphere can drive the gas uphill, mixing and diluting it with air.

Despite the extremely low probability of a leak at Jandakot, it is essential that a non-residential buffer zone be maintained. The actual size of the buffer zone is based on the risk of an escape occurring and the quantity which might be released in such an event. This in turn is determined mainly by the plant design, size of the installation and the manner in which the system is maintained and operated. Risk of a leak at Jandakot has been minimised through the design of the containment building. The future risk will be even less once the change to the liquid chlorination system occurs (section 4.1.3).

The Water Authority conducted a risk assessment which complied with the requirements of EPA Bulletin 278. On the basis of that assessment, a buffer is recommended (see Figure 7.2) around the treatment plant that ensures the general public is not endangered in the unlikely event of a major leak occurring. Outside of this buffer zone, the personal risk of a leak leading to a fatality is less than one in a million in any year. Thus, it is recommended that:

- a buffer zone be maintained around the chlorine storage area of the treatment plant, and
- the treatment plant and chlorine handling be operated in the manner described in section 4, resulting in a level of personal risk of fatality of no greater than one in a million in any year at the buffer zone boundary.

7.6.2 Hydrogen sulphide

Hydrogen sulphide is present in solution in varying concentrations in the superficial groundwater from the Jandakot Mound. It is proposed to use chlorine to remove most of the hydrogen sulphide in the groundwater before aeration at the treatment plant. During the aeration stage of treatment, remaining hydrogen sulphide is released into the atmosphere, producing a characteristic 'rotten egg' odour.

Although the concentrations of the gas are relatively low and not harmful to health, the odours produced can be offensive. The odours will be strongest close to the aerator and decrease with distance from the aerator. Since atmospheric conditions and wind direction and strength vary it is necessary to establish a buffer zone around the plant so that, under most conditions, the concentration will be below the noticeable level at the nearest dwellings.

The Water Authority proposes that the buffer zone be not less than the distance defined by an anticipated hydrogen sulphide concentration of 5 parts per billion averaged over 30 minutes, as calculated for atmospheric conditions of Parquille class F and 2 metre per second wind velocity. Based on experience gained from operating the Water Authority's Mirrabooka Treatment Plant, which is also close to residential areas, and the results of modelling exercises for the Mirrabooka and Jandakot area, a buffer zone of 400 metres is recommended to meet this criteria. Ground level measurements recorded in a recent study (Stephenson & Associates, 1989) support the results of the modelling exercises. According to WHO (1987), a maximum safe level of exposure is considered to be 100 parts per billion averaged over 24 hours. Eye irritation will occur at concentrations of 10,000 to 20,000 parts per billion.

8 Selecting Operating Strategies

This section describes the methods used to determine appropriate operating strategies (ie those that are economically viable and satisfy the environmental criteria). The computer model used to determine water level changes is described and output from the model is shown.

Much of the modelling background information in this section is drawn from the 'Jandakot Public Water Supply Area Groundwater Management Review' (WAWA, 1987a) and the 'Perth Urban Water Balance Study' (WAWA, 1987b;c).

8.1 INTRODUCTION

The term 'operating strategy' includes planning, design, construction and operation of the Jandakot GWS. When selecting an operating strategy, the Water Authority seeks an appropriate balance between the cost of providing water to the community, the impact on the environment and the social expectations of the community. This also includes managing private abstraction.

8.1.1 Current operating strategy

The Water Authority is currently required to submit annual reports to the EPA on the environmental impacts of Stage 1 of the Jandakot GWS. The most recent report (WAWA, 1989b) outlines the present operating strategy in which groundwater is drawn from 1 artesian well and 13 of 15 wells in the superficial aquifer. Of the two unused wells, one has a potential water quality problem due to its proximity to a previous waste disposal site while water from the other is excessively turbid and is very expensive to treat.

Abstraction from the wellfield has generally commenced in October and continued through until June of the following year. Figure 8.1 shows production from the superficial aquifer for the last four 'water years' (a water year is from 1 October to 31 September of the following year).

8.1.2 Objectives of a future operating strategy

A suitable operating strategy for the groundwater scheme must:

- have minimal environmental impacts (ie generally satisfy the environmental criteria recommended in this report), and
- have an appropriate balance between cost, water quality and security of supply.

Relative Use of the Superficial and Artesian Aquifiers

The ratio of water that can be drawn from the superficial and artesian aquifers is relatively fixed for water quality reasons. Water from the artesian wells in the Leederville Formation has higher salt levels than the superficial water. This brackish water is mixed with water from the superficial wells and from Hill's sources to reduce the salinity to a level which meets the Water Authority's water quality objectives.

There is some uncertainty as to the sustainable yield of the Leederville Formation beneath the Jandakot Mound. A conservative yield has been estimated to be around 2 million cubic metres a year. At present, however, it is proposed to maintain the present draw of 1 million cubic metres per year. Artesian abstraction will not be considered further in this section of the PER as it is not believed to cause any significant environmental impact. However, leakage to or from the Leederville Formation is accounted for in the computer model (see Appendix 11).

Time of Withdrawal

It is most economical to supply the greatest quantities of groundwater when local demand is at its maximum. This reduces the distribution costs from the more distant Hill's sources. However, it is presently uneconomic to send groundwater outside the Jandakot Area via trunk mains because of the large costs associated with pumping.

Approximately 80% of annual demand occurs in the 6 to 7 months over the summer-autumn period. Therefore it is desirable to have most of the annual draw in this period, provided that the environmental criteria are satisfied.

It is usually necessary to shut down groundwater schemes for one to two months a year for maintenance purposes.

It is expected that the Stage 2 wellfield would be operated for periods ranging between 6 and 10 months in any year. This will largely be determined by local demand.

Location of Wells

When selecting the location of wells the following are taken into account:

- water quality — wells generally need to be located 'upstream' of potential sources of pollution such as the Kwinana Freeway extensions and areas of intensive horticulture,
- environmental impact — criteria have already been recommended for this. Where feasible, the collector main will be located in disturbed areas,

- efficiency of the wells — if the wells are placed too close together they will be less efficient and drawdown of the water table will be greater in some areas. If they are placed too far apart it may not be possible to draw the full sustainable yield of the resource,
- cost — it is most economical to have the collector main as short as possible, laid in readily accessible areas such as road reserves,
- enhancing drainage — in areas where the water table is close to the surface, wells will, as a secondary objective, be located to assist drainage schemes.

8.2 ASSESSING FUTURE OPERATING STRATEGIES

To ensure that environmental impacts are acceptable, the criteria recommended in the PER need to be satisfied. Most of these criteria are in terms of water levels and for this reason some means of predicting water levels is required. For this study, a computer model of the groundwater system was used to make predictions of water levels under different scenarios. This model allowed:

- the individual impacts of various factors (eg drainage, rainfall, land use, abstraction) currently influencing the groundwater system to be separated from the total observed response, as measured from monitoring bores and wetland water levels, and
- the prediction of future water levels under various climatic, land use, well field operating strategies and private abstraction scenarios. These predicted water levels can then be compared with the recommended environmental criteria to check whether a particular scenario is environmentally acceptable.

8.2.1 Principal scenarios considered

Of the numerous scenarios modelled, three are discussed here, these being:

1) current land use and public (Stage 1) and private abstraction — this was modelled to simulate current water levels and thereby show the current drawdown and verify the performance of the model,
2) future land use (without South Jandakot Urban Development) and full public (Stages 1 and 2) and private abstraction, and
3) future land use, including South Jandakot Urban Development, and full public (Stages 1 and 2) and private abstraction.

These will be referred to as scenarios 1, 2 and 3 respectively. The groundwater uses under each scenario are summarised in Table 8.1.

It is recognised that at least part of the South Jandakot Urban Development is likely to proceed. However, all of the modelling for this study was completed before the Minister for Environment approved the modified development. Also, as the urbanisation has a significant impact on the water table levels and the development will be staged over many years, it was still considered desirable to show the effect of no development as a separate scenario, Note that, for scenarios 2 and 3, the modelling also assumes that the Jandakot South Groundwater Scheme is abstracting water near the southern boundary of the Jandakot Area.

Table 8.1 Different scenarios modelled. All values are in millions of cubic metres of shallow groundwater per annum. 'Outside PWSA' represents shallow groundwater drawn from the Jandakot South Groundwater Scheme and private usage within the Jandakot Area but outside the PWSA. All other quantities shown are drawn within the PWSA.

Scenario	Outside PWSA	Private	Stage 1	Stage 2
1 current land use and abstraction	9	9	4	0
2 future land use and abstraction	13.5	16	4	4
3 future land use with urban development and abstraction	13.5	16	4	4

Model simulations were performed with variations in wellfield layout and the timing and volume of water abstracted for scenarios 2 and 3. The scenarios shown here were selected from over twenty such variations because they supply the maximum quantity of water while satisfying the criteria and having the least environmental impact. The locations of the wells are shown in Figure 8.2 with 500 metre radius zones around them.

All of the criteria relating to well location are satisfied as none of the wells are within 500 metres of a natural non-degraded seasonally inundated wetland (sumpland) or a System Six area. Wells J230 and J240, which are adjacent to the *Banksia* woodland enclosed by Gibbs, Lyon, Gaebler and Beenyup Roads, will have their production phased in over a period of three years.

Four damplands (ie waterlogged areas) are completely within 500 metres of Stage 2 wells while two are partially within this radius. When the

South Jandakot Urban Development proceeds, three of these damplands will probably be cleared of vegetation and urbanised.

Timing

The increase in abstraction from 3 million cubic metres per year to 4 million cubic metres per year for Stage 1 of the Jandakot GWS only commenced in the 1988/89 water year. Data on the water level impacts from this increased draw from Stage 1 will be available before the proposed commissioning of Stage 2.

With time, as Stage 2 is commissioned, private abstraction increases, and land uses change, water levels will be represented by scenario 2 or 3, depending upon whether the South Jandakot Urban Development proceeds. In this section, scenarios 2 and 3 are compared with the environmental criteria recommended in this PER. Since the shift from current land use to urban land use will be gradual, the changes in water level, and associated environmental changes, will also be gradual.

8.3 MODELLING

To confidently manage groundwater abstraction in a manner which maximises long-term sustainable yield while protecting the environment requires a detailed understanding of the hydrological system being utilised and an ability to reliably predict the hydrological outcome of pursuing various management options.

The Water Authority has developed a sophisticated computer model of the Jandakot Mound which has been demonstrated to accurately reflect the hydrological regime of the area. Various parameters in the model can be changed and the resulting hydrological outcomes observed. Using this approach, abstraction can be planned and managed in such a way as to achieve specified outcomes. Details of the model are given in Appendix 11.

The predictions by the model are based on repeating the climatic record of the past 75 years (1912 to 1987) over the next 75 years. As discussed in section 3.3.2, no allowance has been made for changes in climate as we cannot accurately predict these and groundwater management is sufficiently flexible to accommodate changes as they are observed.

8.4 THE CURRENT SITUATION (SCENARIO 1)

It is not practical to compare actual water level data (see Appendix 5) against the criteria to evaluate the current situation. This is because:

- there is not enough data to have a reasonable level of statistical confidence, and
- it is difficult to separate the effects of climate, land use changes, drainage and other artificial influences.

The current situation was simulated using the model with current land use and abstraction and repeating the climatic record of the past 75 years (1912 to 1987). Figures 8.3 to 8.8 show the current water levels in the larger wetlands as predicted by the model. The water level contours simulated by the model for current land-use on the Jandakot Mound are shown in Figure 8.9.

Average minimum water levels in the major wetlands and their relationship to the environmental criteria are shown in Tables 8.2 and 8.3 respectively.

Table 8.2 Average minimum water levels (in metres AHD) in the major wetlands based on computer model simulations for the wetlands over 75 years.

WETLAND	SCENARIO 1 (m AHD)	SCENARIO 2 (m AHD)	SCENARIO 3 (m AHD)
NORTH	14.15	14.05	14.05
BIBRA	14.9	14.4	14.4
YANGEBUP	17.0	15.0	15.5
KOGOLUP	14.6	14.0	13.75
FORRESTDALE	21.6	21.6	21.5
THOMSONS	12.3	11.9	11.8

Table 8.3 Percentage of years that action criteria are satisfied in the major wetlands based on computer model simulations for the wetlands over 75 years. The compliance requirements shown are based on the current values (ie scenario 1) and the guiding criteria in section 7.1.2.

WETLAND	COMPLIANCE REQUIREMENT* (minimum %)	SCENARIO 1 (%)	SCENARIO 2 (%)	SCENARIO 3 (%)
NORTH	95	100	100	97
BIBRA	95	100	100	100
YANGEBUP	95	100	93	100
KOGOLUP	95	100	100	100
FORRESTDALE	88	92	89	89
THOMSONS	30	30	38	44

* Refers to annual minimum levels

8.5 THE FUTURE SITUATION WITHOUT URBANISATION (SCENARIO 2)

Before selecting the strategy shown here many different strategies were simulated. These were compared to the environmental criteria and subsequently modified. For example, wells were relocated, draw from individual wells varied, some wetlands were artificially recharged and others had their maximum water levels controlled by drainage. More specifically, wetland management included in the modelling consisted of:

- artificial recharge of Bibra Lake to ensure that minimum water levels don't drop below 13.6 metres AHD. This requires that an average of 500,000 cubic metres be added one year in seven,
- artificial recharge of Kogolup Lake to ensure that minimum water levels don't drop below 13.1 metres AHD. This requires that an average of 200,000 cubic metres be added one year in eight. Note that control of maximum water level in Kogolup Lake is not considered in this scenario, and,
- drainage control of Yangebup Lake to ensure that water levels do not exceed 16.5 metres AHD.

Artificial recharge water for Bibra Lake will most likely be drawn from a well located about 200 metres to the west of the lake. Under this scenario, water for artificial maintenance of Kogolup Lake would also be drawn from a well.

Drainage control of Yangebup Lake at 16.5 metres AHD is consistent with the environmental criteria given in section 7.4.2 and will also permit the maximum storm runoff from existing urban development to be compensated within the lake without flooding.

8.5.1 Major wetlands

Predicted minimum water levels in the major lakes are shown in Figures 8.3 to 8.8 and are summarised in Table 8.2. Tables 8.2 and 8.3 show that the action and operational minimum criteria (see sections 7.1.2, 7.4.2 and 7.5.4) are satisfied for all of the lakes, with the exception of Lake Yangebup where the action criteria were breached on two occasions.

A detailed breakdown of predicted minimum levels in Thomsons Lake is given in Table 8.4 (a breakdown of current minimum levels is given in Table 7.3). For Thomsons Lake, the additional impact due to scenario 2 with respect to CALM's criteria, is minor.

Table 8.4 Summary of predicted average minimum water levels in Thomsons Lake under the likely future scenario without the South Jandakot Urban Development. Values are frequency of occurrence. The predictions are based on computer model simulations for the lake over 75 years.

	WATER LEVELS (metres AHD)				
RAINFALL	<10.8 (%)	10.8-11.3 (%)	11.3-11.8 (%)	>11.8 (%)	
wet	0	0	1	11	
medium	0	12	14	51	
dry	1	7	3	0	
TOTAL	1	19	18	62	= 100

Table 8.5 shows the effects of this scenario on Banganup Lake and The Spectacles. Banganup Lake will not meet the criteria recommended in section 7.4.3 during dry sequences of years, without artificial maintenance.

8.5.2 Seasonal wetlands

The effects of this scenario on the significant seasonal wetlands (see section 5.2.1) are shown in Table 8.5. Bartram Road Wetland Complex and Beenyup Road Wetland satisfy the criteria given in section 7.2.4. Twin Bartram Swamp just fails to satisfy the criteria while Solomon Road Wetland clearly fails to meet the desired criteria.

Artificial recharge of Twin Bartram Swamp may be required under this scenario. This is considered in section 9.

Table 8.5 Predicted changes in water levels (in metres) in Banganup Lake, The Spectacles and the seasonal wetlands of significance based on computer model simulations over 75 years. 'Max. depth' is the estimated current maximum water depth.

WETLAND	SCENARIO 2	SCENARIO 3	MAX. DEPTH
Banganup Lake	-0.15	-0.25	0.6
The Spectacles	-0.25	-0.25	1.2
Bartram Road Wetland Complex	-0.10	-0.15	0.8
Beenyup Road Wetland	-0.15	-0.30	?
Twin Bertram Swamp	-0.40	-1.00	0.6
Solomon Road Wetland	-0.75	-1.10	0.1

8.5.3 General drawdown

Figure 8.10 shows the predicted water table levels under this scenario. The expected drawdown of the water table relative to the current situation is shown in Figure 8.11 along with phreatophytic vegetation. There is about 24 square kilometres of phreatophytic vegetation within the model boundary (ie Jandakot Area). Approximately 2.5% of the phreatophytic vegetation in the modelled area will have a drawdown of over 1 metre. This satisfies the general drawdown criteria of section 7.2.2.

8.5.4 Rare flora

The drawdown in all known areas of rare flora will be less than 0.5 metres in all but one case where the drawdown will be around 0.7 metres. This satisfies the criteria given in section 7.2.3 for rare flora.

8.6 THE FUTURE SITUATION WITH URBANISATION (SCENARIO 3)

Urbanisation generally results in increased recharge to the groundwater system because of runoff being directed to drainage sumps, lower vegetation canopy cover (therefore reduced evapotranspiration) and scheme water being imported and recharging the aquifer through infiltration from garden watering. However, increased recharge can be offset by drainage and wells within urban areas. This is discussed further in section 8.7.

Under this scenario, wetland management for the purposes of modelling included:

- artificial recharge of Bibra Lake to ensure that minimum water levels don't drop below 13.6 metres AHD. This requires that an average of 500,000 cubic metres be added one year in seven,
- artificial recharge of Kogolup Lake to ensure that minimum water levels don't drop below 13.1 metres AHD. This requires that an average of 200,000 cubic metres be added one year in seven,
- artificial recharge of Thomsons Lake to ensure that minimum water levels don't drop below 10.8 metres AHD. This requires that an average of 250,000 cubic metres be added one year in eight,
- drainage control of Yangebup Lake to ensure that water levels do not exceed 16.5 metres AHD, and
- drainage control of Kogolup Lake to ensure that water levels do not exceed 14.8 metres AHD.

Artificial recharge water for Bibra Lake will most likely be drawn from a well located around 200 metres to the west of the lakes. Thomsons and Kogolup Lakes will be supplemented with drainage water from the South Jandakot Urban Development, assuming that the quality is acceptable (South Jandakot Drainage Management Plan, DPUD 1990a)

Drainage control of the maximum water level in Yangebup Lake at 16.5 metres AHD will be achieved through pumping and is consistent with the environmental criteria given in section 7.4.2 and DPUD (1990a). It will permit the maximum storm runoff from urban development to be compensated within the lake without flooding.

Drainage control of the maximum water level in Kogolup Lake at 14.8 metres AHD will be achieved through pumping and is consistent with the interim recommendation of EPA (1989a) and DPUD (1990a). This was included in the modelling to show that such control is feasible. Whether such control is desirable or not will be clearer when the research projects listed in Appendix 2 are completed.

This scenario incorporates the management programme for Thomsons Lake that is detailed in the South Jandakot Drainage Management Plan (DPUD, 1990), including a pumping station to remove drainage water entering the lake.

8.6.1 Major wetlands

Predicted minimum water levels in the major lakes are shown in Figures 8.3 to 8.8 and are summarised in Table 8.2. Tables 8.2 and 8.3 show that the action and operational criteria (see sections 7.1.2, 7.4.2 and 7.5.4) are satisfied for all of the major lakes, including Thomsons Lake. A detailed breakdown of predicted minimum levels in Thomsons Lake is given in Table 8.6 (a breakdown of current minimum levels is given in Table 7.3). It will be noted that although the number of years with lower water levels is substantially increased under this scenario, the frequency of occurrence still falls short of that desired by CALM.

Table 8.6 Summary of predicted average minimum water levels in Thomsons Lake under the likely future scenario with the South Jandakot Urban Development. Values are frequency of occurrence. The predictions are based on computer model simulations for the lake over 75 years.

RAINFALL	WATER LEVELS (metres AHD)				
	<10.8 (%)	10.8-11.3 (%)	11.3-11.8 (%)	>11.8 (%)	
wet	0	0	0	10	
medium	0	12	24	45	
dry	0	9	0	0	
TOTAL	0	21	24	55	= 100

Note that although artificial maintenance avoids extremely low water levels during periods of drought, when it is used to the extent proposed, it would have very little effect on average minimum water levels. However, artificial control of maximum water levels as proposed, does have a significant effect on minimum water levels. For example, if the maximum water level for Kogolup Lake is not controlled, the average minimum water level would be 14.45m AHD instead of 13.75m. That is, the impact of controlling maximum water levels is 0.7m on the average minimum water level. Therefore, except for Kogolup Lake, the levels and drawdowns given in Tables 8.2 and 8.8 respectively, would be essentially the same with or without artificial maintenance.

Table 8.5 shows the effects of Scenario 3 on Banganup Lake and The Spectacles. Banganup Lake will not meet the criteria recommended in section 7.4.3 during dry sequences of years, without artificial maintenance.

8.6.2 Seasonal wetlands

The effects of this scenario on the potentially significant seasonal wetlands (see section 5.2.1) are shown in Table 8.5. Bartram Road Wetland Complex and Beenyup Road Wetland satisfy the criteria given in section 7.2.4. Twin Bartram Swamp and Solomon Road Wetland fail to meet the desired criteria. It may be necessary to artificially recharge Twin Bartram Swamp using groundwater from the nearby collector mains. This is discussed further in section 9.5.7 while modification of private abstraction practice is covered in section 8.8.

8.6.3 General drawdown

Figure 8.12 shows the predicted water table levels under this scenario. The expected drawdown of the water table relative to the current situation is shown in Figure 8.13 along with phreatophytic vegetation. Approximately 7.5% of the phreatophytic vegetation in the modelled area will have a drawdown of over 1 metre. However, when allowance is made for the vegetation which is likely to be cleared for the South Jandakot Urban Development, this percentage will drop significantly. It is therefore considered that the general drawdown criteria of section 7.2.2. will be satisfactorily complied with.

8.6.4 Rare flora

The drawdown in all known areas of rare flora will be less than 0.5 metres in all but one case where the drawdown will be around 0.7 metres. This satisfies the criteria given in section 7.2.3 for rare flora.

8.7 PRIVATE USE

8.7.1 Allocation amongst private users

The Water Authority requires that all wells in the Jandakot Public Water Supply Area (PWSA) be licensed. All non-domestic wells must also be licensed in the adjacent Groundwater Areas of Perth, Cockburn, and Serpentine (see Figure 8.14). The legislation which requires this is the Metropolitan Water Supply Sewerage and Drainage Act for the PWSA and Rights in Water and Irrigation Act for the Groundwater Areas.

Each licence stipulates the quantity of water which may be abstracted and a use to which the water can be put. The quantity of water actually used is usually assessed by way of the area irrigated and Department of Agriculture recommended application rates for the crops concerned. Where this method of estimation is inappropriate or a dispute exists, then water usage may be metered.

A decision to grant or refuse a groundwater licence depends mainly on whether the proposed abstraction will exceed the sustainable yield of the shallow aquifer system. For allocation purposes, the resources available for private abstraction have been divided into 11 sub-areas, as indicated in Figure 8.14. The current private usage is estimated to be 9 million cubic metres per year, while the quota for Jandakot PWSA is 16 million cubic metres per year. A breakdown of these quantities by sub-areas is shown in Figure 8.15. The sub-areas have been created mainly on hydrogeological grounds to prevent excessive local and overall abstraction. As can be seen from Figure 8.15, private use is currently greatest in the Mandogalup sub-area.

A number of other factors are considered when determining whether to grant a licence. These are:

- whether the proposed abstraction will provide an economically efficient use of water. In line with this principal, limited water is made available to Special Rural Zone or urban lots. Table 8.7 below summarises this aspect of the allocation policy.
- whether the proposed allocation is fair and equitable to existing and future users and the applicant.
- whether the proposed abstraction may have a potentially significant impact on groundwater quality or the environment. This can relate to the pollution caused by intended activity or the local impact on water levels. Such proposals are referred to the EPA for their assessment.

Table 8.7 Summary of private groundwater allocation policy in the Jandakot PWSA.

USE	ALLOCATION
domestic (with scheme water)	500 m^3/yr
(without scheme water)	650 m^3/yr
special purposes — kennels	600 m^3/yr
Special Rural	1500 m^3/yr
horticulture/lawns	based on area and Department of Agriculture water use data
eg vegetables	15000 m^3/ha/yr
ovals	8000 m^3/ha/yr
industrial/other	each case considered separately

- whether the proposed allocation is fair and equitable to existing and future users and the applicant.
- whether the proposed abstraction may have a potentially significant impact on groundwater quality or the environment, This can relate to the pollution caused by intended activity or the local impact on water levels. Such proposals are referred to the EPA for their assessment.
- whether there is a historical precedent for the activity. In particular, has the proposed activity been undertaken previously on the lot in question?
- whether the proposed allocation requires a large proportion of the available resource. Granting of most of the water resource to one use/user may preclude the realistic future aspirations of other landholders.

8.7.2 Impact of private users

Private users generally have a greater impact on groundwater in the Jandakot Area than the existing or proposed Water Authority groundwater schemes. The impacts due to an increase in private abstraction from the existing allocation of 9 million cubic metres per year to the quota of 16 million cubic metres per year is shown in Figure 8.16. The impacts on wetlands due to increasing private abstraction are compared with those due to proposed increases in public abstraction, from Stage 2 and Jandakot South Groundwater Schemes, and those due to changes in land use in Table 8.8.

Table 8.8 Predicted changes in water level in wetlands due to changes in land use, increasing private abstraction from the existing allocation of 9 million cubic metres per year to the future quota of 16 million cubic metres per year, and Stage 2 and Jandakot South Groundwater Schemes for Scenario 3.

Wetland	Land Use	Private	Stage 2+ Jand. South	Total
	(all in metres)			
North	0.05	-0.10	-0.05	-0.10
Bibra	0.20	-0.45	-0.20	-0.50
Yangebup	main impact due to water level control			
Kogolup	main impact due to water level control			
Forrestdale	0.00	-0.10	0.00	-0.10
Thomsons	0.20	-0.10	-0.05	-0.50
Banganup	0.10	-0.05	-0.05	-0.20
The Spectacles	0.05	-0.15	-0.15	-0.15
Bartram Rd Complex	0.15	-0.20	-0.25	-0.15
Beenyup Road	0.30	-0.30	-0.20	-0.25
Twin Bartram	0.50	-0.80	-0.70	-0.90
Solomon Road	0.55	-0.75	-1.25	-1.10

It should be noted that the total effect of Scenario 3 is not always the sum of the three separate influences. This is because of the effects of altered rates of evapotranspiration, diversion of rural drains and other factors which influence the total effect. Usually these factors act to reduce the cumulative effect of public and private abstraction. For example, a small reduction in water table levels due to public extraction will result in a significant decrease in evapotranspiration, compared to the current scenario, which in turn reduces the impact of private extraction.

8.8 COMPLIANCE WITH CRITERIA

For the scenarios simulated, all criteria are satisfied except for those relating to Twin Bartram and Solomon Road Swamps. The impacts of this plus possible ameliorating measures, such as artificial recharge, are discussed in section 9.

9 Environmental Impacts

This section discusses the likely environmental impacts of the Jandakot GWS Stage 2 extension. Impacts are assumed to be acceptable if they satisfy the environmental criteria recommended earlier in this PER. Note that most impacts relating to water levels have already been checked for compliance with the criteria in section 8.

9.1 INTRODUCTION

Impacts associated with the Stage 2 extension can be divided into several broad groups, these being:

- construction,
- air quality,
- terrestrial,
- wetlands, and
- social issues.

Criteria have been recommended in section 7 to protect the environment from many of these impacts. When these criteria were set, they incorporated many objectives relating to whether they had a minimal or acceptable environmental impact. For this reason, impacts are assumed to be acceptable if the environmental criteria are satisfied.

9.2 CONSTRUCTION

As described in section 4.1, the production and treatment of the additional groundwater from Stage 2 will require the establishment of new wells, collector mains and some minor extensions to the existing Jandakot Treatment Plant.

The potential impacts of the civil engineering works are discussed in the following.

9.2.1 Wells

Of the 13 superficial wells, most will be located in areas already cleared or disturbed by roadworks. Where well sites are to be established in undisturbed locations, a small loss of habitat will occur. The total loss is less than one hectare. The extent of disturbance will be minimal as drilling and wellhead establishment crews will confine their activities to the immediate vicinity of the wells.

9.2.2 Collector mains

The majority of the collector mains pass through disturbed areas such as road reserves. At no point will the collector mains traverse large areas of undisturbed native vegetation (Figure 9.1).

Apart from recently disturbed areas, top-soil will be stockpiled and carefully replaced following construction. Further rehabilitation will follow, as necessary, with the objective of returning the areas, other than access tracks, as closely as possible to their original condition.

During construction, the presence of a trench, pipes and machines may present a local barrier to terrestrial fauna; however this will normally be less than a few weeks at any location.

Following construction and rehabilitation, the route should eventually resemble its original condition apart from a limestone access track and feeder powerlines that will be required in some areas.

9.2.3 Treatment Plant

Most of the treatment plant site in Bartram Road was cleared during the construction of Stage 1 in 1978/79. The original plant was designed and constructed such that future expansion associated with Stage 2 could be readily accommodated.

Some areas of the treatment plant grounds have been retained in their original condition. These Banksia woodland areas will not be required for the Stage 2 additions. The extensions will occur on existing developed areas of the treatment plant site.

Once the on-site works are completed, the extensions to the treatment plant will not be visible from the adjacent road reserve. Some additional landscaping is proposed in the vicinity of the aerators.

9.3 AIR QUALITY

9.3.1 Chlorine

As discussed in sections 4.1.3 and 7.6.1, no major chlorine leak has occurred in the past from the Jandakot Treatment Plant, or any other Water Authority chlorination site.

Changes to the operating system to be introduced prior to commissioning Stage 2 will further reduce the probability of such a leak and the volume of chlorine which could escape in such an event. However, a buffer zone precluding residential development is prudent. The recommended zone (Figure 7.2) will ensure compliance with the EPA's prescribed personal risk of fatality level of less than 1 in 1 million per annum.

9.3.2 Hydrogen sulphide

Chlorine dosing before aeration will remove up to 98% of the hydrogen sulphide that occurs naturally in Jandakot groundwater. The hydrogen sulphide remaining will be released during aeration of groundwater at the Jandakot Treatment

Plant. The levels experienced within the recommended 400 metre buffer zone will be noticeable and even offensive at times. The levels however present no danger to health. Outside the buffer zone, levels of hydrogen sulphide released during operation of the Treatment Plant will be below noticeable levels.

Private wells in the area produce detectable levels of hydrogen sulphide. Tests undertaken by Stephenson & Associates (1989) indicated that even with pre-treatment removing 98% of hydrogen sulphide at the Treatment Plant, measured levels 350 metres away appeared to fall by only 60% of the previously measured level. The consultant suggested this may be due to hydrogen sulphide emissions from sources other than the Water Authority Treatment Plant such as private wells.

9.4 TERRESTRIAL ENVIRONMENT

9.4.1 Vegetation

Criteria have been recommended for the remnant native vegetation as well as the rare orchids on the eastern side of the Jandakot Area. The impacts are considered acceptable because these criteria are satisfied (see sections 8.5.3, 8.5.4, 8.6.3 and 8.6.4).

It is expected that lowering the water table under vegetation by no more than 1.5 metres will have no appreciable effect on the tree layer and other deep-rooted plants except possibly to reduce transpiration rates (see section 7.2.2). There may be a gradual shift in the vegetation, for example (Mattiske, 1989):

- a shift towards xeric vegetation in some areas with reductions in some species which tolerate wetter and moister conditions,
- a replacement of older and larger trees with seedlings, particularly for the tree species which tolerate moister soil conditions, and
- an increase in species which tolerate dry soil conditions or are not site specific in their occurrence.

Note that projected changes in climate, due to global changes, may well result in these vegetation shifts, as has already been noted in the Gnangara Mound area. Changes in the structure and composition of the vegetation association as described above, have the potential to cause changes in orchid assemblages. For example, changes in community structure may increase the level of competition for an existing niche that is already occupied by orchids; this may be from more aggressive native and exotic (weed) species (van Leeuwen, 1989).

The criteria for the protection of the rare orchids, such as the donkey orchid (*Diuris purdiei*), are satisfied, and as such, the impact will be minimal. Additionally, the rare flora sites are well removed from the expected drawdown cone areas of the wells. This should result in a gradual lowering of the water table in these areas, allowing an adaptive response in the vegetation associated with the rare flora.

9.4.2 Terrestrial fauna

No measurable impacts on the terrestrial fauna are anticipated. Some minor effects may occur associated with changes in the composition of the understorey vegetation. These impacts will be minimised through adherence to the criteria set for protection of the terrestrial environment.

9.4.3 Reserves for conservation and recreation

There is one System Six area which consists solely of upland habitat in the Jandakot Area: Recommendation M94, which is *Banksia* woodland on Commonwealth land surrounding Jandakot Airport. This area and the upland areas of the other three System Six areas in the Jandakot Area, Recommendations M93, M97 and M95, would generally be affected less than the upland vegetation discussed in section 9.4.1. This is because these areas are protected from the impacts of the drawdown cones immediately surrounding the wells by the environmental criteria of section 7.2. Also, the wetland criteria will afford additional protection for those System Six areas including major wetlands.

Although details of the proposed Jandakot Botanical Park were not available at the time of writing this PER, drawdowns in the general area of the Park are less than 0.5 metres and mostly less than 0.25 metres. Groundwater abstraction will therefore have a minimal impact.

9.5 WETLANDS

Management for conservation of wetlands in the Jandakot Area, impacts on them and mitigation of the impacts have been previously assessed in this PER in the sections that recommend environmental criteria.

9.5.1 Water levels

The criteria have been complied with (see sections 8.5.1 and 8.6.1) for the major wetlands. As such, the impacts of the scheme on these wetlands are considered acceptable. The impacts of the project will be beneficial in reducing artificially high water levels in some wetlands, particularly North, Bibra and Yangebup Lakes.

Banganup Lake

Rigorous criteria for Banganup Lake have not been developed due to the lack of detailed information including bathymetry. Considering the pristine nature and importance of Banganup Lake, and the modelled effect of the most likely scenario (scenario 3), the predicted impact is unlikely to be acceptable. As already stated, much of this impact is unavoidable if groundwater levels are managed in accordance with CALM's desire for lower water levels in Thomsons Lake.

Artificial maintenance is clearly an option to mitigate the effects of drawdown. It is proposed that the Water Authority, in conjunction with CALM and the University of WA, undertake a study to establish detailed criteria for the lake and consider the effectiveness of artificial maintenance. The study will look at the ecological role of the wetland, the hydrogeology of the area and include a bathymetric survey. Proposed criteria and management will be detailed in the management and monitoring programme (see section 10). Responsibility for implementation of the programme must also be addressed.

The Spectacles

Criteria for The Spectacles have not been developed due to the lack of detailed information. As well, some of the drawdown impact on the wetlands will be due to the Jandakot South Groundwater Scheme. The Water Authority is not seeking approval to develop this Scheme as it is unlikely to for about 15 years.

Flows in the Peel Main Drain will be reduced by the general lowering of the water table over the southern part of the Mound. This will cause smaller flows into The Spectacles. However, the impact on The Spectacles would be so small as to be indeterminable from natural variations. This is because The Spectacles is not very sensitive to small changes in flow in the drain. For example, if inflow to The Spectacles from the drain was reduced by 10 percent there would be a reduction in the total inflow to The Spectacles by around 3 percent. However, this would be somewhat offset by drainage outflow being reduced by a similar amount. The net result is that water levels will be essentially unaffected but that the residence time of water in The Spectacles may be slightly increased.

As indicated in Table 8.8, the lake may be affected by drawdown due to increased groundwater abstraction by private users. Water levels in the lake will need to be closely monitored. There is an opportunity to manipulate residence time and water level in the lake by controlling drainage outflows if considered desirable. The impacts on seasonal wetlands are considered in section 9.5.7.

9.5.2 Vegetation

The recommended criteria for the wetlands are based on maintaining the fringing native vegetation. As these criteria are satisfied, the impacts on native fringing, aquatic and emergent vegetation of the major wetlands in the Jandakot Area are expected to be minimal. In general, slight shifts in the position of vegetation on the lower slopes of the wetland may be expected.

One potential impact of water drawdown in some lakes could be the spread of bulrushes. Although the relative importance and ways in which water depths and quality affect the growth and spread of bulrushes are not well understood, the environmental water level criteria were set with the possibility of bulrush spreading in mind. Also, apart from Thomsons Lake, significant increases in the area of any habitat, including bulrushes, are precluded by criteria set out in section 7.5.4. As already indicated, the mechanisms behind the spread of bulrushes are being addressed by current research. It is likely that shifts in habitat types at Thomsons Lake will be a consequence of CALM's criteria.

9.5.3 Waterbirds

Criteria have been recommended to ensure that waterbirds breeding and feeding habitats are maintained (sections 7.4.2 and 7.5) and that important refuge areas (Forrestdale and Thomsons Lakes) are protected (section 7.3). These criteria have been satisfied and as such the environmental impacts are considered acceptable.

9.5.4 Invertebrates

Criteria have not been specifically set to protect invertebrates because of the difficulty in understanding food webs and the invertebrates' position in them (see section 6.8.3). However, lowering water levels is likely to lead to an increase in habitat diversity which in turn will lead to increased species diversity (see section 5.2.1). Species abundance may be reduced slightly for some species.

9.5.5 Odours and midges

In those instances where a wetland dries out, midge numbers and odour problems will be reduced considerably. In some wetlands, lowering of water levels can lead to higher concentrations of nutrients, which, along with higher temperatures can lead to increases in odours and the size of midge populations (see section 6.6). However, the changes in odours and midge populations due to water level changes will generally be very small when compared to those due to elevated nutrient levels.

9.5.6 Nutrients

The average (ie end of winter) nutrient status of the wetlands will not be altered. Evapoconcentration of nutrients due to lower water levels has the potential to result in higher wetland nutrient levels at the end of summer. Groundwater abstraction will result in generally lower water levels in the wetlands and, therefore, has the potential to enhance evapoconcentration. However, most of the wetlands in the Jandakot Area already dry during summer without the proposed groundwater abstraction. Thus, the impact of the scheme on these wetlands will be to bring forward the time of drying, and any evapoconcentration of nutrients, to earlier in the summer; there will be no additional evapoconcentrative effect due to groundwater abstraction in the vast majority of the seasonal wetlands.

In permanent wetlands, lower water levels could enhance the evapoconcentrative effect, resulting in longer periods of elevated nutrient concentrations over summer/autumn. However, most of the permanent wetlands (Bibra, Yangebup) will be artificially recharged to maintain water levels over summer and this should act to reduce the effects of evaporation on nutrient levels.

It is also worth considering that in a recent study of ten wetlands, including Thomsons and Forrestdale Lakes, Rolls *et al.* (unpubl.) found little evidence of significant evapoconcentration of nutrients over summer. This was presumably due to other nutrient cycling processes that occurred in the wetlands and the generally higher water levels that year. This result is in contrast to some earlier studies (eg Davis and Rolls, 1987), however it serves to highlight that the significance of evapoconcentration in markedly altering nutrient levels in wetlands is far from certain.

9.5.7 Seasonal wetlands

Up to six damplands (waterlogged areas) will be significantly degraded. These have a total area (calculated using information from Middle (1988)) of less than 0.2 square kilometres. Assuming that the South Jandakot Urban Development proceeds, three of these damplands would be cleared and urbanised. The significant seasonally inundated wetlands meet the criteria without artificial maintenance apart from Twin Bartram Swamp and Solomon Road Wetland.

Twin Bartram Swamp

It is likely that Twin Bartram Swamp would need to be artificially recharged to meet the criteria. If required, this would be done by adding groundwater via a spur pipeline running from the nearby collector main. The amount of water required would depend on, among other factors, the drainage design and rate of development, for the proposed South Jandakot Urban Development. A study is proposed to look at the effectiveness of artificial maintenance for Twin Bartram Swamp. To this end, the Water Authority has commenced water level monitoring in Twin Bartram Swamp and will commission a hydrogeological study. Prior to commissioning of the Stage 2 GWS the Water Authority will provide the EPA with details of its proposals as part of the Management and Monitoring Programme (see section 10).

Solomon Road Wetland

The main value of the Solomon Road Wetland area is as a refuge and feeding and breeding area for non-aquatic species of invertebrates (LeProvost *et al.*, 1987).

Impacts on Solomon Road Wetland are likely to include:

- water levels being lowered by up to 1.25 metres,
- the South Jandakot Urban Development, and
- the southward extension of the Kwinana Freeway.

It is unlikely that the environmental values of Solomon Road Wetland can be maintained due to the number and range of likely impacts. To reduce the water level impacts would require a large quantity of water to be foregone from the proposed Stage 2 GWS plus private abstraction may have to be limited in the area. This would impose significant financial costs. To relocate the wells would have larger environmental impacts in areas of higher environmental value.

Artificial maintenance has been examined but is not considered a reasonable option to maintain the values of the Solomon Road Wetland area. This is because of the cost associated with either pumping large quantities of groundwater or trying to maintain a perched area above the water table, as well as other impacts. For example, it is not currently possible to determine the future conservation values of Solomon Rd Swamp given that proposed urban development will completely surround the wetland. Also, given that the impact of the proposed groundwater abstraction on Solomon Rd Swamp is as great as predicted, it may not be possible to artificially maintain the wetland without also ceasing to draw water from the area for the GWS. However, should Solomon Rd Swamp maintain some of its environmental values despite the effects of urbanisation, the Water Authority will examine options for actively managing water levels. In summary, Solomon Road Wetland will have major changes to the structure and composition of its vegetation. Most fauna will cease to use the area (LeProvost *et al.*, 1987b)

9.5.8 Artificial maintenance of water levels

Artificial maintenance of water levels by adding water to wetlands has been demonstrated to be an effective and reliable way of maintaining minimum water levels for many wetlands.

Reliability

Most of the equipment used to supply recharge water from wells is reliable by its very nature. In any case, repairs can usually be carried out within a few days. For example, should a pump fail it would be replaced with a spare rather than having to wait for repairs to be carried out.

A power strike or failure would result in groundwater not being available for recharge purposes. However, most strikes or power failures have been of relatively short duration.

In summary, artificial maintenance is generally a reliable process. At worst, artificial maintenance may have to be stopped for a few days on rare occasions.

Impacts

The impacts of artificial maintenance on wetlands were discussed in section 6.8.6. In summary, the impacts are likely to be:

- lower nutrient levels,
- lower concentrations of dissolved salts,
- lower pH,
- a minor cooling effect (less than 0.1 degrees Celsius),

Nutrient levels are likely to improve because the major wetlands have over 2 milligrams per litre of nitrogen while the Stage 2 groundwater has an average of less than 1 milligram per litre.

Dissolved salt concentrations are likely to improve because the freshest of the major wetlands, has around 500 milligrams per litre concentration while the Stage 2 groundwater has an average of less than 300 milligrams per litre. There is, however, a possibility that the wells drilled specifically for artificial maintenance may be in areas of the superficial aquifer with higher than average levels of dissolved salts.

Groundwater from the Stage 2 GWS will have an average pH of 5 to 6 whereas the major wetlands are alkaline with pHs of 7 to 9 (EPA, 1987b). It may be necessary to correct the pH of incoming groundwater if artificial maintenance is likely to significantly alter the pH of a wetland.

9.6 SOCIAL ISSUES

Social issues addressed in this PER include:

- aesthetic and recreational values and uses associated with wetlands and their conservation; and
- potentially competing demands for groundwater by the environment, private and public users.

Social issues are introduced and outlined in section 5.4.4. Criteria and management objectives involving environmental aspects of these issues are discussed in section 7. Environmental management objectives are largely based on maintaining historical water level regimes in wetlands. Therefore the social impacts of Stage 2 should, in general, be minimal.

9.6.1 Aesthetic and recreational uses

It is recognised that there is more active and managed recreation in the north of the Jandakot Area, especially around North Lake and Bibra Lake, and more passive recreation and use related to conservation values in the south, particularly around Thomsons Lake.

Water abstraction from the mound will be regulated to maintain historical water levels in the lakes by keeping them between the operational water level criteria given in Tables 7.2 and 7.5. Although in the long term lake levels are expected to be low more often than during the last ten years, they will be maintained at levels higher than the action minima. Because Bibra Lake's aesthetic and recreational importance is so great, the lake's action minimum water level was set at 13.6 metres AHD, higher than its environmental action minimum, 13.3 metres AHD.

Implementation of the scheme will improve recreational use of Bibra and North Lakes by reducing the risk of flooding of recreational facilities and roads. As a result of the implementation of the South Jandakot Drainage Management Plan, maximum levels in Yangebup Lake will be limited to around 16.5 metres AHD to prevent flooding of roads and surrounding vegetation. However as explained previously, there is no guarantee that desirable maximum water levels will not be exceeded. Maximum levels in Kogolup Lake can be controlled if this is deemed beneficial to the wetland.

The overall impact of lowered water levels on the recreational use of the wetlands will be minimal due to most of that recreational use being independent of water levels (see section 5.4.4).

9.6.2 Competing demands

The Water Authority believes that the proposed allocation of groundwater between private and public users and the environment is balanced. Of the groundwater abstracted from the Jandakot PWSA, twice as much will be available for private users as public. This private allocation is considered to be sufficient to meet the needs of nearly all users in the foreseeable future.

Prior to commissioning, the Water Authority will conduct a pump test for each of the Stage 2 wells and will liase with private users of groundwater located close to the wells. This will enable an assessment to be made of the likely impact that Stage 2 wells will have on private wells located nearby.

9.6.3 Land use

Establishment of further horticultural operations in the Jandakot PWSA is likely to be minimal, due to the possible impact on the Peel-Harvey Estuary and the groundwater resources of increased nutrient levels from fertiliser application. It is expected that the impacts on land use due to this proposal will be minimal as the Jandakot wellfields area has been declared an UWPCA and a PWSA for over 15 years.

Some low-lying areas within the Jandakot PWSA are used as summer pasture. Although there was considerable concern about this matter prior to commissioning of the Jandakot Stage 1 wellfield, operational experience would suggest that the impact on summer pasture has been minor. Since many of the areas which will be affected by drawdown from Jandakot Stage 2 are ultimately zoned for urban development, alterations in groundwater levels will have little long-term effect on summer pasture.

10 Management and Monitoring

Environmental management and monitoring is an essential component of any major project. This section of the PER sets out the principles by which the Water Authority proposes to manage groundwater abstraction from the Jandakot Mound (these are summarised in Appendix 12). It gives a range of specific undertakings related to the future utilisation of groundwater from the Jandakot Mound. It also addresses the appropriate timing for preparation of a Management and Monitoring Programme.

10.1 INTRODUCTION

In terms of manipulation and changes in the hydrological regime of the Jandakot Mound, groundwater abstraction is a relatively small factor. The Jandakot Area has experienced and is still undergoing dramatic changes in both land use and management. Land-use has intensified and the next few years will most likely see further areas urbanised. In the same time-frame, plans for the creation of the Beeliar Regional Park and other conservation and recreation reserves will most likely be implemented.

All of these activities and initiatives will entail the development and implementation of active management plans. The respective managing agencies will develop specific management objectives and criteria for the areas under their responsibility. An Environmental Protection Policy is also being developed for the area.

Co-ordination of land and water planning is essential for effective protection and management of the Jandakot Mound groundwater resource. The Water Authority and DPUD are currently preparing an integrated Land Use and Water Management Strategy for the Jandakot Mound to ensure rational development.

The Water Authority is responsible for groundwater protection and utilisation and is committed to performing these functions in an environmentally responsible manner. To assist it in its role, the Authority has supported the establishment of a number of three year research projects to increase understanding of wetland ecology, the interaction between wetlands and groundwater and the impacts of groundwater abstraction on wetland function and values. The Authority has also commissioned a three year study of groundwater well drawdown cone impacts and their mitigation in *Banksia* woodlands. An outline of these studies is presented at Appendix 2.

Development of the second stage of the Jandakot GWS is currently scheduled on the 'most likely' Source Development Timetable for commissioning in October 1993. While this date may appear well off in the future, the planning, design and construction lead-times are such that environmental review and assessment is timely.

This PER and the management principles and criteria proposed are not a comprehensive land and water management plan. The investigations undertaken, culminating in this report, do however establish that under appropriate conditions, the Jandakot Mound can supply a substantial and sustainable groundwater yield for the benefit of the community, with acceptable environmental impact.

The PER sets out the principles for management and monitoring of the Stage 2 Scheme within the context of total groundwater abstraction from the Jandakot Mound. The Water Authority proposes to prepare a Management and Monitoring Programme, satisfactory to the EPA, prior to commissioning of the Stage 2 Scheme. Such timing permits the resolution of some land use uncertainties and maximum progress on the environmental studies outlined in Appendix 2.

10.2 NEED FOR MANAGEMENT

The approach to planning the Stage 2 GWS has been to recommend criteria for protection of the environment and to then design, within the context of total sustainable groundwater use, a scheme which satisfies those criteria. Management and monitoring of the expanded GWS and total groundwater use will:

- ensure that groundwater abstraction is undertaken in compliance with the recommended environmental criteria,
- allow improvements in the understanding of the environment and impacts of abstraction to be incorporated in the groundwater management and monitoring programme,
- involve the community in future review of the management criteria.

As discussed earlier in this report, in relation to setting criteria, flexibility in changing management practices is considered fundamental. Therefore neither this management plan nor any other should ever be 'cast in concrete'. It should instead evolve in response to improved knowledge of the project concerned, the system being managed and changed social values.

10.3 THE ROLE OF GOVERNMENT AGENCIES

Many government agencies have responsibilities related to the management of the Jandakot Mound.

The Water Authority operates the Jandakot GWS, manages private abstraction, protects the water resource from pollution and manages Main Drainage under the Water Authority Act (1984) and related Acts.

Other agencies with significant roles in the Jandakot Area are the:

- Environmental Protection Authority,
- Department of Conservation and Land Management,
- Department of Planning and Urban Development (formerly the State Planning Commission),
- Western Australian Museum, and
- Department of Agriculture.

The EPA's role as defined by the Environmental Protection Act includes protection and enhancement of the environment. In performing this function the EPA assesses the significance of environmental impacts associated with developments such as the Jandakot Stage 2 GWS. The EPA advises the Minister for the Environment as to the environmental acceptability of projects and appropriate conditions. This PER has been prepared at the request of the EPA to assist it in performing that task in relation to this project. The EPA also has a statutory role in controlling pollution, including protection of groundwater quality.

CALM, operating under the Conservation and Land Management Act (1984), has the role of managing Crown Reserves, including National Parks and Nature Reserves vested in the National Parks and Nature Conservation Authority. The Department is also responsible for looking after the State's natural assets such as rare flora.

CALM manages a number of "A" Class Reserves in the project area, such as Thomsons Lake and it is intended that, as well as additions to the conservation estate, CALM will have a major role in the management of the proposed Beeliar Regional Park.

The Department of Planning and Urban Development carries prime responsibility for shaping the pattern of land development in Perth. This is carried out under a number of Acts, particularly the Metropolitan Region Town Planning Scheme Act (1959) and the Town Planning and Development Act (1928). The Department generates proposals aimed at providing for the city's future land requirements and assesses the proposals of local government and private developers for compliance with that plan. An example closely related to the management of water on the Jandakot Mound is the South Jandakot Urban Development.

The Western Australian Museum's Department of Aboriginal Sites administers the Aboriginal Heritage Act (1972) which gives protection to Aboriginal sites. These sites can be important because they contain archaeological material of Aboriginal origin or have particular cultural significance to living Aborigines.

The Department of Agriculture advises on agricultural practice. Aspects which are particularly relevant include control of clearing (through the Soil Conservation Commissioner) and water and nutrient management for horticultural projects.

10.4 CURRENT MANAGEMENT

There are five proclaimed Groundwater Management Areas in the Jandakot Area (see Figure 8.14):

- Jandakot Public Water Supply Area (PWSA) and the Jandakot Underground Water Pollution Control Area (UWPCA), the boundaries of which coincide,
- Perth Groundwater Area
- Cockburn Groundwater Area,
- Serpentine Groundwater Area,

With the proclamation of the Perth Groundwater Area in December 1989, all of the Jandakot Mound is now subject to groundwater management by the Water Authority.

The Groundwater Areas were proclaimed to allow for management of private groundwater abstraction through the licensing of private groundwater abstraction. An Advisory Committee meets regularly to assist the Water Authority with groundwater allocation and licensing matters.

Currently, groundwater abstraction for public water supply is only occurring in the Jandakot PWSA.

10.4.1 Jandakot Public Water Supply Area

The PWSA was proclaimed to provide for the development of the Jandakot GWS and for the management and licensing of private groundwater users.

A proposal for staged development of the public water supply abstraction scheme on the Jandakot Mound was referred to the Department of Conservation and Environment in January 1976. Construction and operation of the Scheme was approved by the EPA in February 1976 subject to a number of conditions. These principally consisted of continuing surveillance of groundwater behaviour and the surface environment, reporting annually to the EPA and advising EPA in advance of any significant change in operation of the Scheme which might affect the environment. In November 1984, the EPA changed the reporting requirement to triennial reports on environmental impacts with annual summary reports detailing any unusual impacts or aspects in Scheme operations.

Stage 1 of the Scheme has been operated since 1979. During that period the first line of wells has consistently produced a yield around the estimated 2.7 million cubic metres per annum. With the agreement of the EPA, production from that line of wells has, from 1989, increased to 4 million cubic metres per annum.

Current management of private abstraction in the Jandakot PWSA is summarised in section 8.7.1.

An extensive network of groundwater monitoring wells is maintained across the Mound. These are generally monitored monthly. Monthly monitoring of water levels is also conducted in a number of lakes: North, Bibra, Yangebup, Kogolup, Banganup, Thomsons, Forrestdale and The Spectacles. This monitoring is undertaken to permit both active management of the public and private abstraction, and as the basis for reporting to the EPA. Monitoring has revealed that the impacts of abstraction on water levels have been less than those predicted in 1976 upon which EPA approval of the Scheme was based.

Reports on Jandakot Stage 1 impacts have been submitted to EPA as required, the last triennial report covering the period to September 1986, followed by annual reports to September 1987 and 1988 respectively. Due to the comprehensive review of groundwater management being undertaken for this PER, EPA has agreed that further reporting be delayed until after the Ministerial conditions are set on both stages of the Jandakot GWS.

10.4.2 Jandakot Underground Water Pollution Control Area

The Jandakot UWPCA was proclaimed at the same time as the area was proclaimed a PWSA. The UWPCA boundary is coincident with the PWSA boundary. The Water Authority has powers under its Act to make by-laws to protect the quality of groundwater in the UWPCA for public water supply. These by-laws principally relate to the control and regulation of activities which cause, or may cause, groundwater contamination.

Activities controlled by the Authority's current by-laws include;

- storage and transport of pesticides,
- storage of animal manures,
- installation and operation of septic tanks,
- discharge of wastes and chemicals to ground,
- premises handling, storing or using chemicals or other materials which are hazardous to groundwater, and
- installation and operation of underground storage tanks.

The Water Authority is presently revising the current by-laws to increase control over potentially polluting activities in the area. It is planned that the revised by-laws be implemented following the enactment of the new Water Act, which is intended to go before Parliament in the near future.

In addition to application of the by-laws to control specific activities, the Water Authority also acts to protect groundwater quality in the area by influencing land-use planning and zoning for the area. The Water Authority provides advice to the Department of Planning and Urban development and the local authorities on the acceptability of land development and zoning proposals, and appropriate conditions to be applied.

Examples of this are the Authority's policies regarding the density of septic tanks allowed for Special Rural zones in the area, and the restriction on underground storage tanks in sensitive parts of the area.

The Water Authority has applied a number of conditions to the planned South Jandakot urban development to ensure that it will have a minimal impact on the groundwater resources to be used for public water supply from that area. The area will be sewered, and there will be controls on the locations and types of commercial activities, and restrictions on underground storage tanks.

Further details on the integration of land and water management in the Jandakot area are provided in Section 10.5.3.

10.5 PROPOSED MANAGEMENT

10.5.1 Management of the public groundwater schemes

The Water Authority, in consultation with and to the satisfaction of the EPA, undertakes to manage the public groundwater scheme in accordance with the commitments listed in this section. Further, the Water Authority will include in the Management and Monitoring Programme, an operational plan for the Jandakot GWS incorporating, but not limited to, the considerations listed under 'operation'.

Construction

Construction of the Jandakot Groundwater Scheme Stage 2 will involve a number of elements as described in section 4.1:

- nominally 13 wells into the shallow aquifer,
- security compounds around wells located outside urban areas,
- approximately 12 kilometres of collector main running between the wells and connecting them to the Jandakot Treatment Plant,
- a service track in areas where the collector main does not follow an existing road,
- a low voltage power supply to each well site, and
- extensions and modifications to the Treatment Plant.

The following commitments are given in relation to mitigation and management of impacts associated with construction of the Stage 2 Scheme:

- clearing of vegetation at well sites will be restricted to the area of the enclosure (approximately 25 metres square) in non-urban areas, and the immediate area of the well head in the case of wells located in public open space in urban areas,
- where practical the collector main will be located within existing road reserves, obviating the need for construction of a new access track at that location,
- on Crown Land, top-soil from the collector main trench will be separately stripped, stockpiled and re-spread on completion of pipe laying,
- on private land, the collector main route will be left in a state agreed to by the land owner/occupier,
- where feasible, well site compounds will be used for the storage of materials and for contractors' facilities, in preference to the establishment of separate short-term sites,
- where temporary construction sites are established, the area will be returned either to its original state, in the case of Crown Land, or to a state agreed to by the land owner/occupier,
- all work on extensions to and modifications of the Jandakot Treatment Plant will be undertaken on existing cleared areas within the boundary of the Plant site, and
- all workers involved in project construction in natural areas will be instructed on environmental protection procedures.

Operation — Groundwater Abstraction

The primary management objective for operation of the Jandakot GWS is to abstract the maximum quantity of water that can be produced on a sustainable basis while protecting water quality and the environment. The initial target is to abstract an additional 4 million cubic metres per annum from the shallow aquifer using the Stage 2 line of wells.

Protection of the environment is seen as ensuring that water abstraction from the Mound does not cause unacceptable impacts to components or functions of the environment. In general, this means maintaining as closely as possible the 'existing state' of the environment with due allowance being made for natural fluctuations, evolution and change (section 6.5.1). Some specific impacts, both adverse and beneficial, will result from implementation of the proposal (section 9).

One purpose of this PER is to establish bounds within which such changes are judged acceptable by the community, the Environmental Protection Authority and the Minister for Environment. It is proposed that the Stage 1 and 2 GWS will be managed, in association with private abstraction, in such a manner as to operate within the criteria proposed in section 7 and the details given in sections 8 and 9.

Artificial maintenance of wetlands is a integral part of the strategy to maximise groundwater abstraction while minimising the impact on wetlands. However, because modelling of the impacts of groundwater abstraction are considered to be conservative (ie actual impacts are likely to be less than those predicted through modelling), artificial maintenance schemes will not be put in place until monitoring indicates that it is clear that they are required to satisfy the criteria or mitigate unacceptable impacts. There following artificial maintenance schemes are likely to require implementation:

- maintenance of Bibra Lake when the water level is close to the action minimum of 13.6 metres AHD. The source of recharge water is likely to be a well located approximately 200 metres to the west of the Lake.
- maintenance of Kogolup Lake if it is likely that the action minimum of 13.1 metres AHD will be reached. Because this level is below the lake bed, water would need to be added

to the Lake prior to it drying out at 13.6 metres AHD. It would be preferable to use good quality drainage water which may be available late in winter. If acceptable quality drainage water is not available, then it would be necessary to pump water from a well, and

- maintenance of Thomsons Lake if it is likely that the criteria will be breached, and particularly if the action minimum of 10.8 metres AHD is likely to be breached. The source of water and timing of artificial maintenance would be similar to that for Kogolup Lake.

As indicated in section 9.5, it is also possible that artificial maintenance will be required for Banganup Lake and Twin Bartram Swamp. However, this will be subject to further monitoring of water levels and studies of the wetlands, including their hydrogeology and bathymetry.

In the event that monitoring indicates that continued operation of the Scheme will result in significant impacts of a nature not predicted in this evaluation or a breach of the specified criteria, then as discussed in section 6.9 the Water Authority must undertake one or more of the following:

- demonstrate to the satisfaction of the EPA that the breach in criterion is not a result of groundwater abstraction, or
- satisfy the EPA that the breach of criterion is transient and not of permanent significance, or
- take the relevant action as specified in section 7:
  - — modify pumping from any well where the resultant effect is measurable (say 1 centimetre impact), except in extenuating circumstances such as where significant economic hardship would occur, or CALM declare that the low water levels would be beneficial,
  - — in the case of a wetland, artificially maintain the 'action minima' water level (see Table 7.5) by pumping directly from appropriate wells or diverting good quality drainage water (see sections 9.5.1, 9.5.7 and 9.5.8 and this section), and
  - — implement a short-term detailed monitoring programme to establish the condition of agreed species in the affected area.

Operation — Groundwater Treatment

As described in section 4.1.3, chlorine will be used in the water treatment process as an oxidising and disinfecting agent. Chlorine will be transported to the site and unloaded in the normally accepted manner. Prior to commissioning of the Stage 2 line of wells the chlorine withdrawal system will be modified to a liquid process. This reduces from three to one the number of on-line chlorine cylinders, thus reducing by two-thirds the worst possible release from a failure in the withdrawal system. This is reflected in a reduced zone of impact in the event of a maximum release and accordingly a smaller required buffer zone surrounding the plant. The Water Authority proposes a non-residential buffer zone around the treatment plant. The Water Authority will continue to operate the treatment plant so that within the buffer zone, the personal hazard risk of fatality associated with chlorine release will be less than one in a million in any year.

The Water Authority will operate the treatment plant so that within the buffer zone boundary, hydrogen sulphide levels attributable to plant operation will be below the noticeable level of 5 parts per billion (see section 7.6.2).

10.5.2 Management of private groundwater abstraction

Private groundwater abstraction from the Jandakot PWSA will continue to be actively managed by the Water Authority.

The management objectives are to:

- ensure that combined private and public abstraction does not exceed the sustainable yield of the superficial aquifer,
- ensure a distribution of groundwater among private users that is equitable and allocates water on the basis of best use,
- ensure that groundwater allocations are distributed such that private users have minimal environmental impact,
- ensure that irrigated uses involving fertilisers are controlled to avoid unacceptable impact on the groundwater quality for public and private use, and
- ensure that specific proposals which may have a significant environmental impact are referred to the EPA for assessment.

This management takes the form of licensing of all wells under provisions of the Metropolitan Water Supply Sewerage and Drainage Act. The licences entitle the holder to abstract a specific volume of water for a specified purpose.

The Water Authority will manage private water abstraction in a number of ways. The Authority will continue:

- to regularly review the bulk allocation for private abstraction, as part of the total water abstraction allocation for the Jandakot PWSA, with regard to the sustainable yield of the superficial aquifer, including consideration of the environmental impacts of that abstraction,

- the practice of restricting the issuing of licences for private water abstraction to the limits set by the bulk allocations, for both the Jandakot PWSA in its entirety and the licensing sub-areas, and
- to investigate and implement allocation mechanisms for efficient distribution of groundwater.

The Water Authority will conduct pump tests on all Stage 2 wells prior to commissioning and will liaise with nearby private users of groundwater to assess the effect of Stage 2 wells on private wells.

10.5.3 Integrated land and water management

Perth is unique as an Australian capital city as it is situated over the fresh groundwater source upon which it depends for public and private water supply and maintenance of the associated wetland environment (WAWA, 1988c). This emphasises the need for careful management of activities which could potentially harm the quantity or quality of that valuable resource.

A formal land planning policy, aimed at protecting the groundwater, was developed by the Water Authority in 1988 (WAWA, 1988c). The policy, which is currently under review, seeks to ensure that land development in the Perth region does not unduly diminish community benefits afforded by the underlying groundwater resources. The policy identifies three broad categories of beneficial use of the resources:

- environment and recreation,
- public water supply, and
- private water supply.

The Water Authority is seeking to have the identified priority beneficial water uses for the groundwater resource statutory embodied into the Environmental Protection Policies (EPPs) under the Environmental Protection Act.

A significant step in achieving this goal was the release by the EPA of a public discussion paper entitled "Protection of the Groundwater, Wetlands and Associated Ecosystems of the Swan Coastal Plain" in June 1990 (EPA, 1990 d). This paper was prepared by an Advisory Committee responsible to the EPA (Tonkin Committee) and included a draft Environmental Protection Policy. This generic policy for the Swan Coastal Plain will provide some level of protection for groundwater resources in the Jandakot PWSA through the identification of compatible land uses. Activities which are not considered to be compatible will need to be assessed under Part IV of the Environmental Protection Act.

The policy also provides for the development of local EPPs to cover individual catchments and groundwater flow systems of the Swan Coastal Plain. A local EPP will identify more specifically those parts of the environment which are to be protected, their compatible land uses as well as management criteria to be applied. The EPA's Advisory Committee is currently preparing a draft EPP for the whole of the Jandakot Mound.

The Water Authority is also working with the DPUD to prepare an integrated Land Use and Water Management Strategy for the central portion of the Jandakot Mound. The emphasis of this study is to develop appropriate policies and mechanisms for promoting acceptable forms of land use and development consistent with the protection and management of the water resource.

An essential output of the study will be plans which will complement the Metropolitan Region Scheme and recommend acceptable land uses over the next twenty to thirty years. This will be supported by a report recommending short-term and longer term actions, policies and priorities which will be necessary to implement the strategy.

Another report which is under preparation and is relevant to water management in the Jandakot Area is the Environmental Management Programme for drainage associated with the South Jandakot Urban Development. The EPA recommended in its Report and Recommendations on the revised Drainage Management Plan (EPA, 1990c) that such a report be prepared prior to subdivision approval. The programme is to accommodate the commitments in the revised Drainage Management Plan, the recommendations contained in the EPA's Report and Recommendations and the results of further investigations required by the EPA. It should also establish reporting and review mechanisms. The Water Authority is preparing this report.

The Water Authority will ensure that its Management and Monitoring Programme is consistent with the Jandakot Mound Environmental Protection Policy, the Jandakot Land Use and Water Management Strategy and the Environmental Management Programme for drainage associated with the South Jandakot Urban Development.

In summary, the Water Authority will continue to protect the groundwater resource by active participation in:

- the development of Environmental Protection Policies and groundwater management strategies to protect groundwater
- the review of Regional Plans proposed by DPUD, Local Government Town Planning Schemes, and rezoning and development applications,
- allocation for and management of private water abstraction, and
- review of development submissions to EPA.

10.5.4 Water conservation

The Water Authority is committed to the efficient utilisation of fresh water resources (section 3.3.1) and for this reason is actively pursuing programmes in both supply and demand management. These are believed to have reduced annual consumption in Perth by 3.6%.

A new Water Conservation Plan is in preparation to follow on from the 1987/89 Plan (WAWA, 1988b). The 1990/92 Plan will continue most of the major initiatives of the first Plan as set out in section 3.3.1. This includes ongoing public information programmes, and where appropriate, regulation enforcing design changes and regular reviews of pricing to conserve water. Opportunities for further efficiencies in the Authority's supply system will also be pursued.

10.5.5 Ongoing review

As discussed throughout this PER, and in particular in section 6.5, groundwater use is only one of the many factors influencing the Jandakot environment. The Water Authority will continue to participate actively in the process of integrated management of the Jandakot catchment, including reviewing the implications for maintaining the beneficial uses of the groundwater resource.

As knowledge of the Jandakot environment and its response to groundwater manipulation improves, the management criteria and strategies will be modified, with the agreement of EPA, to optimise environmental protection and groundwater yield.

The Water Authority will continue to review opportunities for reducing the radius of the buffer zone required around the treatment plant to achieve the acceptable personal risk and hydrogen sulphide levels discussed in section 10.5.4.

10.6 MONITORING

Monitoring will be undertaken for a number of reasons, these are principally to:

- check compliance with the environmental protection criteria set for Scheme operation,
- review the nature and magnitude of predicted impacts of Scheme operation, and
- provide a basis for adapting management criteria and practices in order to optimise groundwater abstraction while ensuring environmental protection.

The Water Authority will develop a monitoring programme as an integral part of the adaptive Management and Monitoring Programme. The monitoring programme will provide feedback on compliance with the environmental protection criteria. More importantly, monitoring will be designed to confirm that physical, biological and social environmental objectives of groundwater management are being achieved by such compliance. Reports on the results of monitoring will be submitted to EPA as proposed in section 10.7.

The Water Authority is currently undertaking monitoring of the effects of public water supply abstraction from the Jandakot Mound (section 10.4.1). The Authority is also engaged in baseline research of the environment and water abstraction impacts on the Jandakot and Gnangara Mounds (Appendix 2). This work and future monitoring and research will be integrated to provide an input to management.

Baseline monitoring for wetland vegetation, invertebrates and waterbirds is being undertaken through many of the research projects which are listed in Appendix 2.

Monitoring of aquifer performance, improvement of the hydrological model used to predict water level changes and review of groundwater allocation policy for the Mound are all essential components of the management of the aquifer system. To achieve these, it is necessary to regularly measure the extensive network of monitoring wells.

10.6.1 Water monitoring

Water levels in the Jandakot Area will be monitored at groundwater monitoring wells and by measurement of water levels of all major and several smaller wetlands. Water quality parameters yet to be determined will also be monitored periodically in nominated monitoring wells and wetlands.

The Water Authority currently monitors a range of wells in the Jandakot Area for various purposes:

- 44 Jandakot Regional Monitoring wells,
- 16 Southern Perth Area Monitoring wells, and
- 16 clusters of Aquifer Evaluation wells, each consisting of 3 wells generally.

Wells are monitored at a frequency between monthly and three monthly. The frequency of monitoring is reviewed based on the water level trends identified.

As part of establishment of the Stage 2 production wells, some trial wells have been or will be established approximately 25 metres from each proposed production well site. Following test pumping and production well commissioning, these will be used to monitor water levels in the immediate well drawdown cone.

Water level monitoring will be continued at eight major lakes of the Jandakot Area; North, Bibra, Yangebup, Kogolup, Banganup, The Spectacles, Thomsons and Forrestdale. Water level monitoring has also recently been established in Twin Bartram Swamp. The frequency of future measurement is yet to be determined but is likely to be on a monthly basis. Weekly monitoring will be implemented when water levels are approaching action minimum levels.

Water quality in wetlands is currently being monitored as part of the wetland research projects (see Appendix 2). An ongoing water quality monitoring programme will be developed when these projects are completed.

10.6.2 Vegetation monitoring

Native vegetation monitoring will be based on programmes currently being carried out by the Water Authority and its consultants on both the Jandakot and Gnangara Mounds.

Permanent vegetation transects were established in the Jandakot Area in 1988 by E M Mattiske and Associates Pty Ltd. These transects will be monitored triennially to establish whether there are any significant changes in the condition, floristics or structure of vegetation communities. Transects have been located to cover the maximum range of vegetation on different topographical positions from the wetlands to the upper dune slopes. This work is particularly important in the early detection of shifts towards drier vegetation communities. More intensive monitoring is being undertaken as part of the wetland project on the effect of altered water levels on wetland plants (see Appendix 2).

Detailed monitoring of *Banksia* woodland around a well, known as P50, on the Gnangara Mound will provide information on environmentally acceptable rates of drawdown. This three year study (currently in the second year) is examining the impact of groundwater abstraction on vegetation in the drawdown cone of a production well.

Mapping of vegetation and habitats around major wetlands will be undertaken on a triennial basis. This is considered a suitable time scale to detect changes in the biological communities, which are responses to the long-term shifts in the physical environment. More frequent sampling will probably yield little, if any, additional information. The wetland habitats were first mapped in EPA Bulletin 266 (EPA 1990a) and the maps are reproduced in Appendix 8. They will be remapped from aerial photographs prior to the commissioning of Jandakot GWS Stage 2 to provide a recent baseline. This will then be repeated every three years to detect habitat shifts due to groundwater abstraction. It is intended to take aerial photographs in April. Section 7.5 defines classes of habitat and proposes criteria governing maximum acceptable shifts and management initiatives to be implemented in the event of a breach of criteria. This provides the basis for fauna habitat monitoring discussed in section 10.6.3.

10.6.3 Fauna monitoring

It is believed that the fauna of the Jandakot Mound is best protected from adverse impacts of groundwater abstraction by the maintenance of water levels and habitat areas covered by criteria set out in section 7. Proposed monitoring of habitat shifts is described in the previous section. Some direct monitoring of the fauna is desirable to confirm that these strategies are effective.

Fauna monitoring will concentrate on the following in selected wetlands:

- assessment of changes in area of fauna habitat,
- waterbird species diversity and breeding success, and
- the number of families of aquatic invertebrates recorded and at infrequent intervals, the species richness.

Monitoring programmes will be developed for each of these prior to commissioning the Stage 2 GWS. Baseline monitoring for waterbirds is currently being undertaken in 13 wetlands in the Jandakot Area through the joint CALM and the Royal Australasian Ornithologists Union Project (see Appendix 2).

In the event that criteria governing habitat shifts (section 7.5) will be breached, a detailed short-term programme will be implemented to monitor the response of strategic species.

The details of the monitoring programme for aquatic invertebrates will be determined after the completion of the two research projects which are currently being undertaken by Murdoch University (see Appendix 2).

10.6.4 Social monitoring

The response of the community to groundwater abstraction will be monitored by both formal and informal mechanisms.

Meetings will be held at least annually with a Jandakot Consultative Committee which will be established in consultation with the EPA. This Committee will be briefed on the scheme's operations, and will provide feed-back to the Water Authority. More frequent meetings will be held when considered appropriate by the Water Authority or requested by Committee members.

The Water Authority will continue to monitor community response as reported by the media and will maintain the current practice of public accessibility of its officers. Upon request and adequate notice, Water Authority officers will address community groups on issues associated with groundwater management.

10.7 REPORTING AND ASSESSMENT

The Water Authority will, after commissioning of the Stage 2 GWS, follow the practice of reporting to the EPA established for the Gnangara Mound and the Jandakot Stage 1 Scheme. This will consist of:

- annual reports addressing compliance with the environmental protection criteria, and
- triennial reports including, in addition to a review of compliance with the criteria, an evaluation of the effectiveness of the criteria in meeting the environmental protection objectives.

The Water Authority will also advise the EPA immediately upon it becoming aware that specific environmental protection criteria might be breached. Details of the actions taken to avoid such a breach of criteria, or in the event of a breach occurring, its consequences, will be reported to the EPA at the earliest feasible date.

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Glossary

Aboriginal archaeological site	a place containing physical evidence of the past presence of Aboriginals.
Aboriginal ethnographic site	a place, which can also be an archaeological site, which is of importance to people of Aboriginal descent because of its sacred, ritual, ceremonial or historical common use significance.
abstract	to withdraw water from an aquifer.
aeolian	wind-borne.
aestivate	dormancy during summer or dry period.
AHD	Australian Height Datum, a reference level which is approximately the same as mean sea-level.
alluvial	river (water)-borne.
aquifer	a geological formation capable of storing, transmitting and yielding significant quantities of water.
artificial recharge	refers to artificial means of adding water, usually to wetlands.
biota	all plants and animals in a specified area.
botulism	a disease produced by the bacterium *Clostridium botulinum*, which periodically causes bird deaths in wetlands.
coffee rock	rock formed by iron oxides cementing sand grains together.
conductivity	the electrical conductivity of water is a measure of the resistance of that water to electrical current or electron flow. It is used as an indication of the amount of salt dissolved in the water.
cretaceous	referring to rocks 65 to 140 million years old.
cubic metre (m^3)	the volume occupied by a cube measuring one metre along each edge. One cubic metre of water equals one kilolitre.
damplands	basins that are seasonally waterlogged.
demand	the amount of water required from the water supply system.
desalination	the removal of dissolved salts from sea or brackish water to make it potable.
desiccate	to dry out.
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.
ecosystem	a community of organisms, interacting with one another, plus the environment in which they live and with which they also interact; e.g. a pond, a forest, a wetland.
eutrophication	enrichment of a water body with nutrients. Natural eutrophication refers to the natural nutrient enrichment that results from deposition of organic material, leaching from soils etc. Cultural eutrophication refers to nutrient enrichment that results from human activities (eg fertiliser run-off, industrial effluent, sewage outfall).
evapo-concentration	the increase in the concentration of dissolved substances in a waterbody due to evaporation.
evapo-transpiration	the combined effect of transpiration by plants and direct evaporation.

Groundwater Area	An area proclaimed under the Rights in Water and Irrigation Act 1911 in which private groundwater abstraction is licensed.
habitat	the particular type of environment occupied by an organism or organisms.
humus	organic matter resulting from decomposition of plant and animal tissue in the soil.
hydrophytic	plants whose habitat is water or very (plants) wet places.
igneous rocks	rocks formed from magma (molten rock) which has originated well below the surface.
impermeable	non-porous, not allowing water through.
interception	rainfall caught and held on the leaves of trees and vegetation before reaching the ground and returned to the atmosphere by evaporation.
invertebrate	an animal without a backbone.
Jandakot Mound	the mound of groundwater which occurs in the superficial formations bounded by the Indian Ocean, Swan, Canning and Southern Rivers and a hydrologic boundary approximately between Forrestdale, Wellard and Rockingham (Figure 5.3).
jurassic	referring to rocks 140 to 195 million years old.
lake	basins that are permanently inundated.
life history	life cycle. The progressive series of changes undergone by an organism from fertilisation to the death of that stage which produces young.
metamorphic rocks	are formed from pre-existing rocks which have been subjected to increases in temperature and pressure, or both, such that the rocks undergo change.
penetrative convection	is the process where cold and hence dense water 'parcels' sink and mix the water. This generally occurs at night when the air temperature drops below that of the upper layers of water.
perched water table	a water table which occurs above an impermeable zone, which is underlain by unsaturated materials.
permeable	porous, allowing water through.
phreatophyte	a plant that obtains its water supply from the zone of saturation (ie in or near the water table).
pipehead dam	a small dam which collects river flow in winter and spring. The water is pumped to storage reservoirs (pumpback) or supplied directly to the water supply system.
PWSA	an area defined under the Metropolitan Water Supply, Sewerage, and Drainage Act, 1909-1977 in which a public water supply is developed and the amount of groundwater abstracted privately is controlled through licensing.
quaternary	referring to rocks up to 2 million years old.
rehabilitation	to undertake works to return a disturbed area as far as possible to its original state.
seasonality	refers to the seasonal fluctuations in water levels and in particular to wetlands that dry on an annual basis.
sedimentary	sediment in some areas consists of fragments from pre-existing rocks which have been disintegrated by erosion and organic debris such as shell fragments and dead plants. Sedimentary rocks are formed by the accumulation and compaction of sediments.

Sources Development Timetable	a schedule for the chronological development of new water sources to supply projected demand.
species richness	the number of different species.
sumplands	basins that are seasonally inundated.
superficial formations	the Pliocene to Holocene (less than 5 million years old) sedimentary deposits which immediately underlie the Swan Coastal Plain in the Perth Basin.
sustainable yield	(of an aquifer) the quantity of water that can be drawn over a period of time that will be replaced by recharge.
system yield	the maximum unrestricted annual demand that the water supply system can sustain under specified expectation of restrictions (currently restrictions are expected in 10% of years).
transpiration	loss of water vapour by plants. Occurs mainly from the leaves and differs from simple evaporation in that it takes place from living tissue and is therefore influenced by the plant physiology.
UWPCA	an area defined under the Metropolitan Water Supply, Sewerage, and Drainage Act, 1909-1977 in which restrictions are put on activities which may pollute the groundwater.
vertebrate	an animal with a backbone.
water balance	an account of water entering and leaving a system over a specific period.
water year	the period from 1 October of one year to 31 September of the following year.
well	a hole dug or drilled (bore) through the ground surface into an aquifer to withdraw or monitor water.
xeric	having very little moisture; tolerating or adapted to dry conditions.

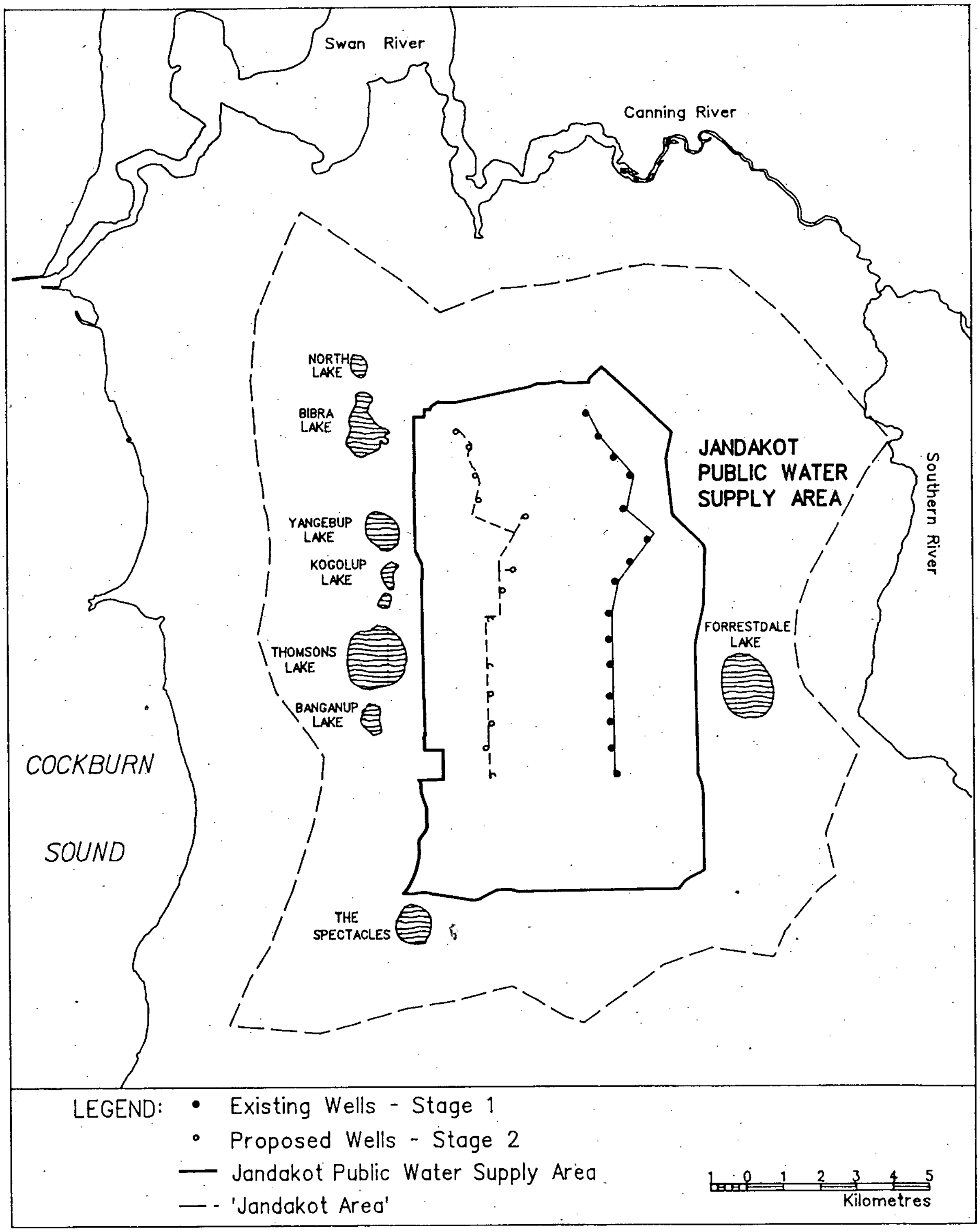


Figure 1.1 Location of Public Water Supply Area and existing and proposed public water supply wells.

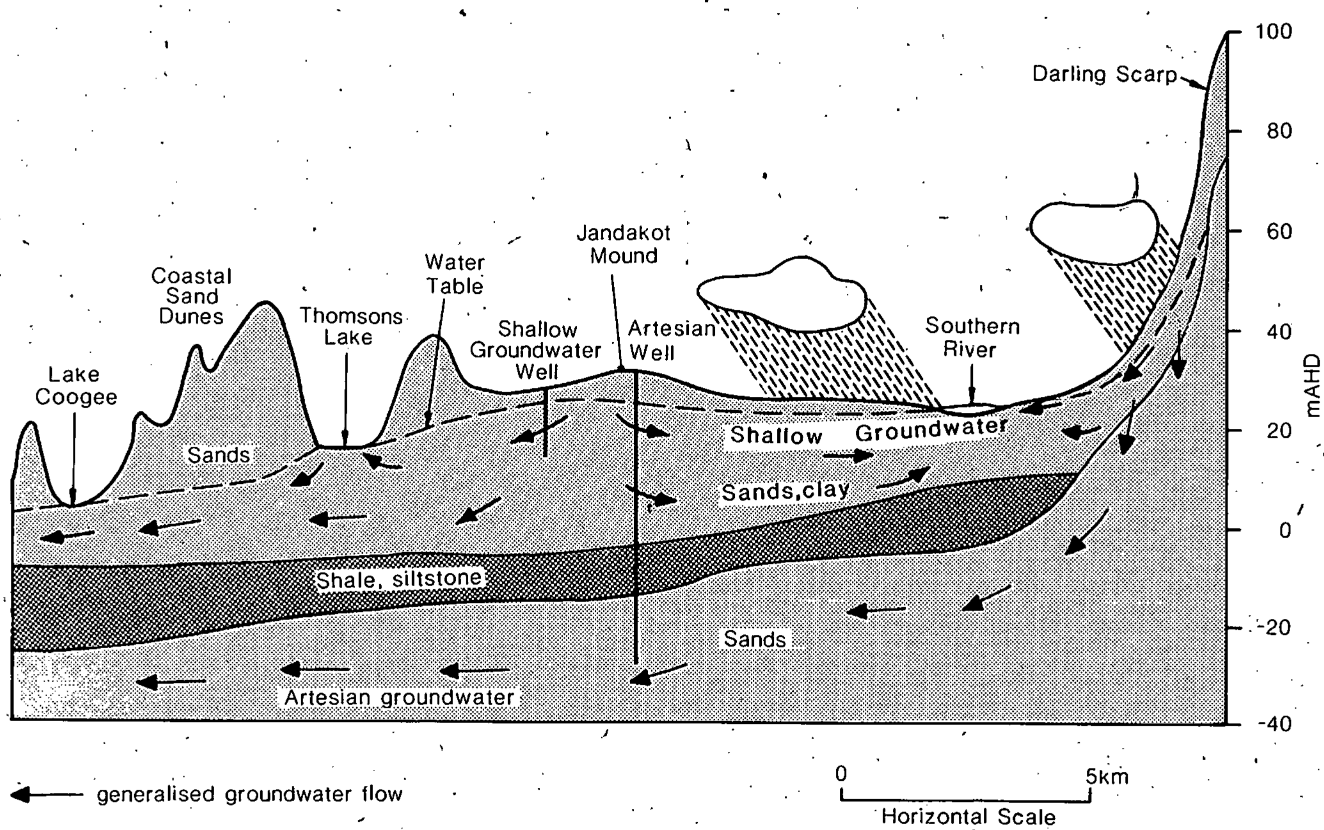


Figure 2.1 A cross-section through the Jandakot Mound showing the occurrence and movement of groundwater.

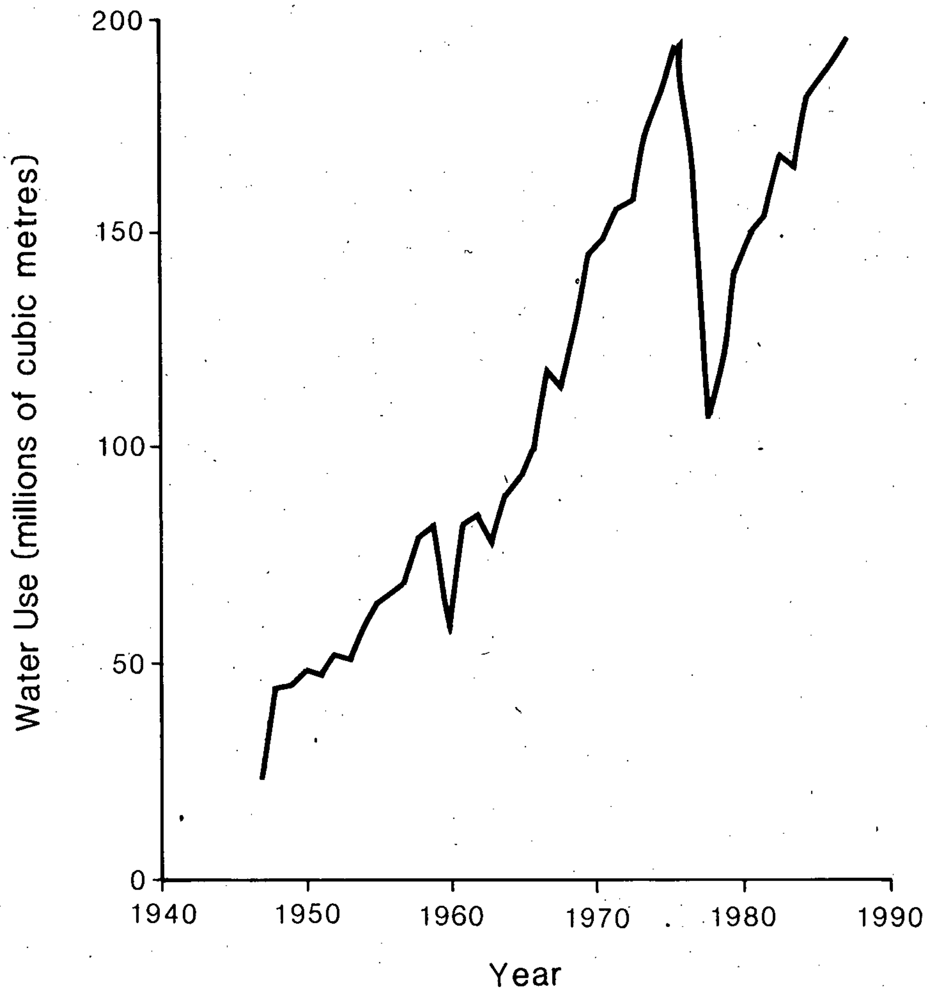


Figure 3.1 Annual water use from Perth's Metropolitan Water Supply Scheme

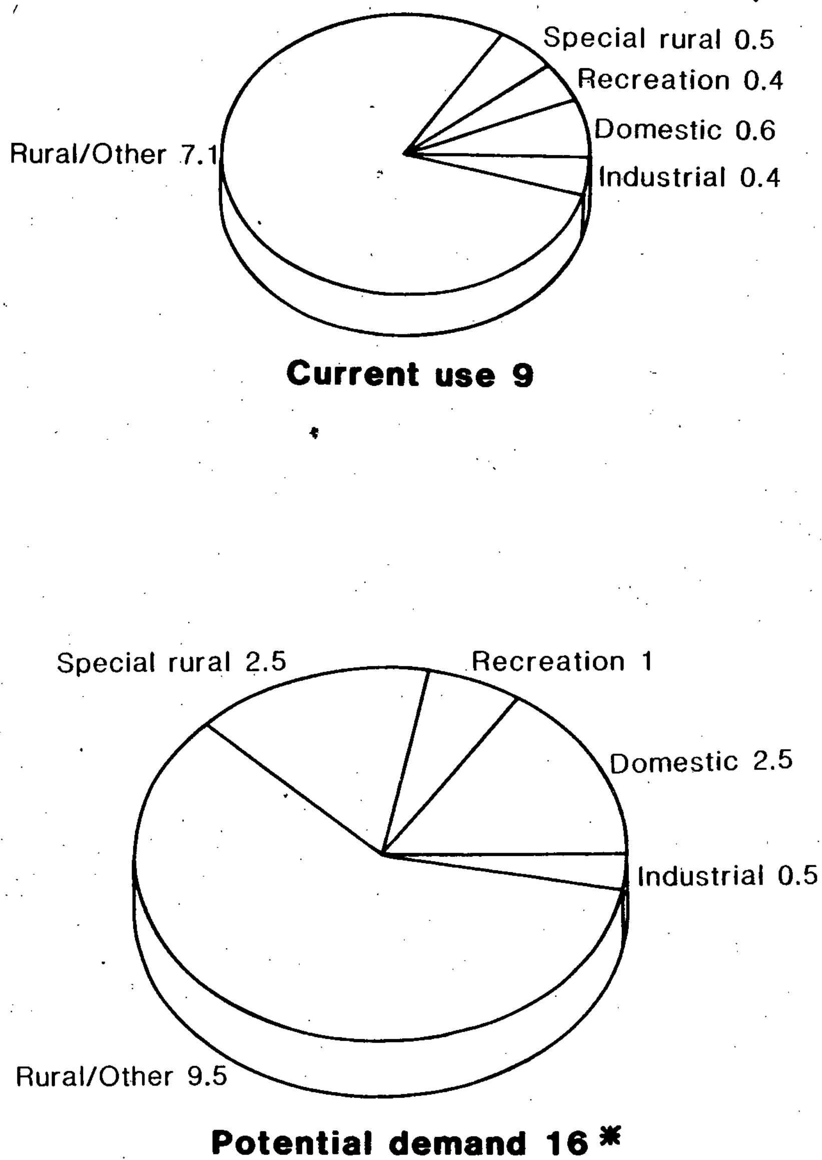


Figure 3.2 Current annual groundwater allocation to different uses in the Jandakot PWSA, as at April, 1989 and the predicted potential annual demand by private users. (* subject to future land-zoning)

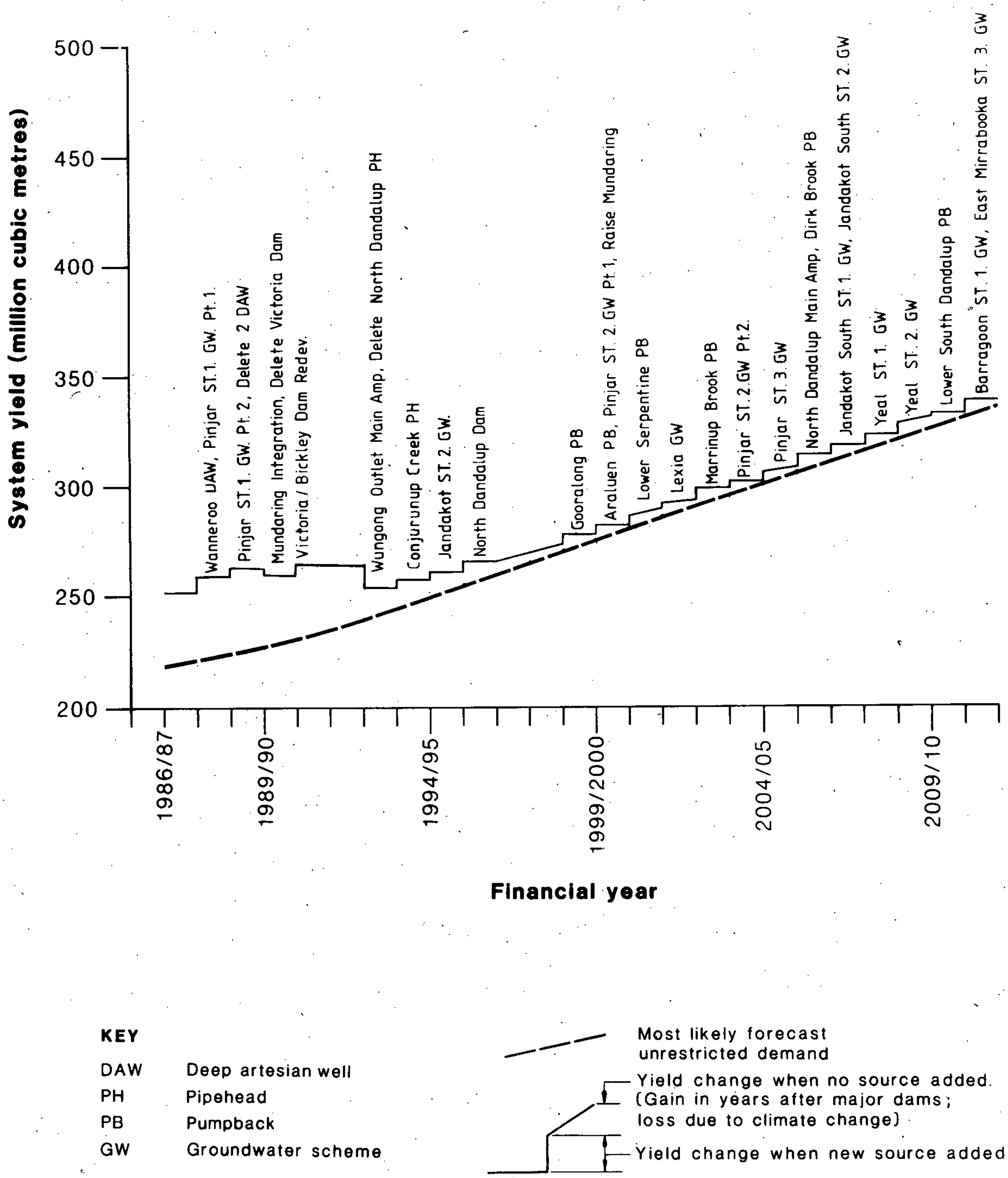


Figure 3.3 Most likely source development schedule.

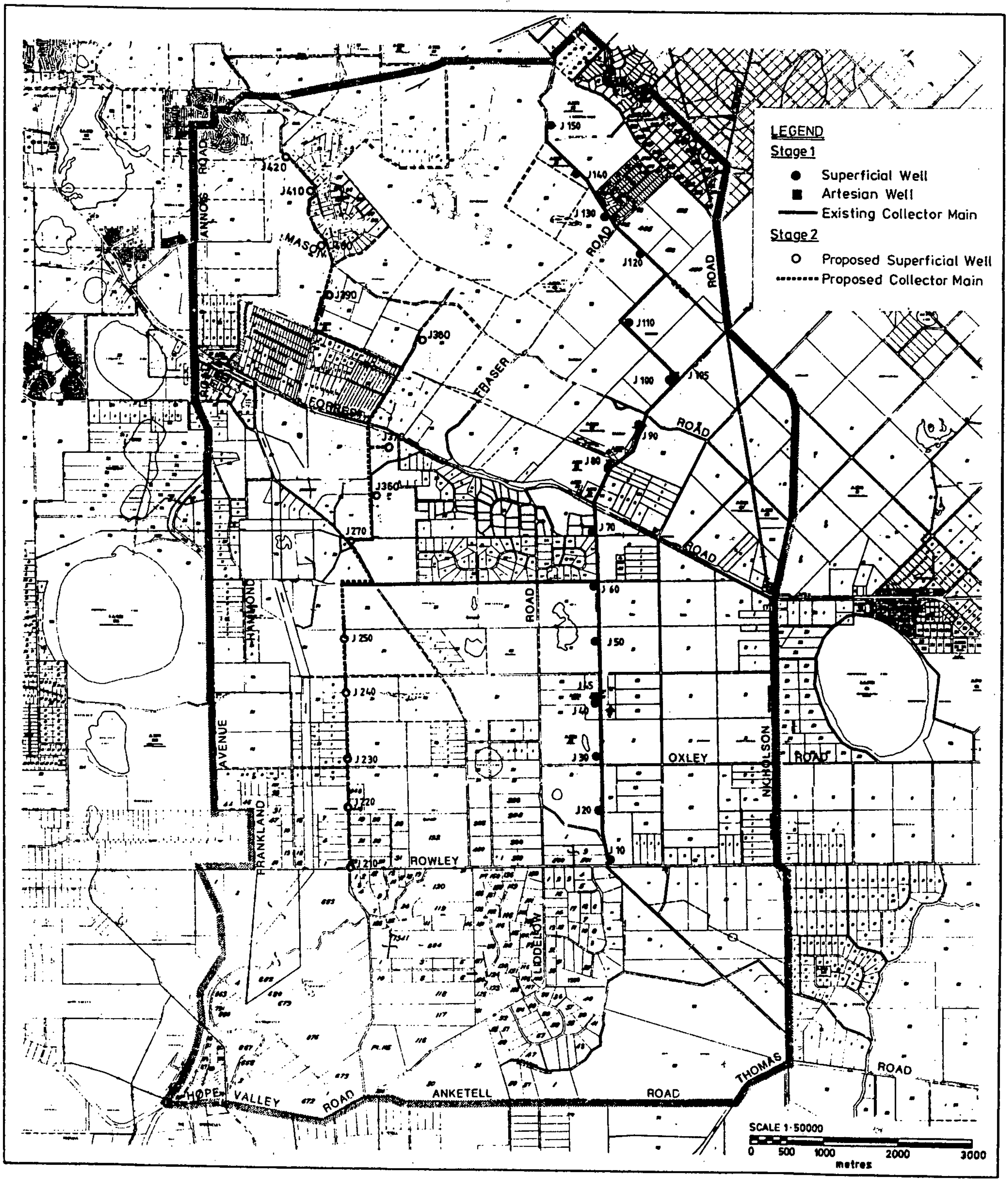


Figure 4.1 Location of existing and proposed public water supply wells.

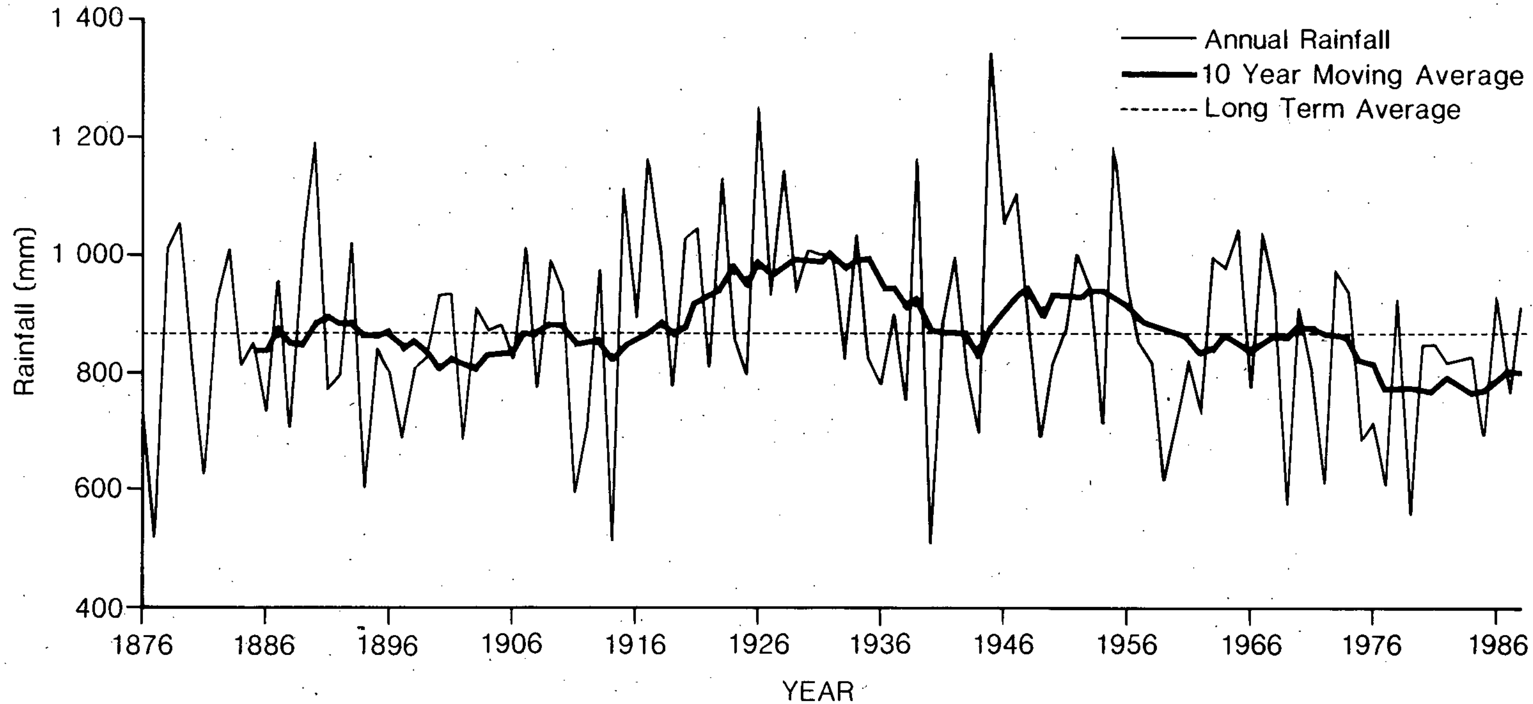


Figure 5.1 Rainfall recorded at the Perth Bureau of Meteorology from 1876-1989.

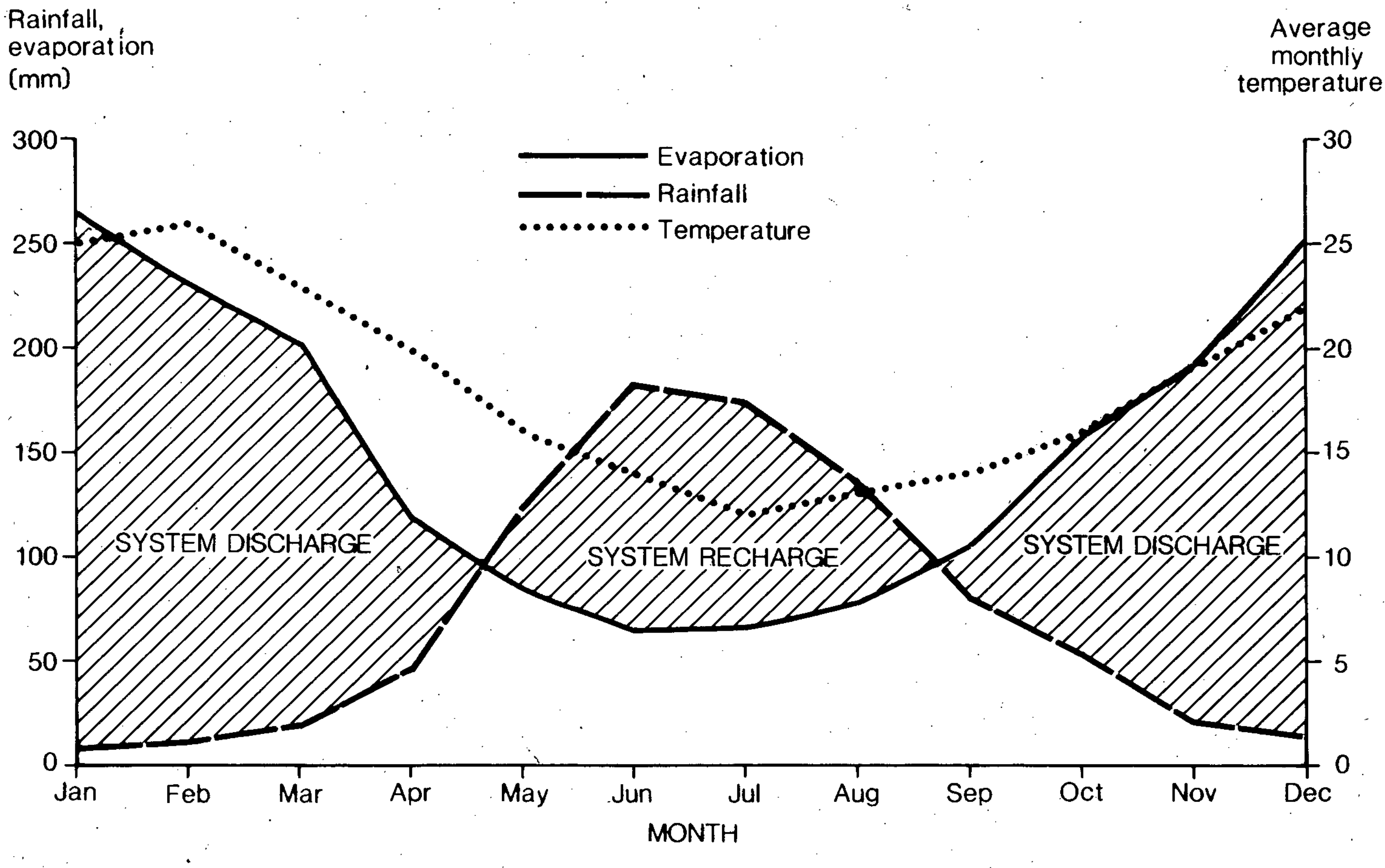


Figure 5.2 Climatic data — monthly means for evaporation, rainfall and temperature.

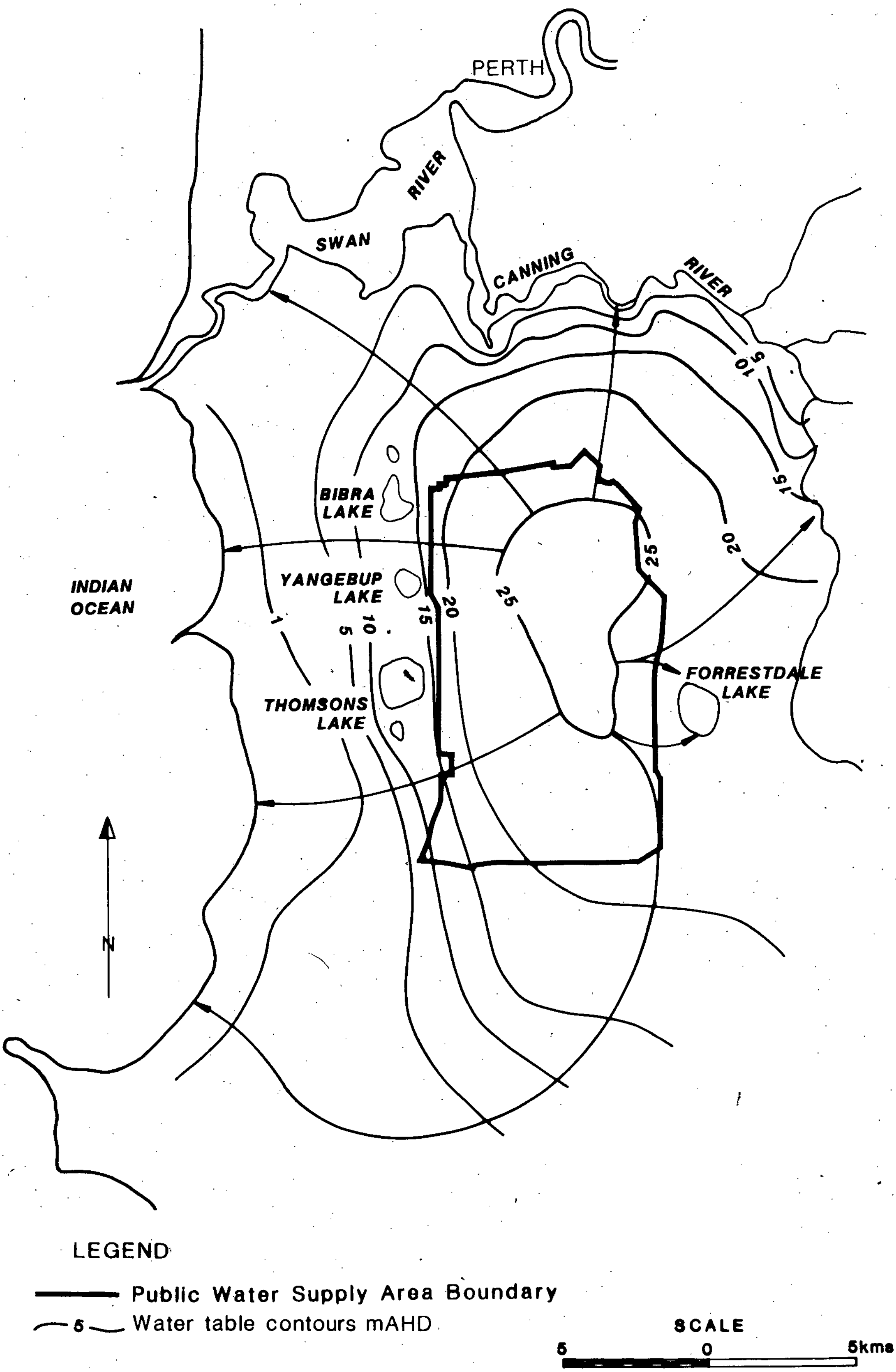


Figure 5.3 Water contours as at 1976 and a schematic flow net of the Jandakot Mound as presented in Davidson (1984).

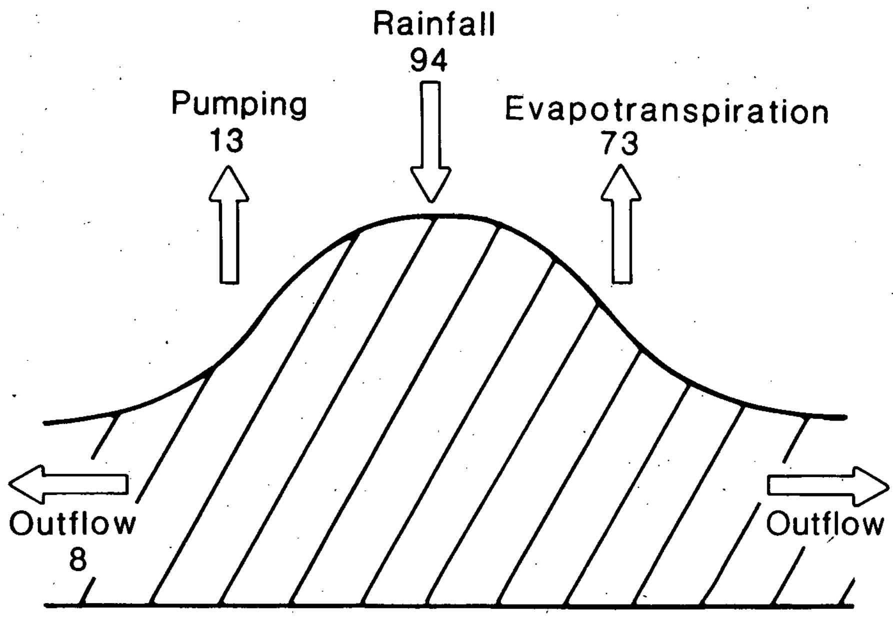


Figure 5.4 Current water balance for the Jandakot PWSA (as millions of cubic metres per annum).

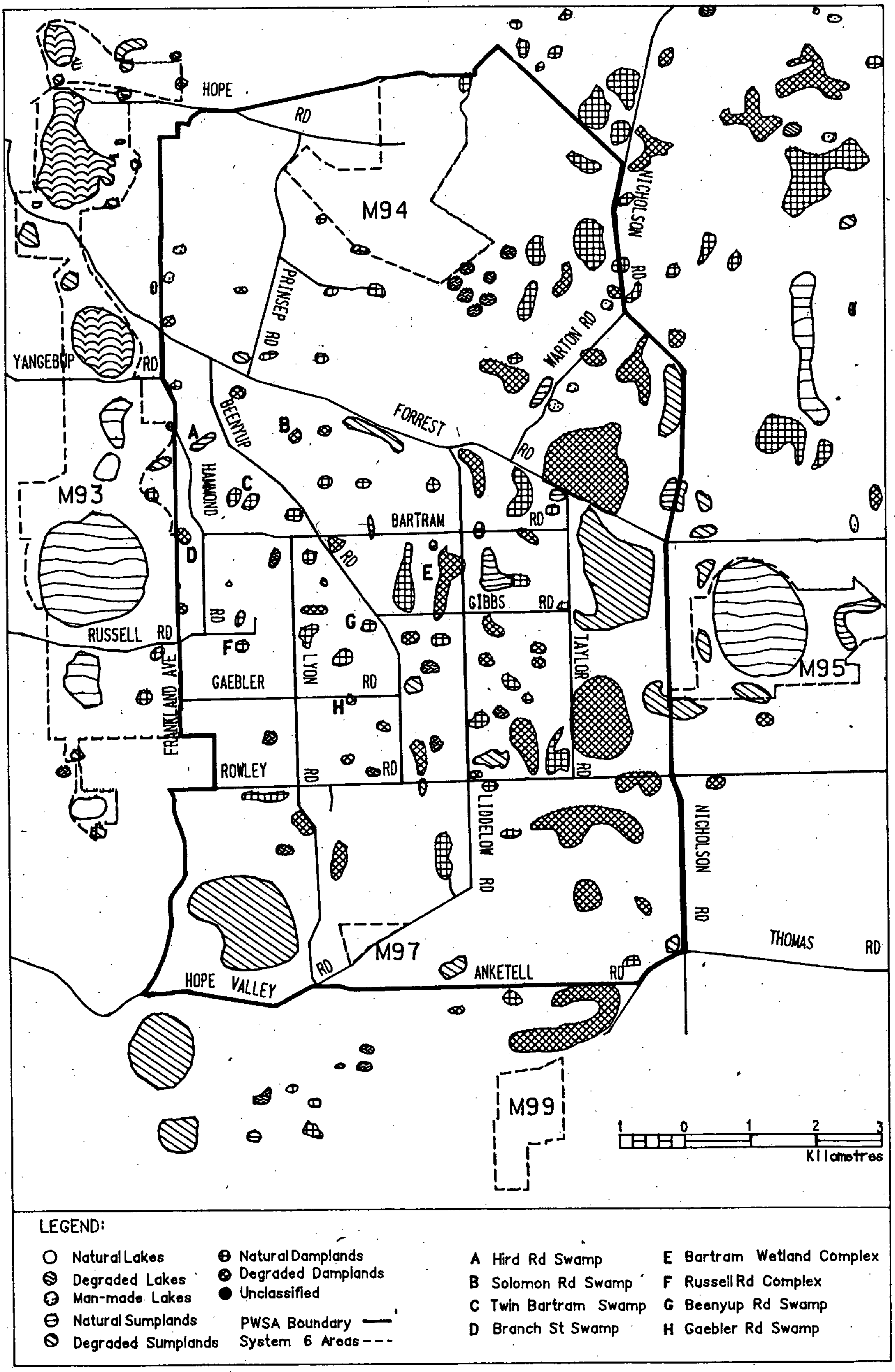


Figure 5.5 Wetlands in the Jandakot Area.

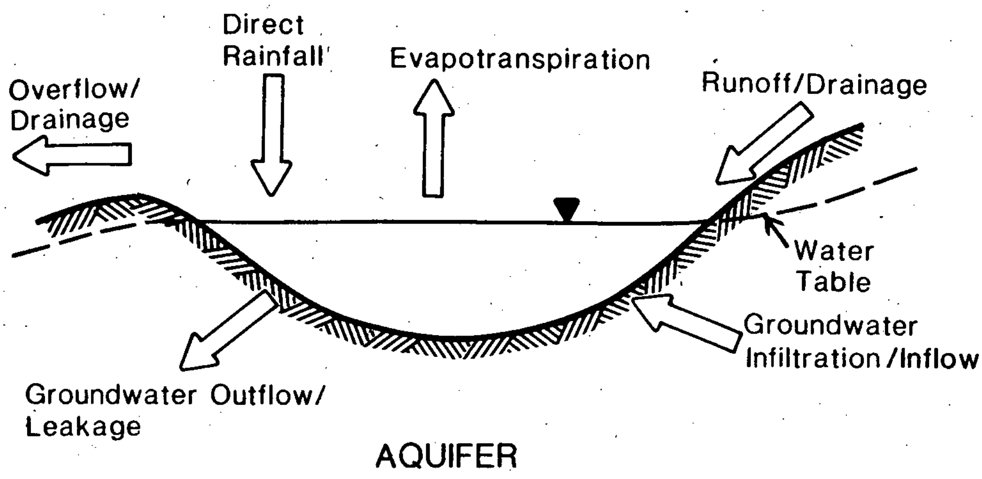


Figure 5.6 Schematic water balance for a typical Swan Coastal Plain wetland.

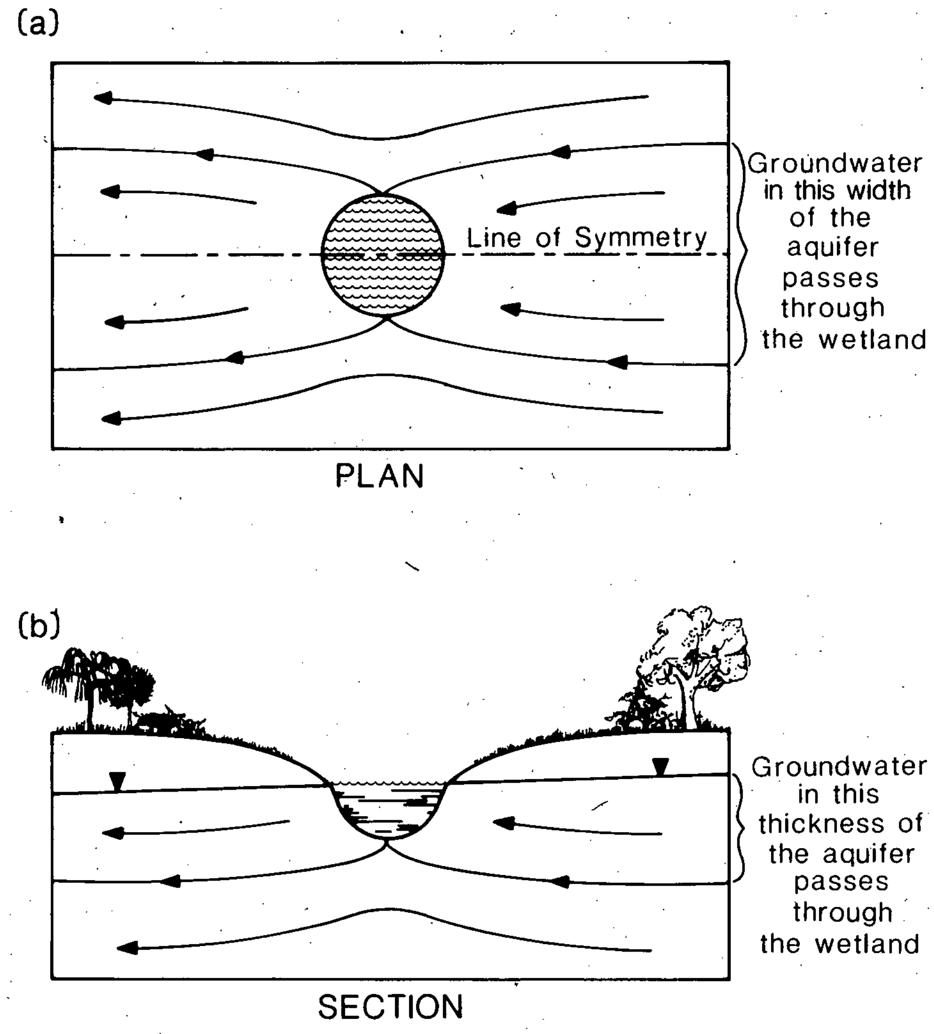


Figure 5.7 Groundwater flow through a typical Jandakot wetland in a) plan and b) vertical section. Note that the vertical section is greatly exaggerated in b).

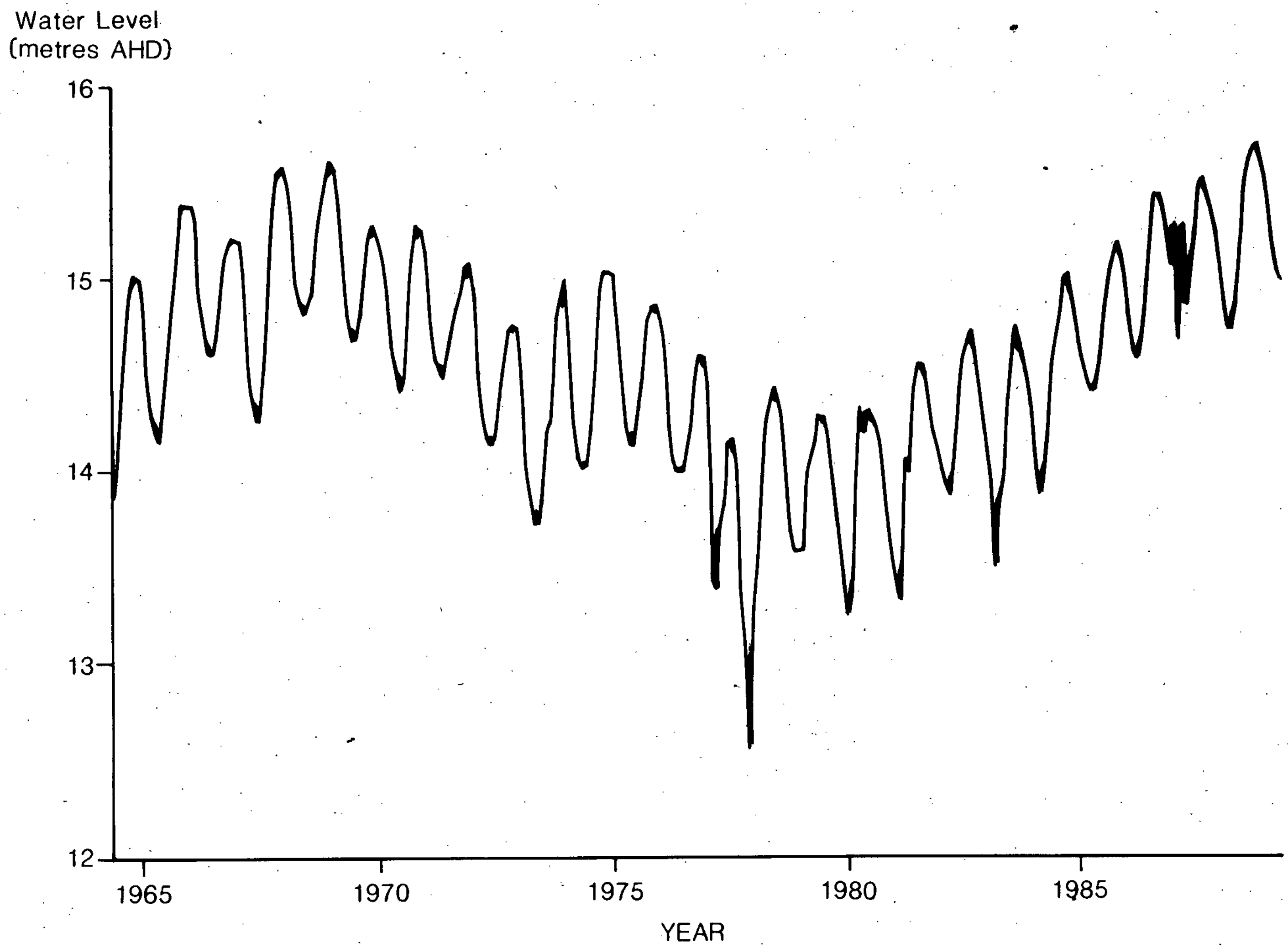


Figure 5.8 Hydrograph of Bibra Lake from 1960 to 1989.

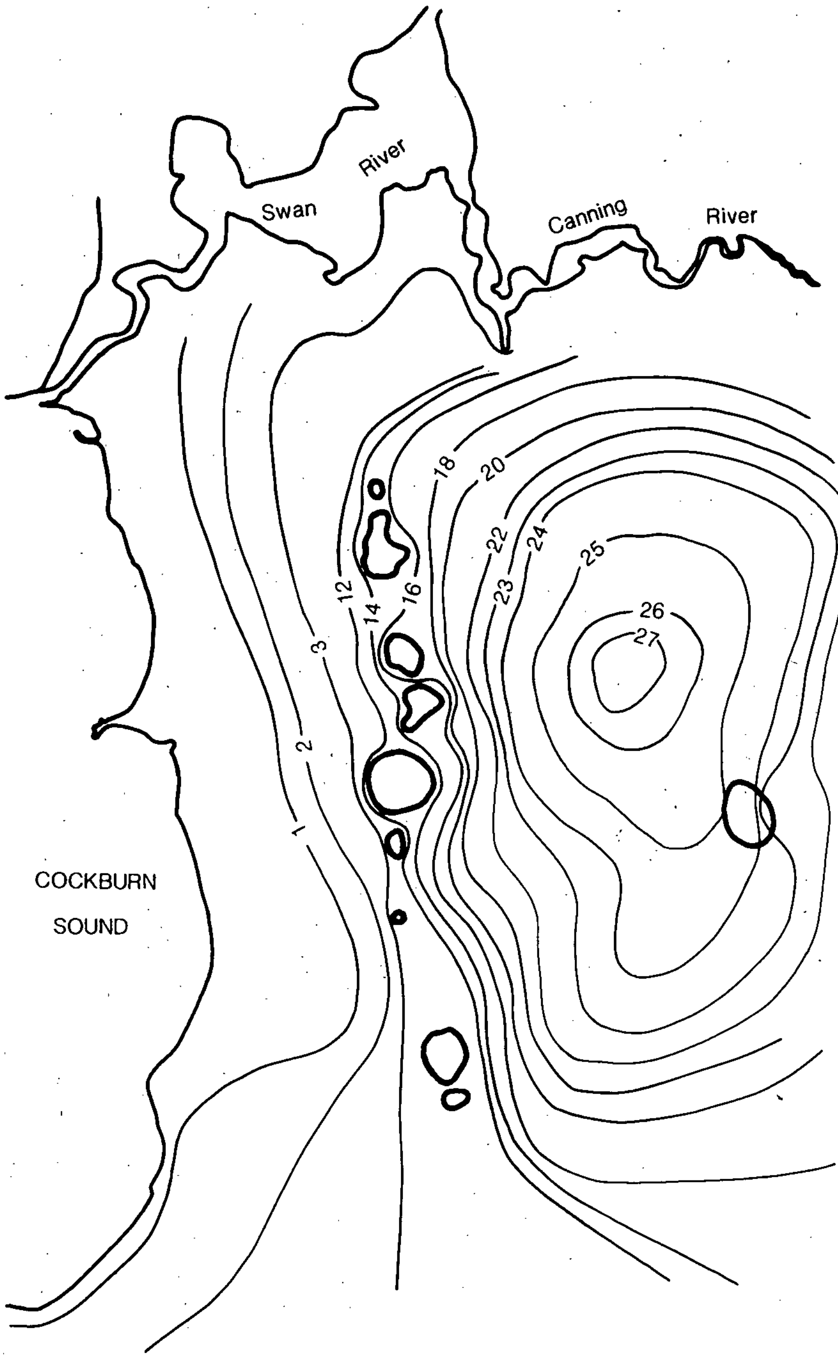


Figure 5.9 The average water table level (m AHD) on Jandakot Mound for 1988.

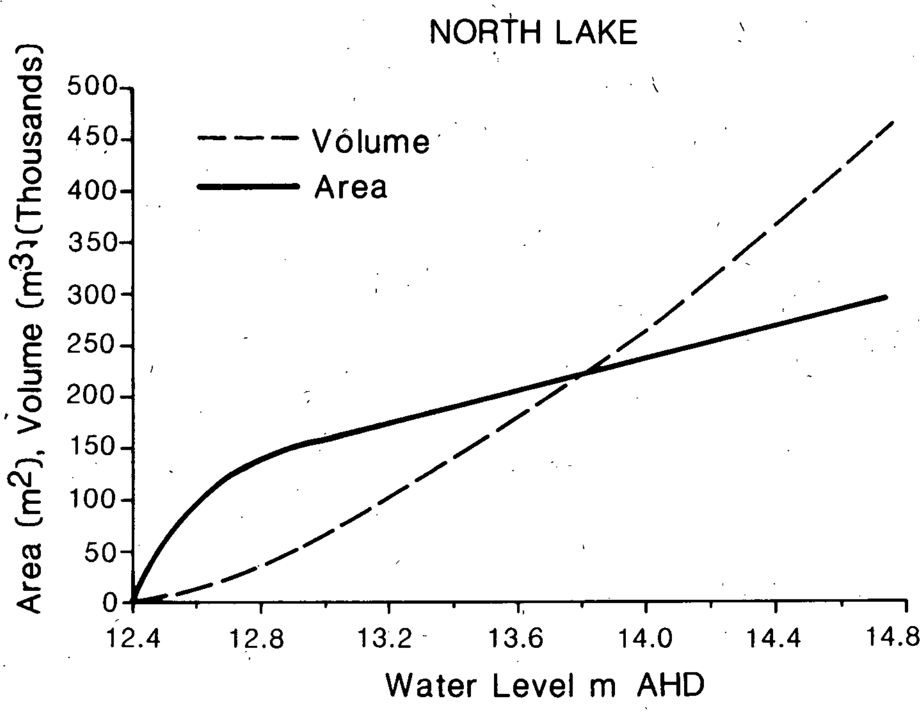


Figure 5.10 Surface area and volume versus water level curves for North Lake.

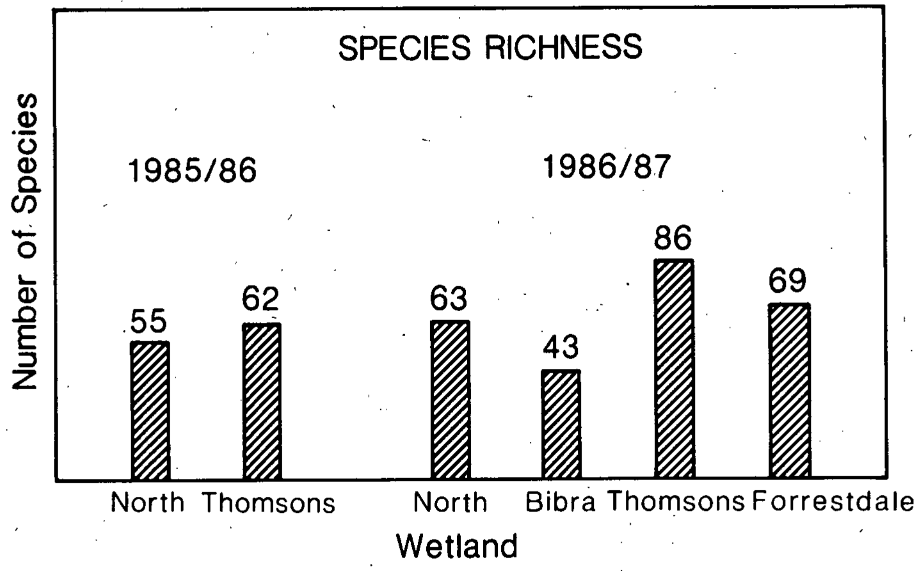


Figure 5.11 Species richness (ie number of species) in Jandakot wetlands.

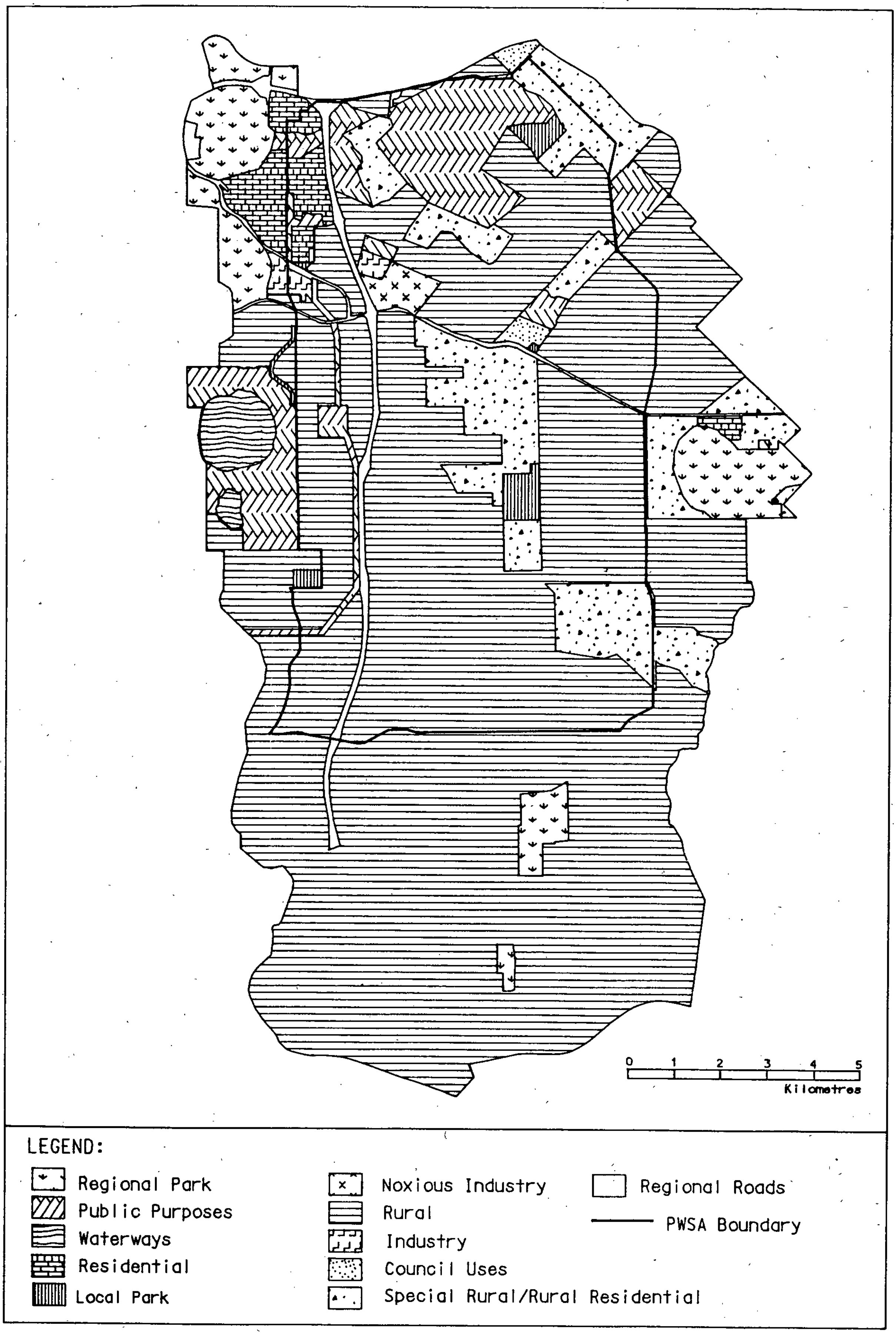


Figure 5.12 Current Local Authority land zoning in the Jandakot area (Source: Information provided by Local Authorities to Wilson Sayer Core Pty Ltd for the Jandakot Land Use and Water Management Strategy).

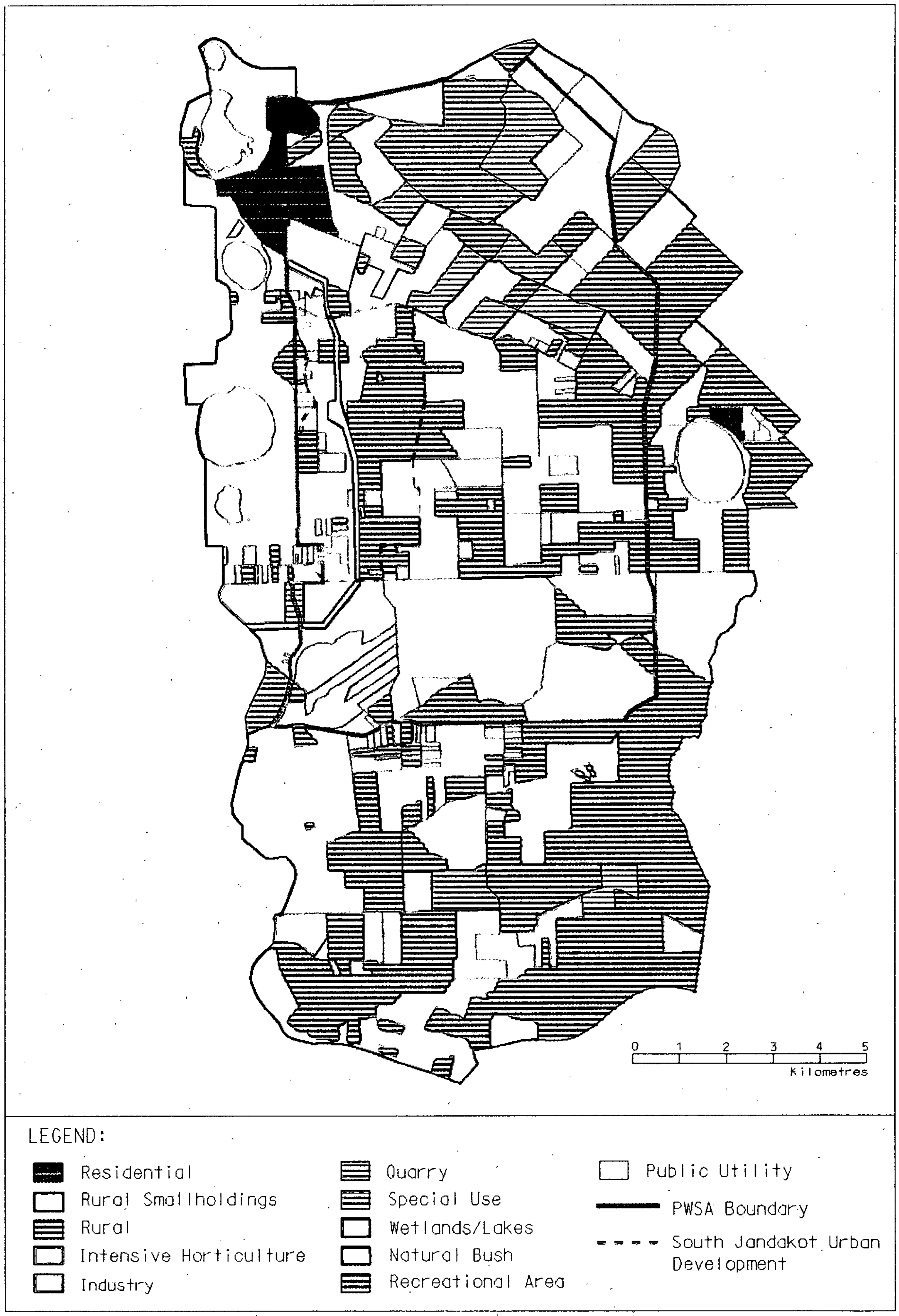


Figure 5.13 Current land use in the Jandakot area (Source: Information obtained from aerial photography, Local Authorities and WAWRC, (1986) by Wilson Sayer Core Pty Ltd for the Jandakot Land Use and Water Management Strategy).

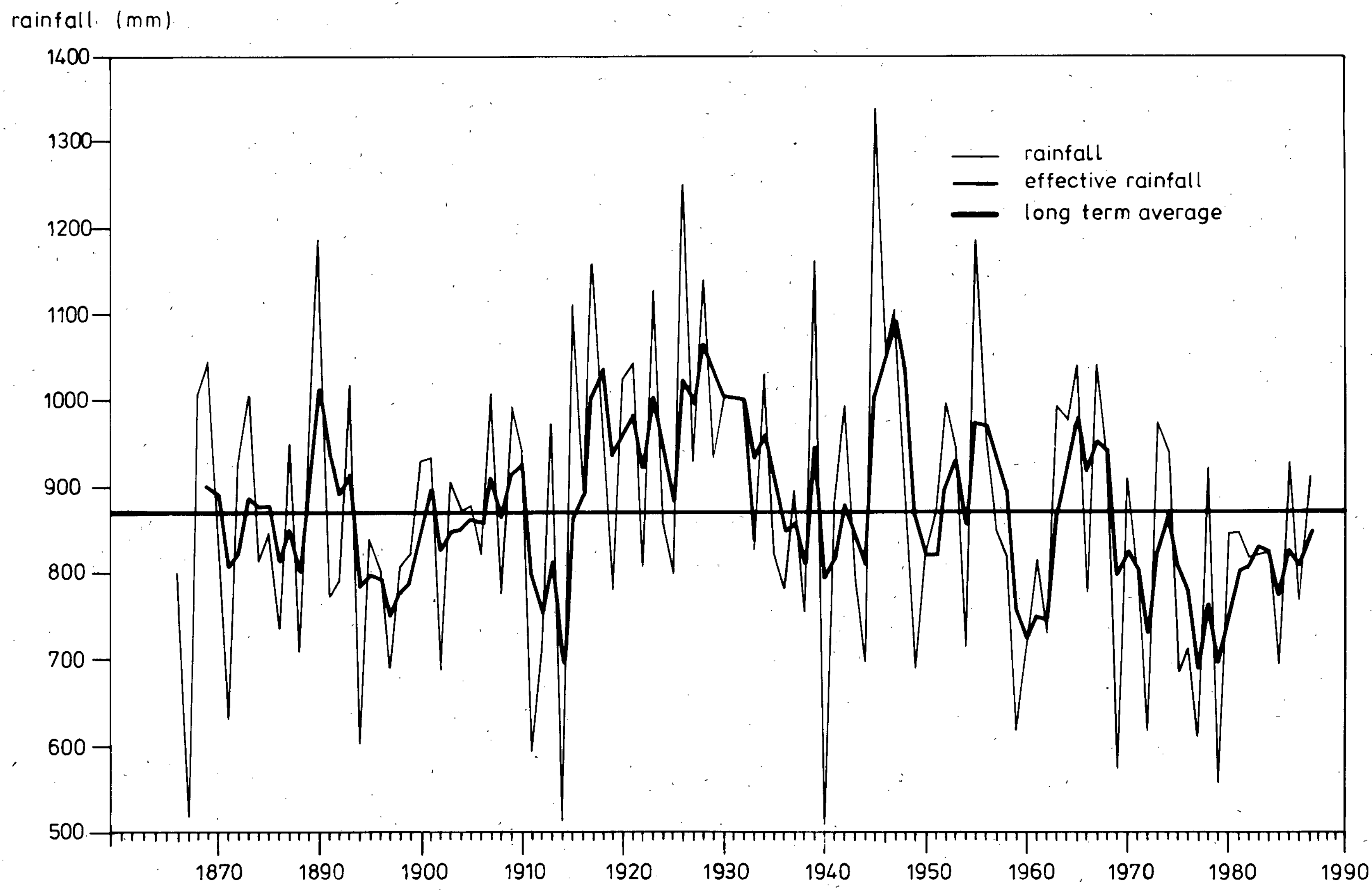


Figure 7.1 The actual and 'effective' rainfall for Perth from 1870 to 1986.

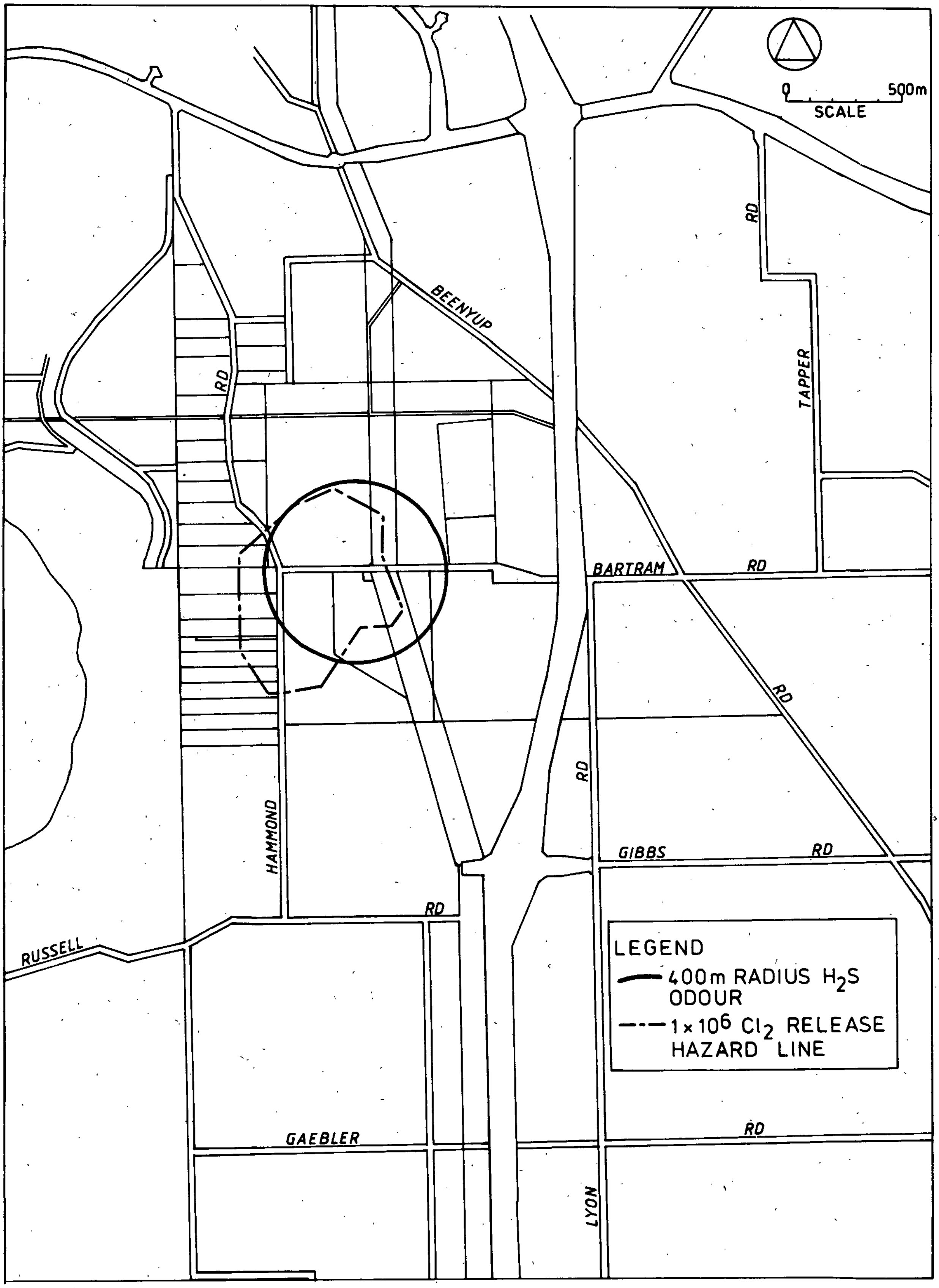


Figure 7.2 The buffer zones required around the treatment plant to ensure public safety from the possibility of chlorine leakage and to minimise hydrogen sulphide odour problems.

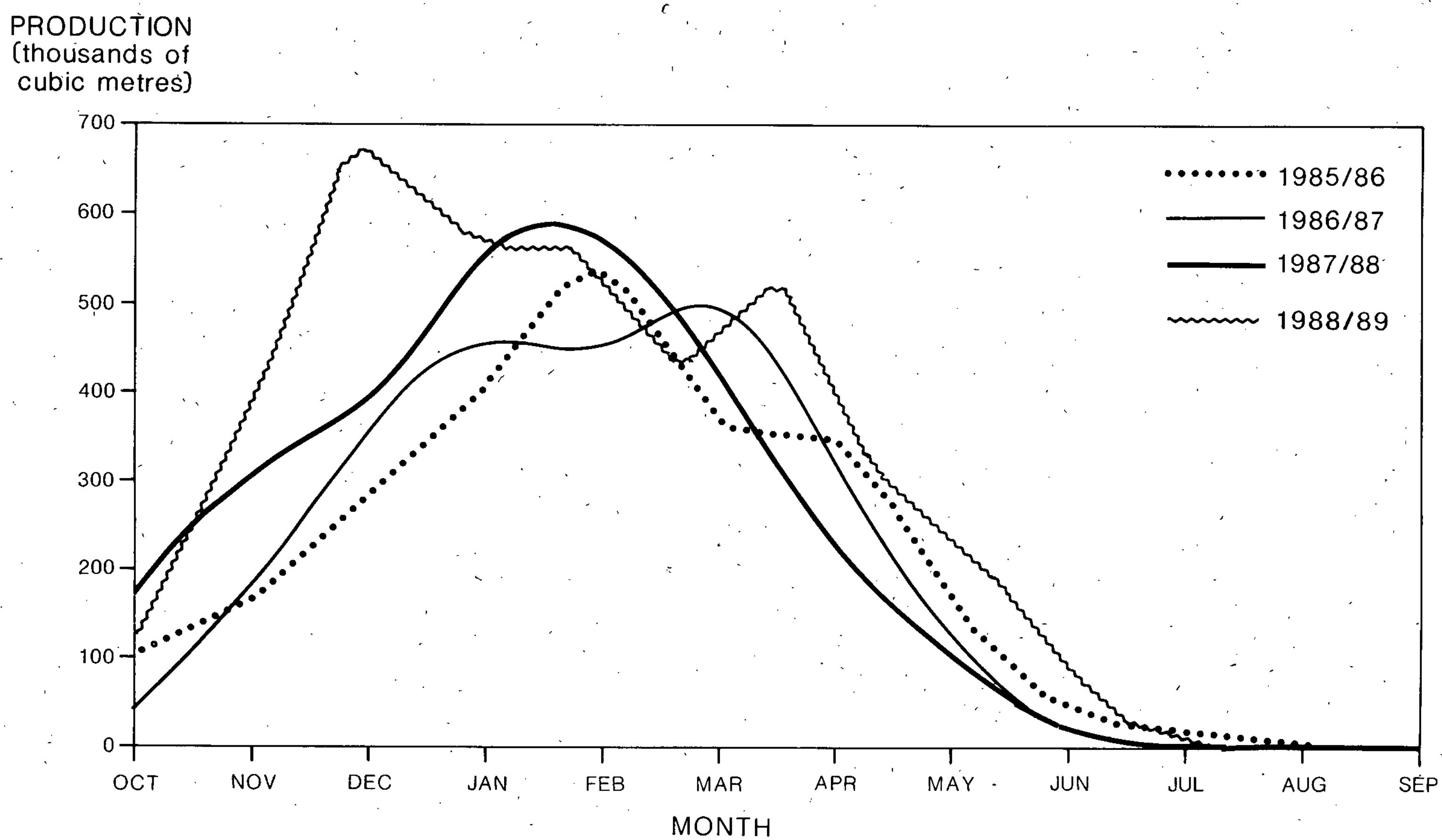


Figure 8.1 Production from the superficial aquifer for the last four 'water years'.

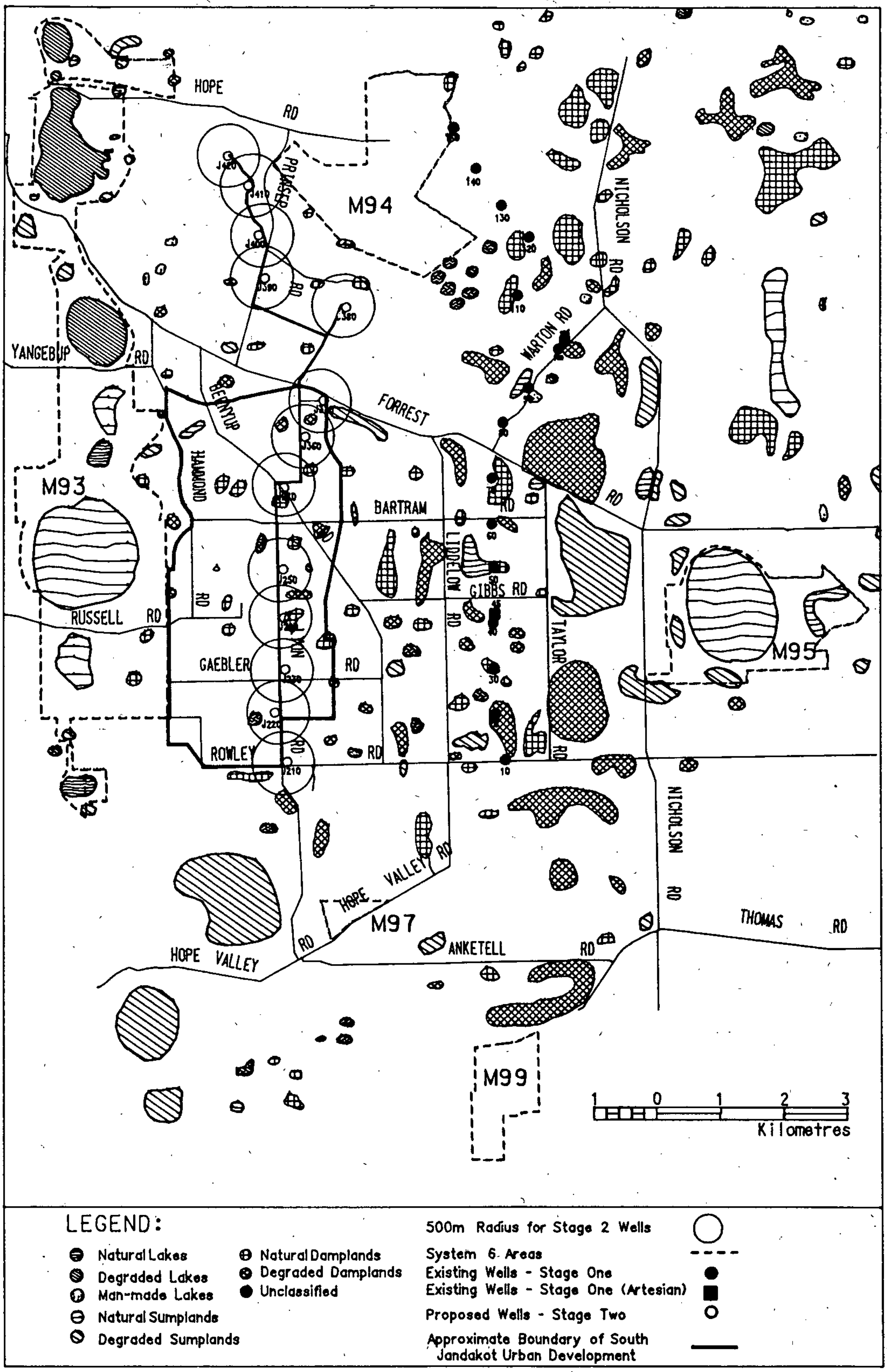


Figure 8.2 Location of proposed Stage 2 wells with respect to environmentally sensitive areas.

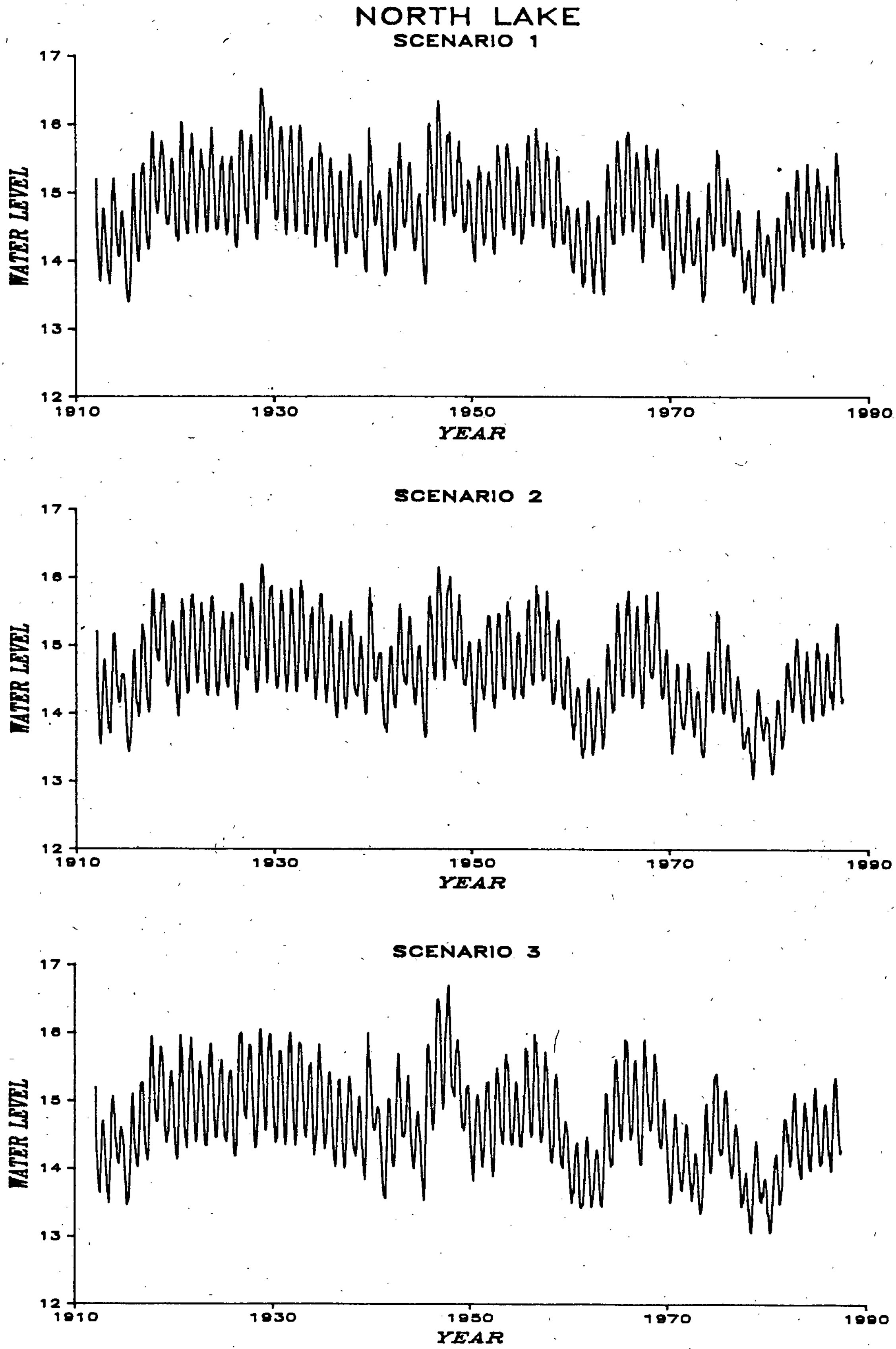


Figure 8.3 Predicted water levels in North Lake under the three different scenarios: current, future without further urbanisation and future with the South Jandakot Urban Development.

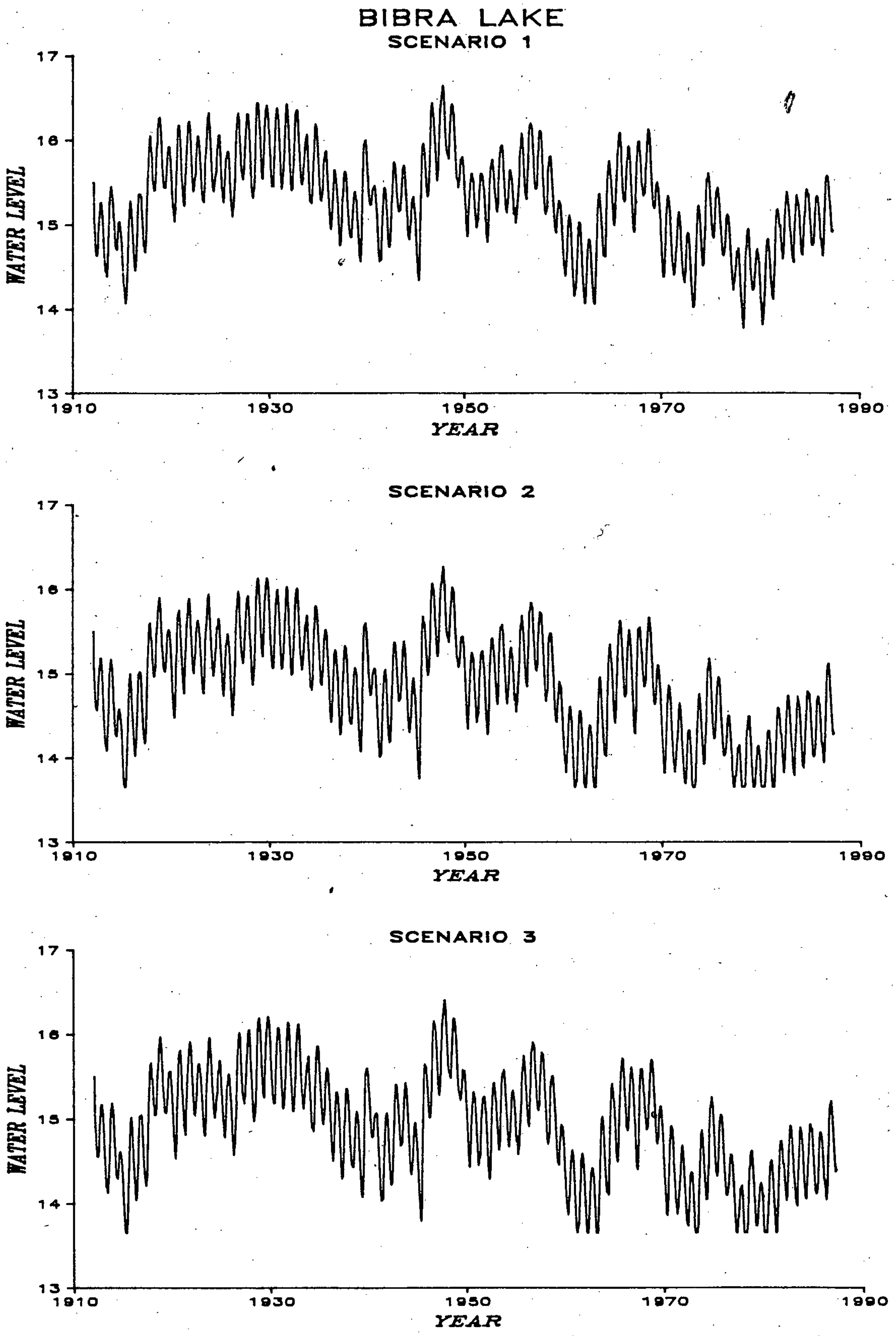


Figure 8.4 Predicted water levels in Bibra Lake under the three different scenarios: current, future without further urbanisation and future with the South Jandakot Urban Development.

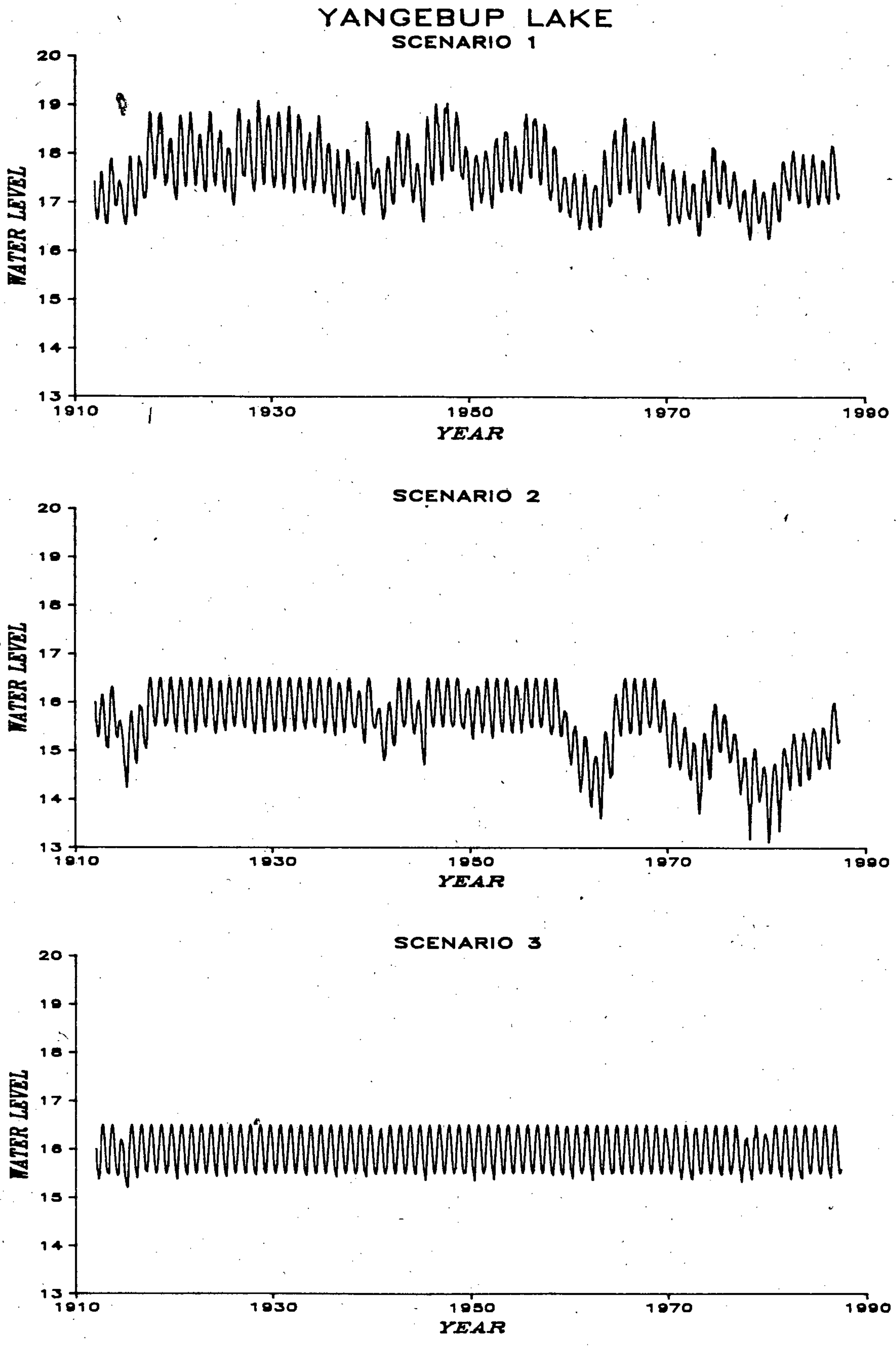


Figure 8.5 Predicted water levels in Yangebup Lake under the three different scenarios: current, future without further urbanisation and future with the South Jandakot Urban Development.

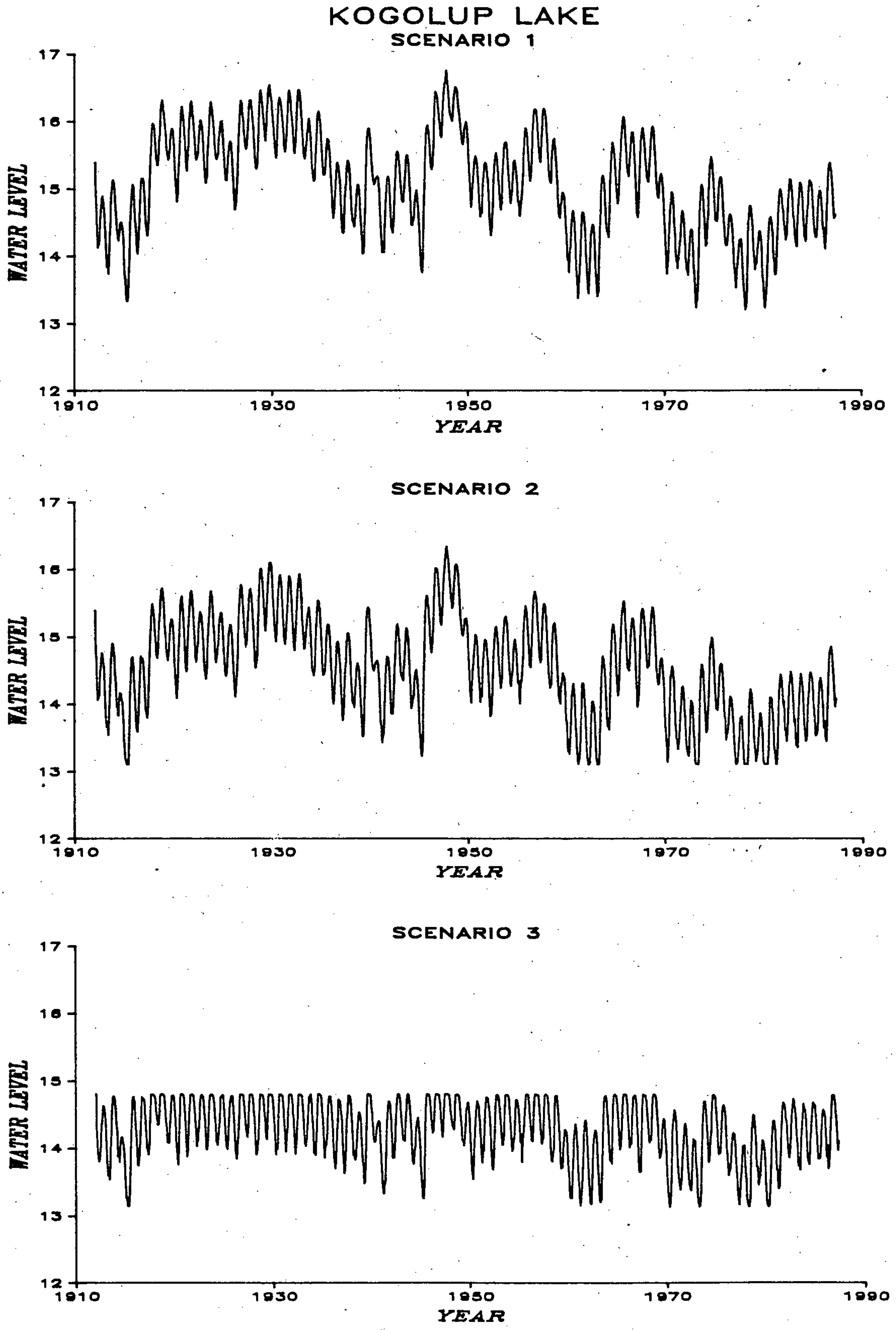


Figure 8.6 Predicted water levels in Kogolup Lake under the three different scenarios: current, future without further urbanisation and future with the South Jandakot Urban Development.

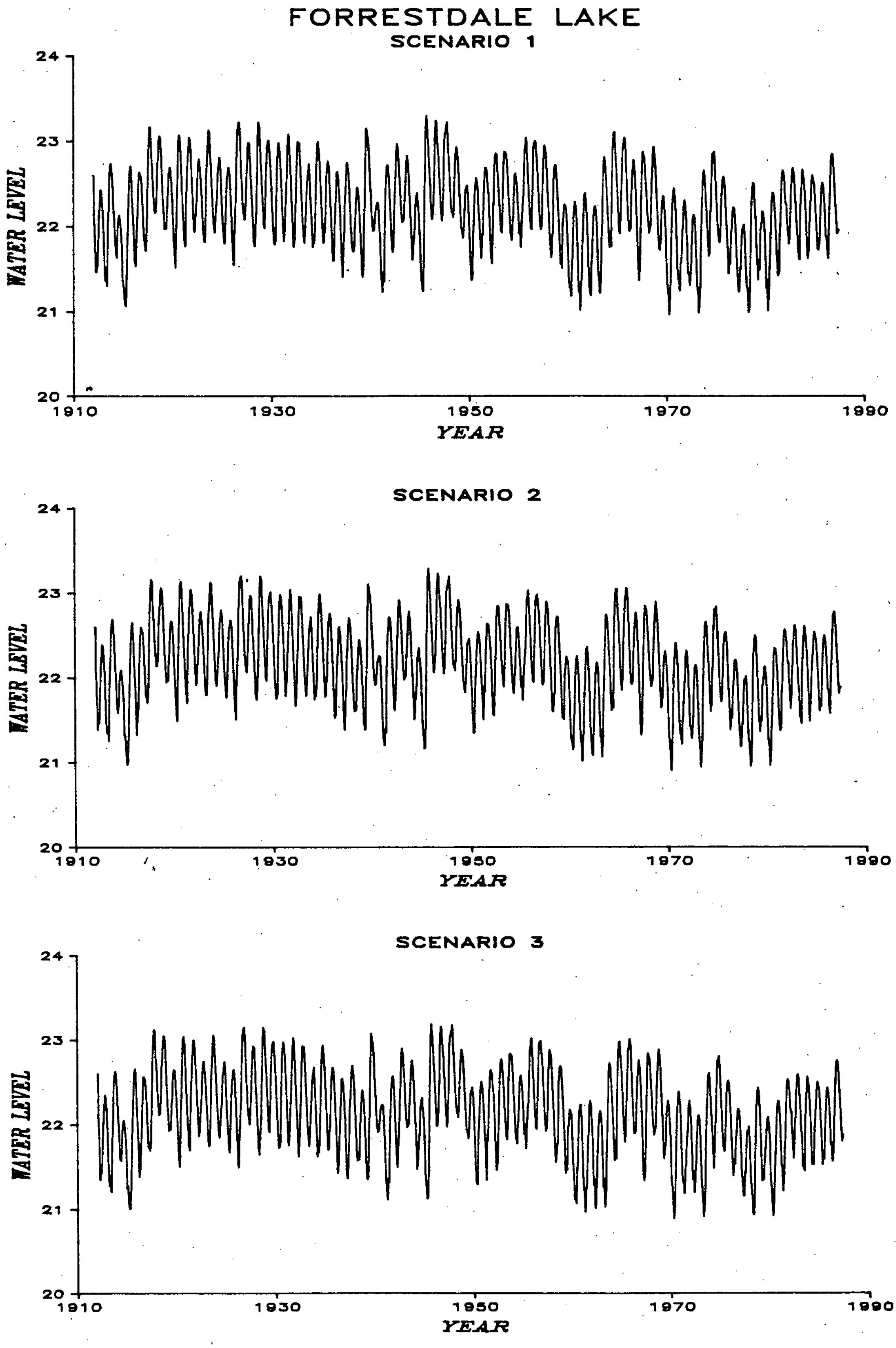


Figure 8.7 Predicted water levels in Forrestdale Lake under the three different scenarios: current, future without further urbanisation and future with the South Jandakot Urban Development.

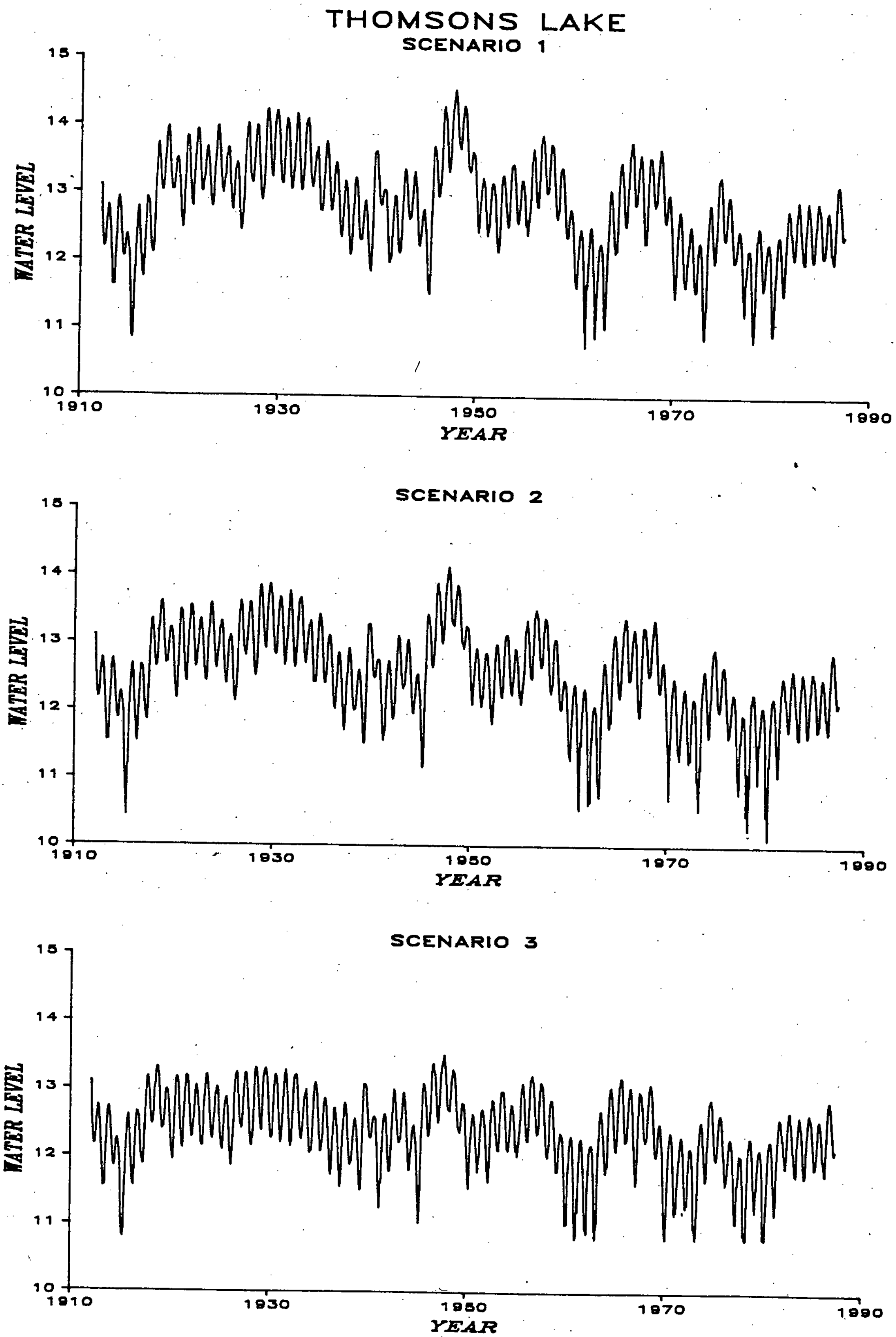


Figure 8.8 Predicted water levels in Thomsons Lake under the three different scenarios: current, future without further urbanisation and future with the South Jandakot Urban Development.

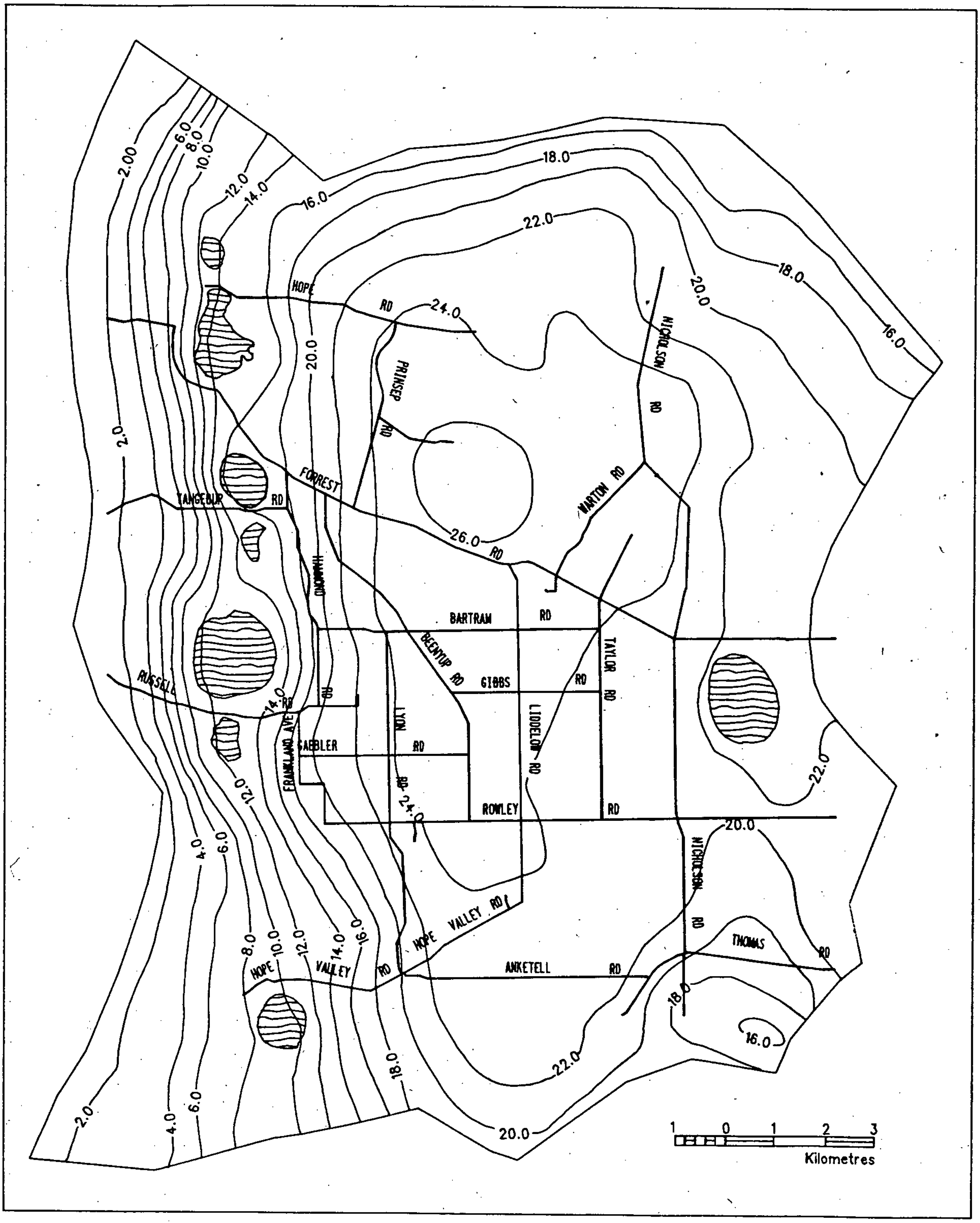


Figure 8.9 Simulated water level contours for current land use on the Jandakot Mound (Scenario 1).

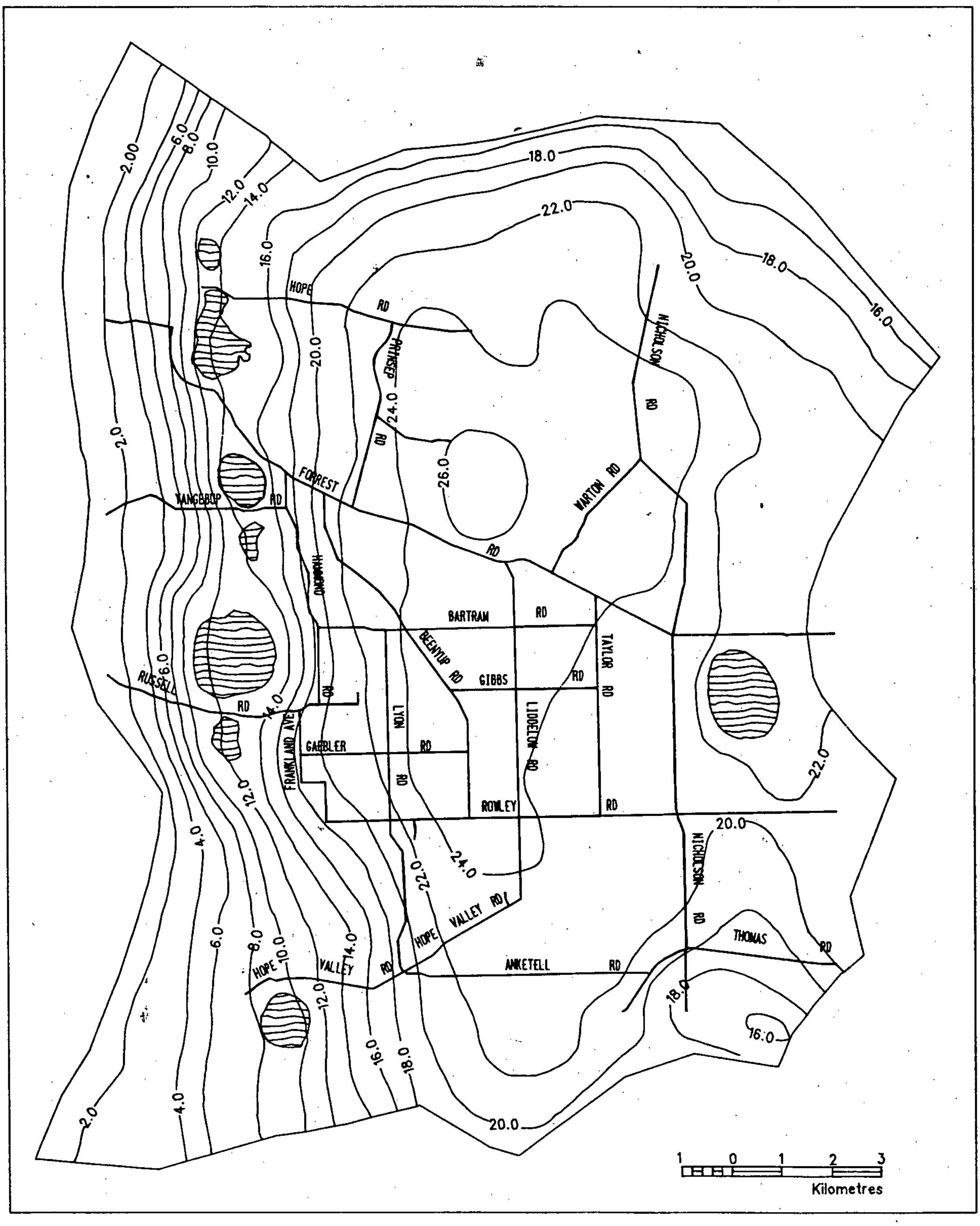


Figure 8.10 Simulated water level contours for future land use, without urbanisation, but with Stage 2 of the Jandakot GWS (Scenario 2).

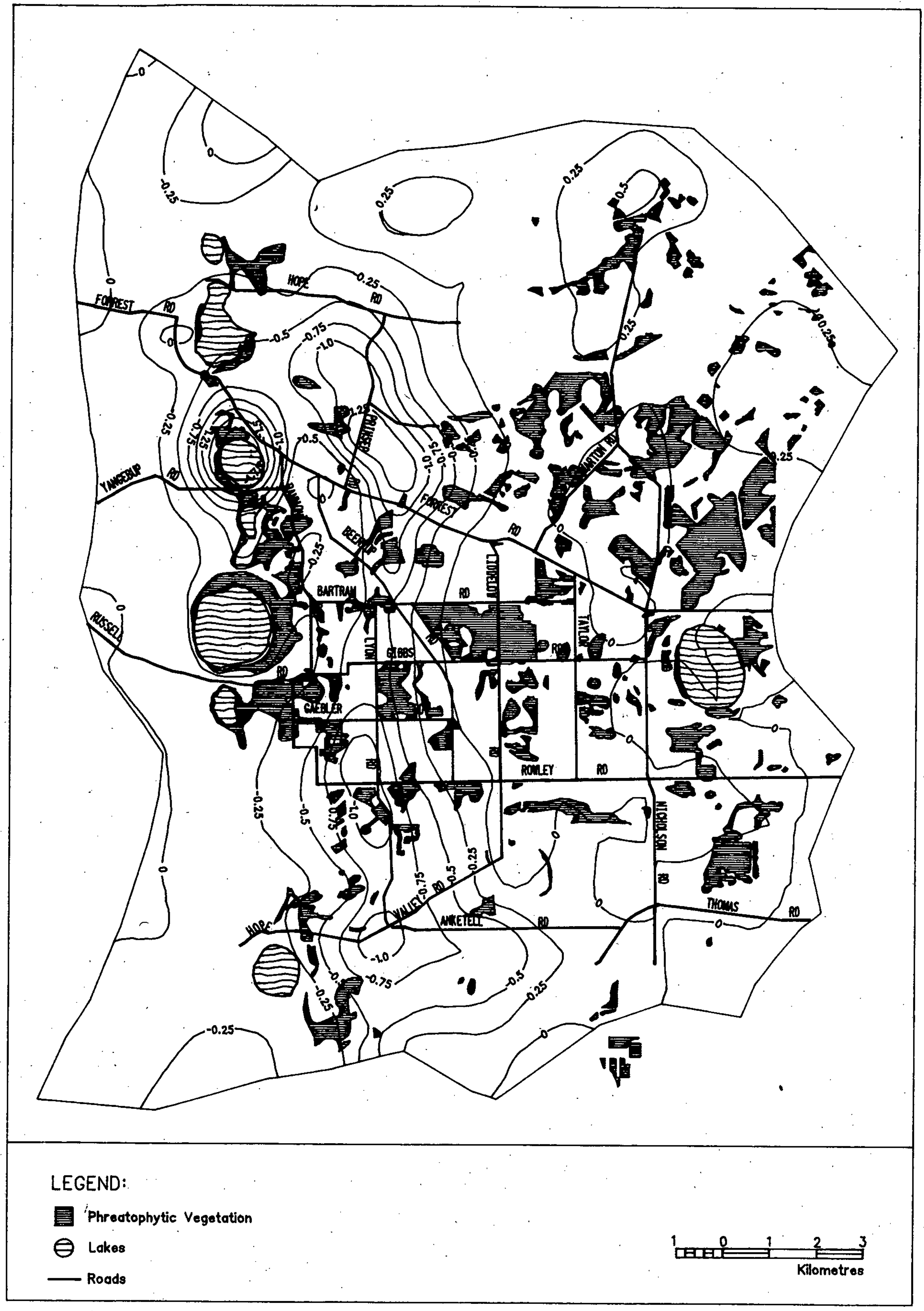


Figure 8.11 Simulated contours of changes in water level showing the effect of future land use, without urbanisation, and Stage 2 of the Jandakot GWS on the Jandakot Mound (Scenario 2). Also shown are areas of phreatophytic vegetation.

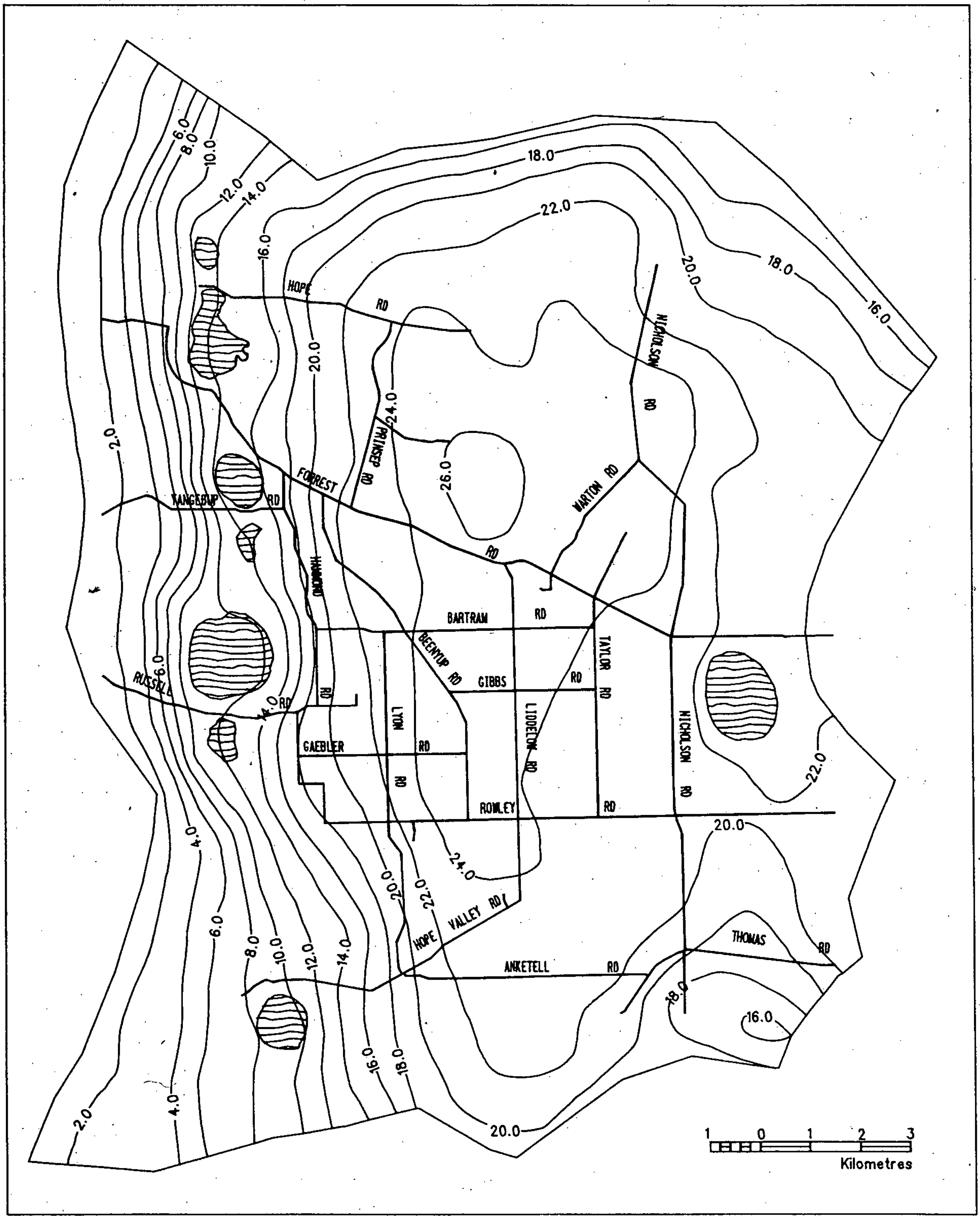


Figure 8.12 Simulated water level contours for future land use with the South Jandakot Urban Development and Stage 2 of the Jandakot GWS (Scenario 3).

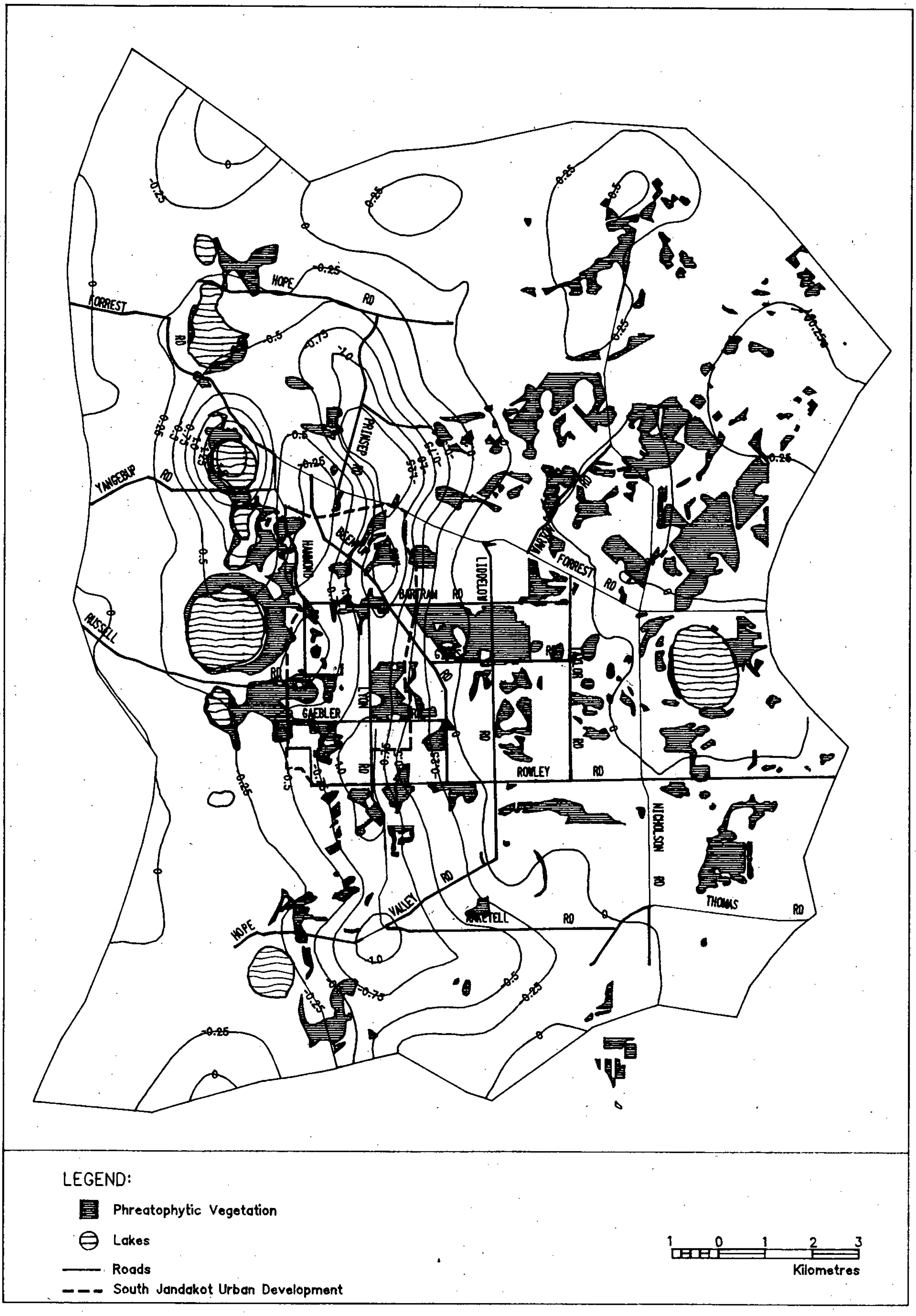


Figure 8.13 Simulated contours of water level changes showing the effect of future land use with the South Jandakot Urban Development and Stage 2 of the Jandakot GWS (Scenario 3). Also shown are areas of phreatophytic vegetation.

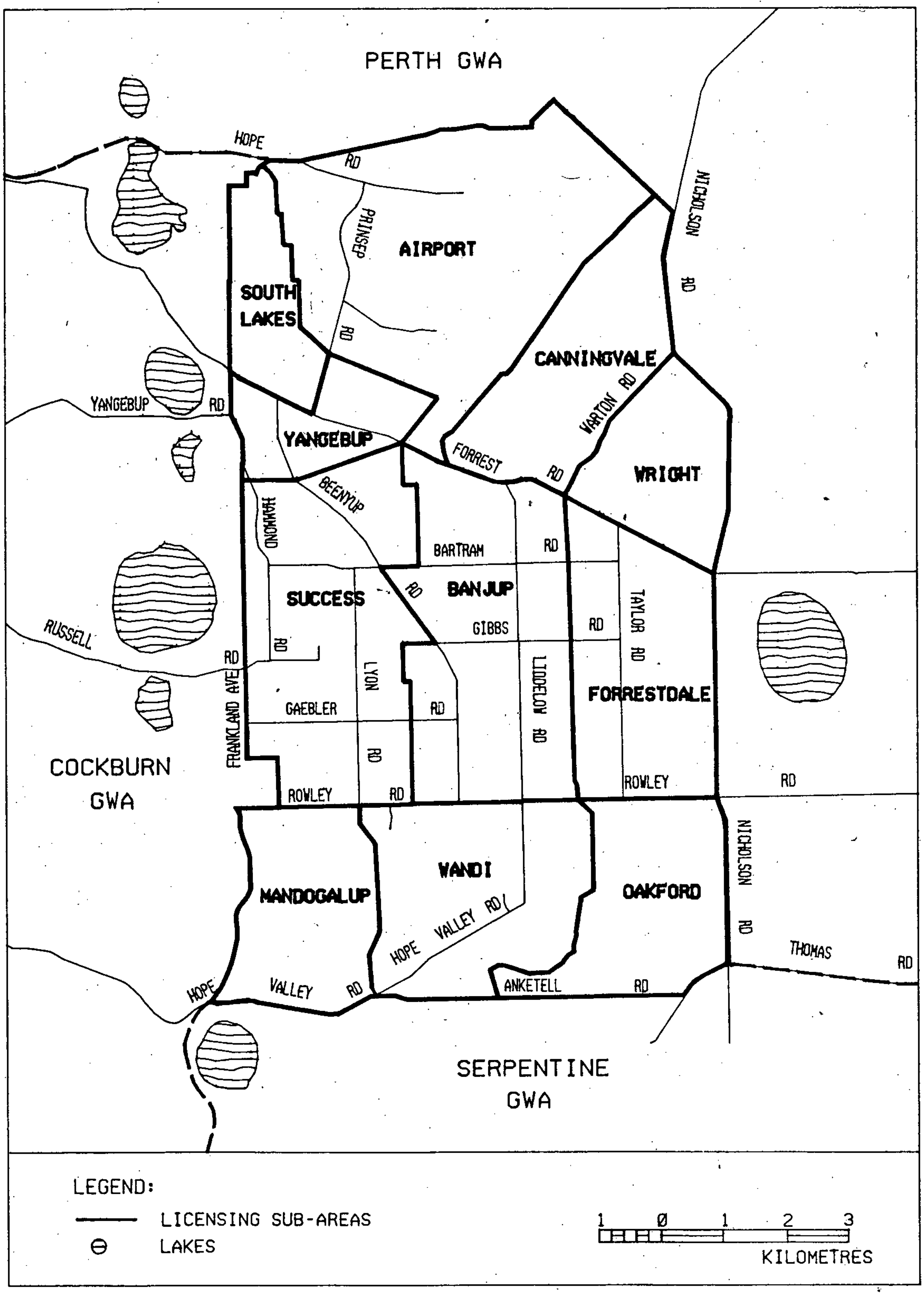


Figure 8.14 Licensing subareas in the Jandakot Public Water Supply Area. Also shown are the surrounding Groundwater Areas.

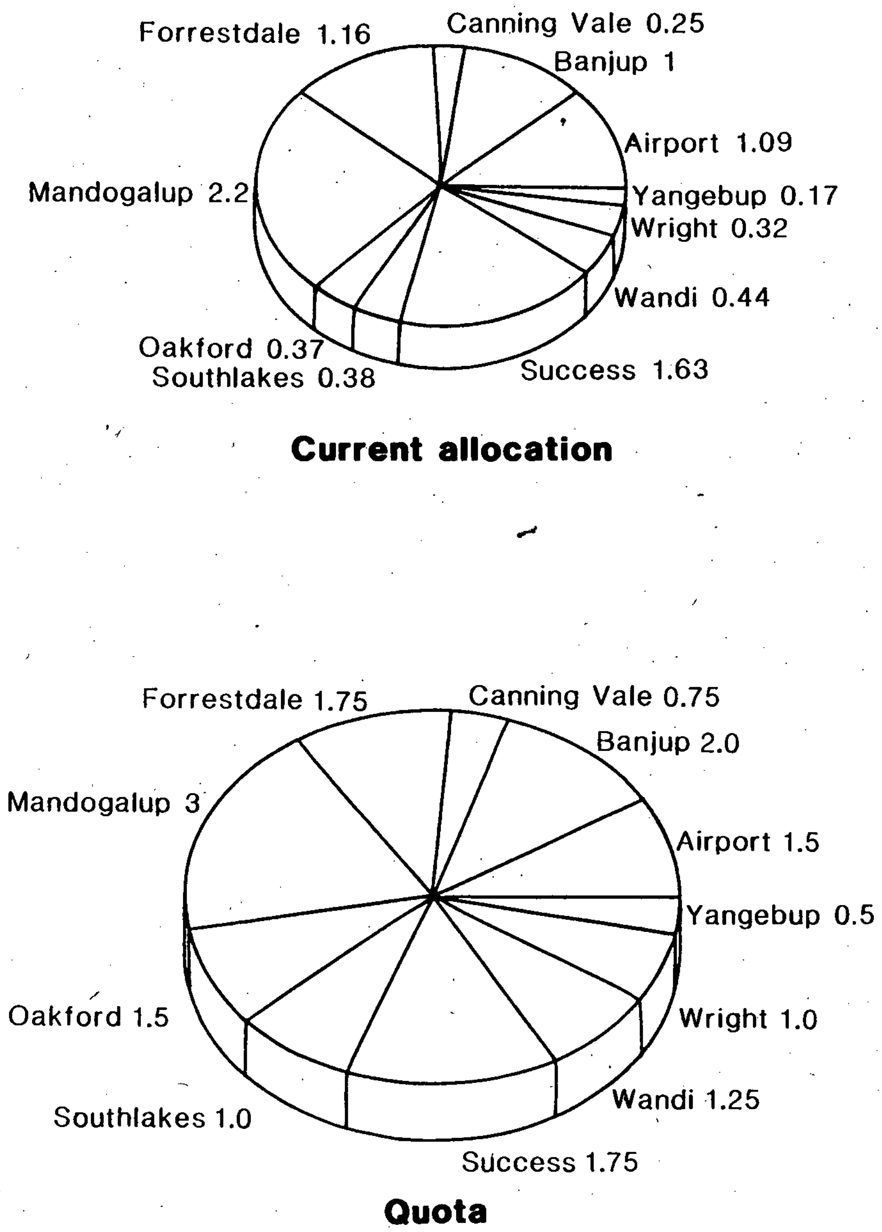


Figure 8.15 Breakdown of the current allocation by subarea and likely future quota for private groundwater use on the Jandakot PWSA.

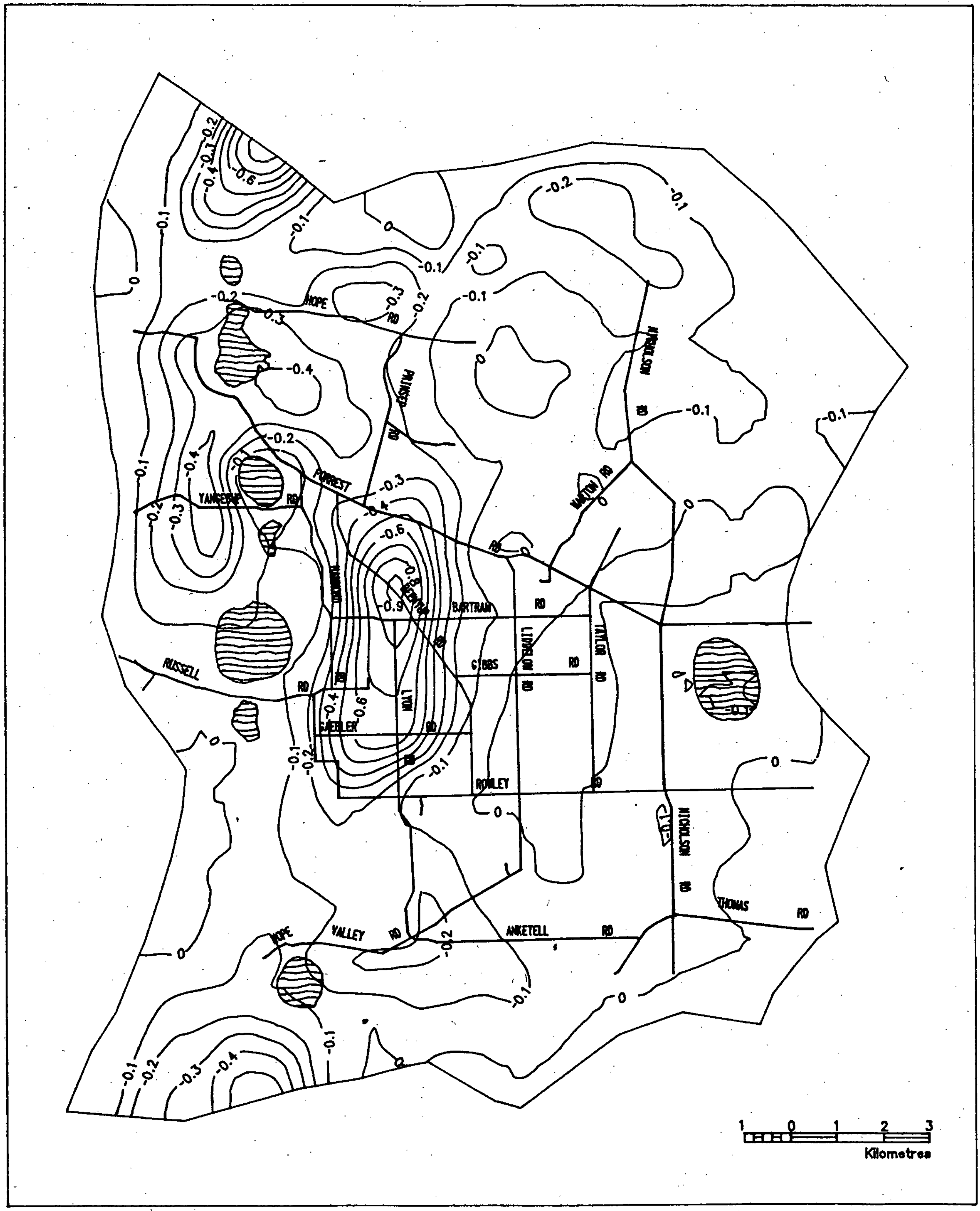


Figure 8.16 Simulated contours of water level changes showing the effect of likely future private groundwater abstraction.

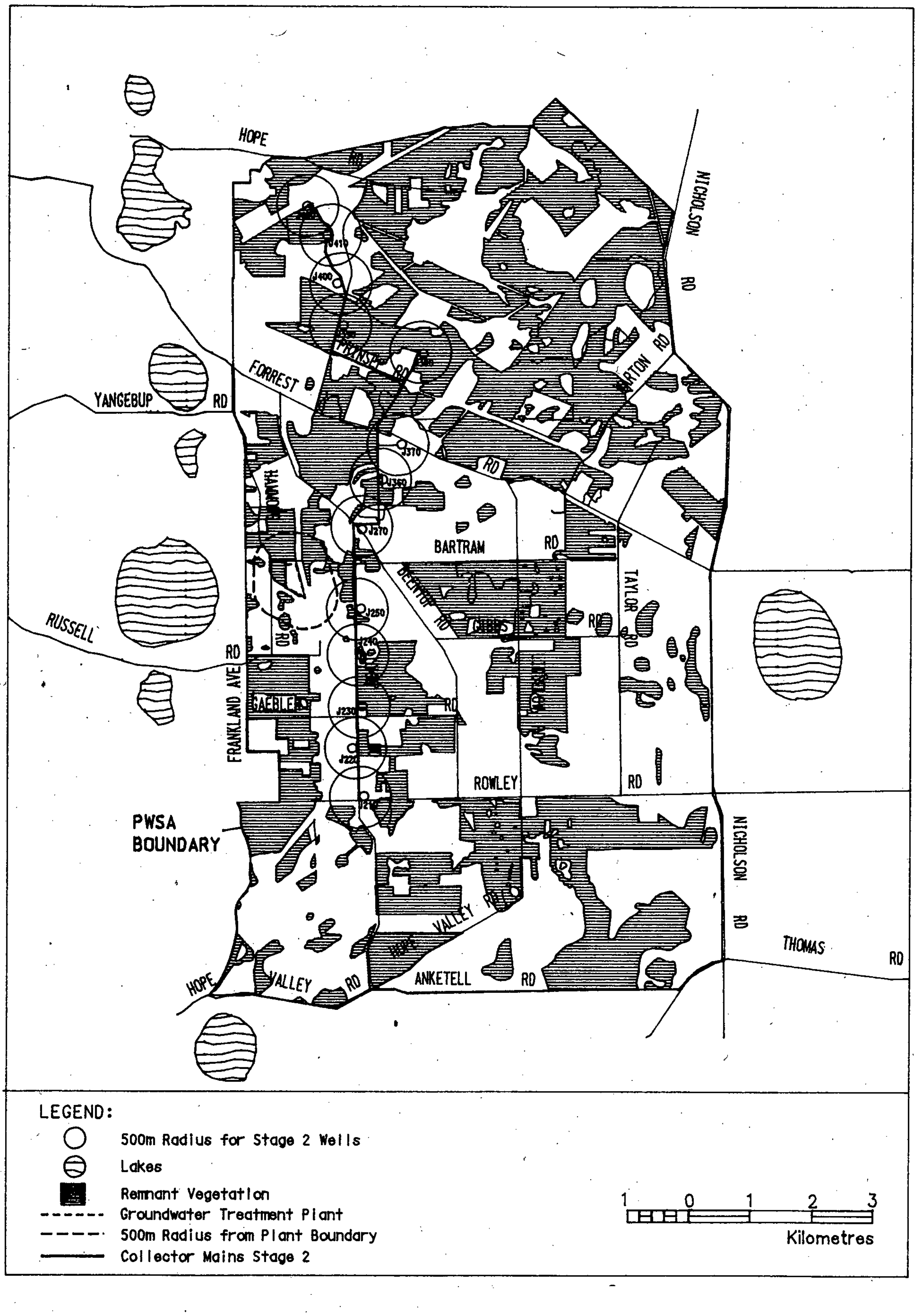


Figure 9.1 Jandakot PWSA showing remnant vegetation, the proposed route for the Stage 2 GWS collector mains and the buffer zone around the treatment plant.

Appendix 1

Environmental Protection Authority Guidelines for the Public Environmental Review

The following guidelines have been prepared for the Public Environmental Review (PER) on the proposed development of Stage 2 of the Jandakot Mound groundwater resource.

These guidelines are issued as a checklist of matters which the Environmental Protection Authority considers should be addressed in the PER. They are not exhaustive and other relevant issues may arise during the preparation of the document: these should also be included in the PER.

It should also be noted that the guidelines are not intended to convey the Authority's wishes with respect to the format of the document. The format is a matter for the proponent and its consultant.

A copy of these guidelines should appear in the PER.

1. SUMMARY

The PER should contain a brief summary of:

- salient features of the proposal;
- alternatives considered;
- description of receiving environment and analysis of potential impacts and their significance;
- environmental monitoring and management programmes, safeguards and commitments; and
- conclusions.

2. INTRODUCTION

The PER should include an explanation of the following:

- identification of proponent and responsible authorities;
- objectives of the proposal;
- background to previous groundwater development of the Jandakot Mound;
- brief details and timing of the proposal;
- relevant statutory requirements and approvals; and
- scope, purpose and structure of the PER.

3. NEED FOR THE DEVELOPMENT

The PER should explain the justification for the project and projected costs and benefits (in the broad sense) at local and regional levels. The justification should include consideration of various demand options.

4. EVALUATION OF ALTERNATIVES

A discussion of alternatives to the proposal, including demand management and alternative development options, should be given. A comparison of these in the context of stated objectives should be included. This discussion should consider various scales (sizes) of the project and their implications.

5. DESCRIPTION OF PREFERRED PROPOSAL

The PER should include brief details of:

- existing groundwater developments;
- overall concept;
- location and layout;
- land uses, land tenures and an indication of boundaries of private and public land;
- construction schedule and methods of construction;

- infrastructure, including pipeline construction;
- access;
- control and staging of project;
- projected lifetime; and
- future expansion.

6. EXISTING ENVIRONMENT

The PER should provide an overall description of the environment and an appraisal of physical and ecological systems likely to be affected by the proposal, at local and regional level.

It should concentrate on the significant aspects of the environment likely to be impacted by the development. Only the processes, habitats, resources and potential resources which could be influenced should be defined. Detailed inventories should be placed in appendices to the PER.

Wherever possible in the discussion of physical and biological processes that are essential determinants in the maintenance of habitats and resources, conceptual models or diagrams should be used to illustrate and synthesise the interactions between the processes.

It would be expected that the PER would particularly address the processes sustaining the ecological systems for the preferred alternative.

The following matters should be addressed:

6.1 PHYSICAL

— climate;
— geology;
— soils and landform;
— hydrology; and
— water quality.

6.2 BIOLOGICAL

— vegetation communities on the Jandakot Mound;
— terrestrial and aquatic fauna;
— definition of habitats and ecological relationships;
— vegetation and fauna in pipeline construction and other infrastructure areas; and
— sites affected by System 6 'Red Book' recommendations.

6.3 HUMAN

— land use (existing and future), land tenure, zoning and reservation;
— conservation and recreational areas;
— landscape;
— historical, archaeological and ethnographic sites;
— existing and potential users and use of groundwater, and
— community attitudes.

These issues need to be discussed in both a local and regional context. In addition, the PER should, where appropriate, take cognisance of any other known developments proposed for the general area.

7. ENVIRONMENTAL IMPACTS AND MANAGEMENT

This should show the overall effect on the total ecosystem and social surrounding of the proposal during and after construction.

The objective is to take an overview of the elements of the systems involved and the external factors with which they interact and to present them as a synthesis or conceptual model which can be used to predict system behaviour under the stresses likely to be encountered. This should include an assessment of the resilience of the systems identified in Existing Environment to natural and man-induced pressure. Impacts should be quantified where possible. Criteria for making assessments of their significance should be outlined. Compliance with relevant standards should be demonstrated.

It will be necessary to determine impacts on individual components of the environment before a final overall synthesis of potential impacts is made.

Use of experience from similar projects in comparable sites, landscapes or ecosystems should be made to illustrate or demonstrate changes or expectations outlined in this analysis.

An environmental management programme should be described on the basis of (and cross-referenced to) the synthesis of potential environmental impacts. The purpose of the management programme is to demonstrate the manner in which potential environmental impacts can be ameliorated and monitored. Emphasis should be placed on the manner in which monitoring results will lead, where appropriate, to amendments to the management programme.

Authorities responsible for management should be clearly identified as should management administration, costs and funding.

The following potential environmental impacts should be included in the PER:

- resource utilisation in the Mound;
- effect on particular, representative or significant habitats, with special emphasis on wetlands and associated vegetation;
- effect of alteration of habitat on aquatic and terrestrial fauna;
- groundwater quality and quantity within the Mound;
- landscape;
- any historical, archaeological and ethnographic sites;
- System 6 areas;
- landuse including conservation and recreation aspects;
- effect on existing community and land use; and
- services (power, pipeline).

The final synthesis should include an assessment of the significance and timing of the various potential impacts identified.

Procedures for reporting the results of monitoring and management to appropriate authorities should be given.

It is important that specific commitments are given to all components and procedures of the management programme and that these are clearly listed in the PER.

8. CONCLUSION

An assessment of the environmental acceptability of the project in terms of its overall environmental impact and in the context of the proposed management programme should be given.

9. COMMITMENTS

A list of commitments given in the PER should be provided.

10. REFERENCES

A list of references should be included in the PER.

11. OTHER

If necessary, a glossary providing definitions of technical terms or abbreviations should be included.

Technical information should appear in Appendices.

Appendix 2

Research projects relating to wetlands

Project 1 WETLAND CLASSIFICATION ON THE BASIS OF WATER QUALITY AND INVERTEBRATE COMMUNITY DATA

Objectives:

- to provide a classification and ranking of wetlands in the Perth area;
- to determine relationships between invertebrate community assemblages and water quality parameters
- enable changes in wetland communities to be predicted;
- to design an ongoing biological and chemical monitoring programme; and
- to determine water quality criteria and specific management strategies for the urban wetlands.

Undertaken by:

Water Authority (Dr R Rosich) and Murdoch University (Dr's J Davis and J Bradley).

Funded by:

Water Authority, EPA, Australian Water Resources Advisory Council (AWRAC).

Status:

Commenced January 1989. Due for completion January 1992. Main activities are currently data collection and processing.

Project 2 EFFECTS OF ALTERED WATER LEVELS ON WETLAND PLANTS

Objectives:

- to study the consequences of reduced water levels on the survival of individual species of common emergent plants, and on the composition of emergent plant communities in wetlands of the Swan Coastal Plain; and
- to develop predictive capabilities using an empirically-based computer model.

Undertaken by:

Murdoch University (Prof A McComb and Dr R Froend).

Funded by:

Water Authority, EPA and AWRAC.

Status:

Commenced in January 1989. Due for completion in January 1992. Main activities are currently data collection and processing, both in the field and in the laboratory.

Project 3 INTERACTION BETWEEN LAKES, WETLANDS AND UNCONFINED AQUIFERS

Objectives:

- to understand the hydrological behaviour of shallow lakes and define the upstream capture zone for groundwater flow which passes through the lake;
- to experimentally verify predictions of lake-aquifer interactions using physical, hydrological, chemical and stable isotopic measurements in the field; and
- to develop modelling capabilities specifically for studying groundwater flow systems in the vicinity of lakes.

Undertaken by:

CSIRO (Drs L Townley and J Turner).

Funded by:

Water Authority, EPA and AWRAC.

Status:

Commenced in January 1989. Due for completion in January 1992. Main activities are currently data collection and processing as well as model development.

Project 4 LIFE HISTORY STRATEGIES OF AQUATIC FAUNA, NUTRIENT ENRICHMENT AND WATER LEVEL FLUCTUATIONS

Objectives:

— to analyse the life history strategies of key invertebrate species and mosquito fish, in seasonal and permanent wetlands, as a means of assessing the likely effect of changes in hydrologic regime and nutrient enrichment.

Undertaken by:

Murdoch University (Dr J Davis and Ms S Balla).

Funded by:

Water Authority, EPA and AWRAC.

Status:

Commenced in June 1988. Due for completion in June 1991. The study is concentrating on the Odonata family (dragonflies, etc). Main activities are currently data collection and processing.

Project 5 ASSESSMENT OF THE VALUE OF DIFFERENT TYPES OF WETLANDS FOR WATERBIRDS USING THE SWAN COASTAL PLAIN AS A CASE STUDY

Objectives:

— to document which waterbird species use each type of wetland, in what sort of numbers and at what time of the year;

— to identify the characteristics (eg water quality, vegetation structure) that make a wetland a good or poor example of its type in terms of water bird usage;

— to predict the effect of changes in a wetland, particularly with regard to water depth, on its use by and value for waterbirds; and

— to determine the extent of movement between different types of wetlands.

Undertaken by:

CALM (Drs S Halse and A Storey) and Australasian Ornithologists Union (Mr R Vervest).

Funded by:

Water Authority, CALM, EPA and AWRAC.

Status:

Commenced in June 1989. due for completion in June 1992. Main activities are currently data collection and processing as well as waterbird tagging.

Project 6 IMPACT OF HORTICULTURAL LAND USE ON UNCONFINED AQUIFERS

Undertaken by:

CSIRO (Dr M Sharma).

Funded by:

Water Authority.

Status:

Commenced April 1989.

Project 7 BIOLOGICAL AND CHEMICAL MONITORING OF WETLANDS ON THE SWAN COASTAL PLAIN AND THE GNANGARA MOUND IN PARTICULAR

Undertaken by:

Murdoch University (Dr J Davis and Mr S Rolls).

Status:

Completed June 1988, report to be presented.

Project 8 **VEGETATION AND SOIL MOISTURE STUDIES ON THE JANDAKOT MOUND INCLUDING WETLAND AREAS**

Undertaken by:

Dr E Mattiske and Associates.

Funded by:

Water Authority.

Status:

Undertaken at three yearly intervals, due 1991/92.

Project 9 **VEGETATION AND SOIL MOISTURE STUDIES ON THE GNANGARA MOUND INCLUDING WETLAND AREAS**

Undertaken by:

Dr E Mattiske and Associates.

Funded by:

Water Authority.

Status:

Undertaken at three yearly intervals, due 1990/91.

Project 10 **EFFECT OF PRODUCTION WELL COMMISSIONING ON ADJACENT BANKSIA WOODLANDS**

Undertaken by:

Water Authority and Dr E Mattiske and Associates.

Funded by:

Water Authority.

Status:

Commenced December 1988.

Appendix 3

Study team.

This PER was written by David Luketina and Ian Pound (of Ian Pound and Associates Pty Ltd) drawing on the supporting papers in Volume 2. Paul Lavery assisted with preparation of the PER in the later stages. Steve Wilke assisted with the preparation of the PER to satisfy a requirement for an external study course. The study was managed by Jeff Kite under the direction of Harry Ventriss. Computer modelling was carried out by Joe Miotti under the direction of Kim Taylor. Preliminary design work was carried out by Fred Shier and Mark Wendt. Rebecca Ruiz-Avila produced maps using a geographical information system and assisted with data reduction and editing. Drafting was carried out by Diane Abbott and Christine Davis.

Water Authority of Western Australia

Project Management:	H Ventriss, J Kite
Project Officers:	D Luketina, P Lavery
Principal Consultant:	Ian Pound and Associates Pty Ltd
Assistance with PER:	S Wilke
Computer modelling:	K Taylor, J Miotti
Preliminary design:	F Shier, M Wendt

Steering Committee

H Ventriss (Chairman)	WAWA
J Kite	WAWA
D Luketina	WAWA
K Taylor	WAWA
R Burton	WAWA
B Fleay	WAWA
G Graham/D Haswell	CALM
T Arias/J Pride	DPUD
I Pound (observer)	consultant

Consultants

B O'Brien and Associates	Environmental criteria
E Mattiske and B Koch	Rare flora
E Mattiske and Associates	Vegetation
Stephenson and Associates	Air pollution
R O'Connor, G Quartermaine and C Bodney	Aboriginal sites

Subconsultants to B O'Brien and Associates

J Davis (Murdoch University)	Aquatic invertebrates
K Youngson and J Henry (Ninox Wildlife Consulting)	Terrestrial and avifauna
G Syme and D Macpherson (CSIRO)	Social issues
E Mattiske (E.M Mattiske and Associates)	Vegetation

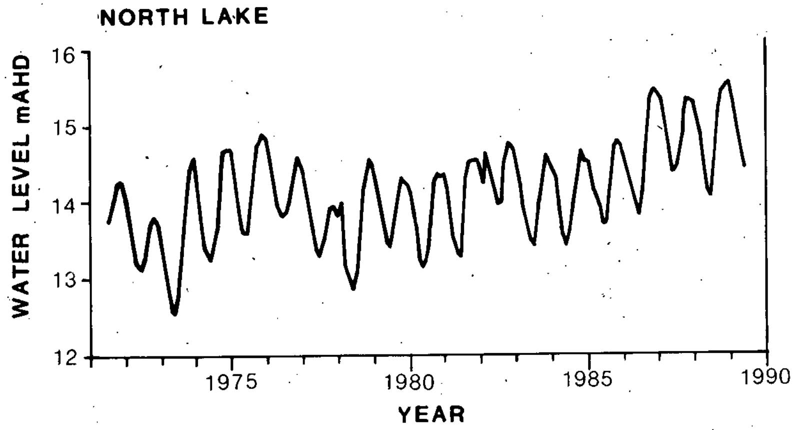
Appendix 4

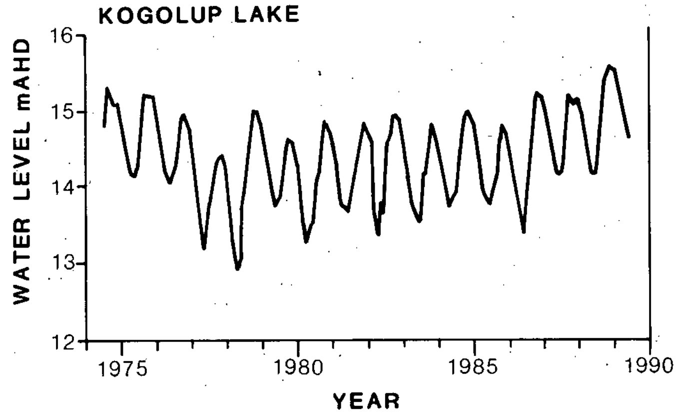
Groundwater Discussion Group

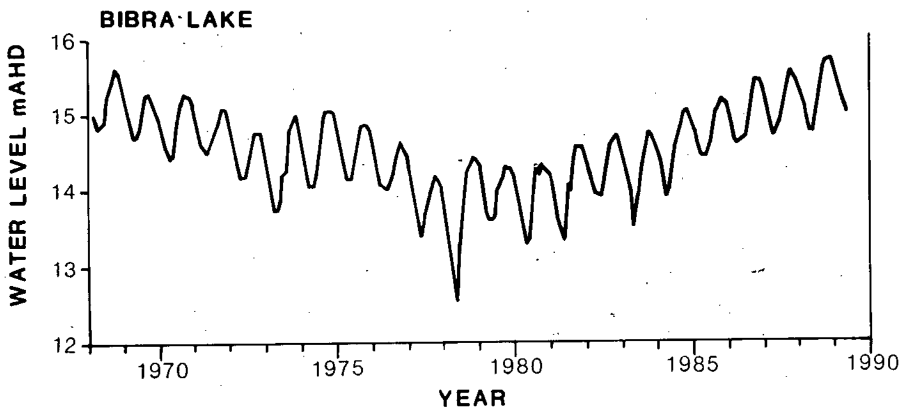
The Jandakot Groundwater Discussion Group was originally established by the Western Australian Water Resources Council's Research Group on Groundwater Management (RGGM, 1989). The members who attended meetings about the Stage 2 development were:

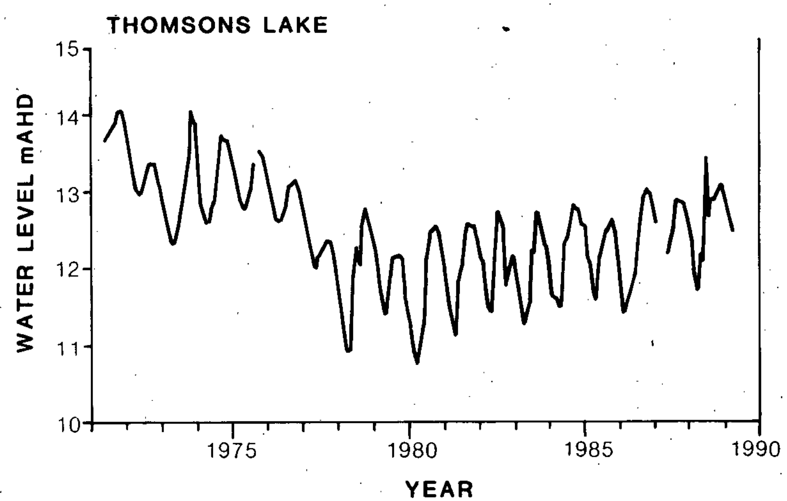
Name	Organisation or Interest
J Kite (Chairman)	WAWA
D Luketina	WAWA
P Lavery	WAWA
I Pound	consultant to WAWA
S Hiller	Town Planner, Cockburn City Council
E Wegner	Councillor, Cockburn City Council
J Duggan	Councillor, Cockburn City Council
P Clay	Thomsons and Banganup Lakes
S Halse	CALM
J Hastings	water drilling
J Sumich	market gardens
N Godfrey	Wetland Conservation Society
P Hancock	Yangebup Progress Association
K Cole	agriculture
J Paton	G B Hill and Partners
P Bottcher	Banjup Action Group

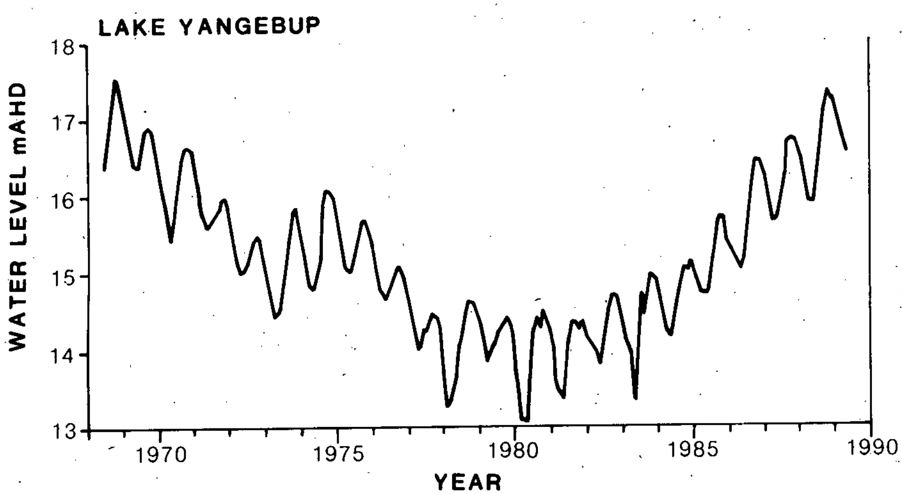
Appendix 5
Hydrographs for major wetlands

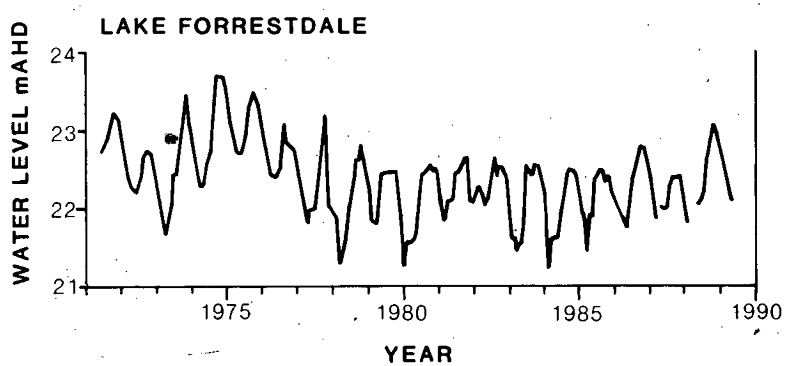












Appendix 6

Conservation status of flora on the Jandakot Mound.

Table A6.1 Conservation status of flora on the Jandakot Mound (from Mattiske and Koch, 1989)

SPECIES	RYE 1982	BARRETT 1982 PATRICK & HOPPER 1982	RYE & HOOPER 1981	STATUS
Aponogeton hexatepalus	—	D	Rare	Rare
Baumea arthrophylla	E	D	—	—
Billardiera parviflora var. *guttata*	—	D	—	D
Caladenia hueglii	—	—	—	Rare
Diuris purdiei	—	E	Rare	Rare
Diuris sp. (Kwinana)	—	—	—	Rare
Dodonaea hackettiana	E	B	Rare	E
Drakaea elastica	—	B	—	Rare
Drakaea sp. (south west)	—	—	—	Rare
Drosera occidentalis	E	D	Rare	Rare
Haloragis platycarpa	E	A	—	C
Hydrocotyle hispidula	E	D	—	—
Hydrocotyle lemnoides	E	B	Rare	Rare
Jacksonia sericea (synonym *J. gracilis*)	E	D	—	E
Lysinema elegans	E	D	—	F
Restio stenostachyus	E	E	—	—
Stylidium utricularioides	E	E	—	—
Tetraria australiensis	—	B	—	D
Thelymitra hybrid (*pauciflora* x *flexuosa*)	—	D	—	D

Note: This appendix is based on gazetted species and the W.A. Herbarium Status whose categories are:

A — no specimens available
B — Rare (apparently rare and quite restricted in distribution)
C — type specimen only
D — poorly collected (less than 5 collections)
E — restricted distribution of less than 100 km
F — restricted distribution of less than 160km.

Appendix 7

Summary of the Main Community Types on the Jandakot Mound

Table A7.1 Summary of the main community types on the Jandakot Mound (from Mattiske, 1988 as extracted from Cockburn Wetlands Committee, 1976; Leprovost *et al.*, 1987; Arnold, 1988)

1	Open forest or woodlands of Tuart (*Eucalyptus gomphocephala*) on the Karrakatta sand dune system on the western fringes of the Jandakot Mound area.
2.	Low-open forest to woodlands of *Banksia attenuata-B. menziesii* and the occasional Prickly-bark or Coastal Blackbutt (*Eucalyptus todtiana*) on the Bassendean dune system. *Banksia ilicifolia* and Jarrah (*Eucalyptus marginata*) occur on the moister lower slopes.
3.	Fringing woodlands of *Melaleuca rhaphiophylla, Melaleuca preissiana, Eucalyptus rudis* and *Banksia littoralis.*
4.	Low-open woodlands of *Melaleuca preissiana* with a very dense shrub-layer of seasonally inundated health species dominated by Myrtaceae species (eg *Kunzea ericifolia, Pericalymma ellipticum, Astartea fascicularis*) ie dampland or sumpland.
5.	Fringing and intrusive wet sedgelands and reedbeds of *Cyperaceae* and *Restionaceae* species with pockets of *Myrtaceae* and *Mimosaceae* shrublands (eg *Melaleuca teretifolia*).
6.	Bare shorelines and mudflats with very shallow margins (see Fauna Section, Ninox Wildlife Consulting, Part B).
7.	Woodlands of *Melaleuca rhaphiophylla* in permanently inundated swamps.
8.	Open, shallow expanses of water
9.	Open, deep expanses of water
10.	Pastures, water meadows, grassy areas or farmland with relict stands of paperbarks (*Melaleuca* spp. and Eucalypts (*Eucalyptus* spp.).

For the purposes of associating vegetation with soil group as used by Wells *et al.* (1986), E.M. Mattiske and Associates determined the groupings given in Table A7.2 and shown in Figure A7.1

Table A7.2 Vegetation complexs that occur in the various sand groups found in the Jandakot Area.

CODE	DESCRIPTION
K	Woodland of *Eucalyptus gomphocephala — Eucalyptus calophylla — Eucalyptus marginata* with admixtures of *Banksia attenuata — Banksia menziesii* and *Allocasuarina fraseriana*. The understorey is variable depending on degree of leaching and proximity to limestone outcrops, see Havel Coastal Plain Site-vegetation Types — C, D, E and F (transition type) (1968).
Bd	Low woodland to low open forest of *Banksia attenuata — Banksia menziesii* with occasional *Banksia ilicifolia, Allocasuarina fraseriana, Eucalyptus marginata* and *Nuytsia floribunda.* The understorey is variable depending on the degree of leaching and soil moisure levels, see Havel Coastal Plain Site-vegetation Types — F (transition type), G and to a lesser extent H (1968).
Bl	Low open forest of *Banksia menziesii — Banksia ilicifolia — Eucalyptus marginata* with occasional *Banksia attenuata.* The understorey is variable depending on the soil types and moisture levels, see Havel Coastal Plain Site-vegetation Types — H, I and J (1968).
Bw	Low open woodland or closed heath dominated by species of *Myrtaceae.* Tree species are predominantly *Melaleuca preissiana* or *Banksia ilicifolia.* The understorey species reflect local soil types and moisture levels and include *Hypocalymma angustifolium, Pericalymma ellipticum* and *Astartea fascicularis*, see Havel Coastal Plain Site-vegetation types — J and K (1968).
Sw	Woodlands of *Melaleuca preissiana — Melaleuca rhaphiophylla* with occasional *Eucalyptus rudis* and *Banksia littoralis.* There is considerable variation in vegetation types on these wetter seasonal swamps and potentially water-logged swamps, with sedgelands of *Baumea* and *Leptocarpus* species and closed heaths dominated by *Myrtaceae* species, see Havel Coastal Plain Site-vegetation Type — K (1968).
L	Woodlands of *Melaleuca rhaphiophylla — Eucalyptus rudis* with the occasional *Melaleuca preissiana* and *Banksia littoralis* on the fringes of regularly water-logged soils and lakes. The woodlands are regularly interspersed with sedgelands of *Baumea, Leptocarpus* and *Typha* and areas of open water or lakes, see Havel Site-vegetation Type K (1968).

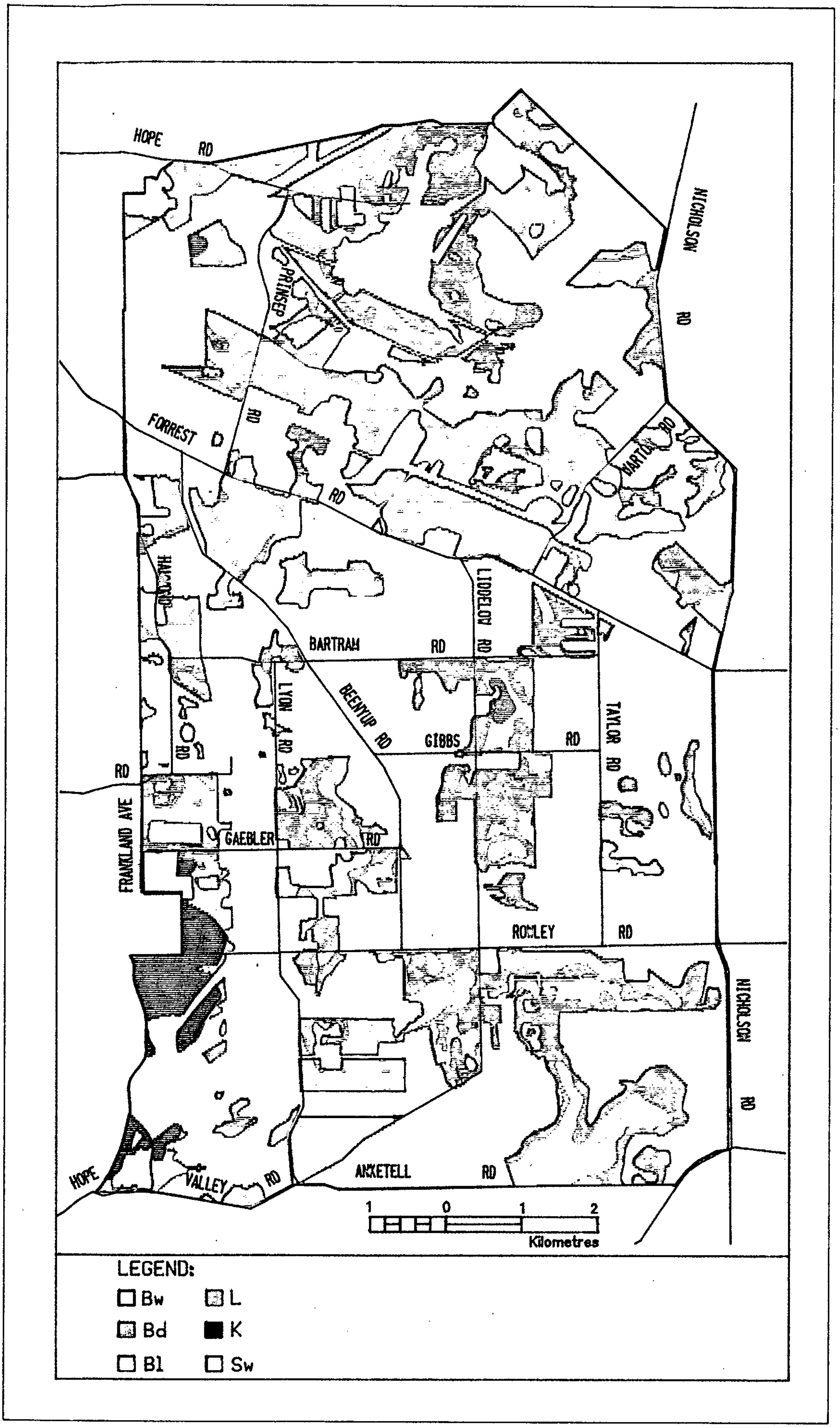


Figure A7.1 Vegetation complexes in the Jandakot Public Water Supply Area. Based on Wells et al. (1986) with a legend as modified by E. M. Mattiske and Associates (see Table A7.2).

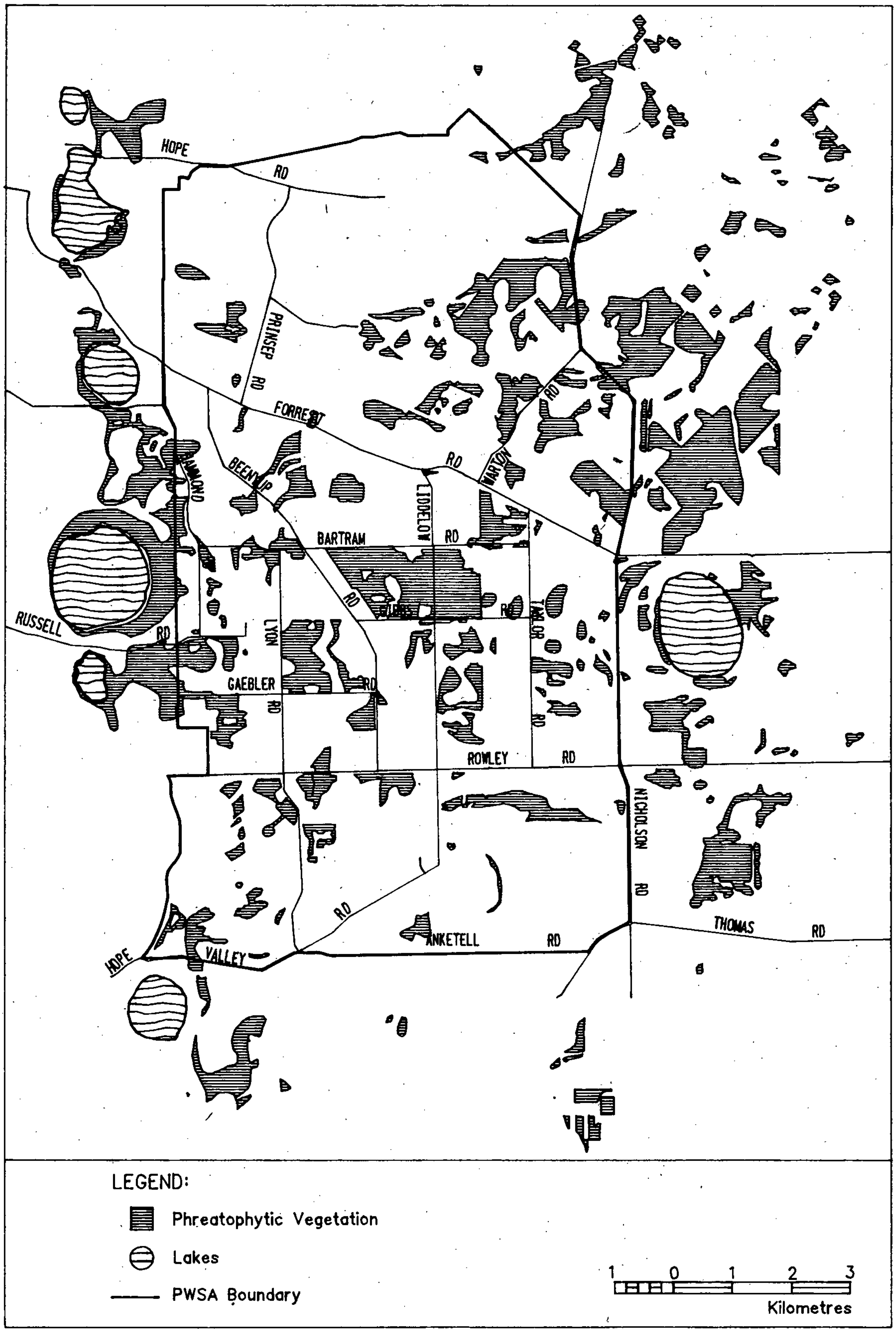


Figure A7.2 Vegetation map for the Jandakot Mound showing phreatophytic vegetation. Vegetation is assumed to be phreatophytic where there is less than 5 metres to groundwater as indicated by the Perth Metropolitan Region 1:50000 Environmental Geology Map Series.

Appendix 8

Bathymetry and vegetation for the major wetlands.

Vegetation maps were prepared from EPA Bulletin 266 (EPA, 1990a). Wetland plant communities were mapped according to dominant genera and, where possible, species. An estimate of vegetation cover was made using upper case letters to indicate physiognomy of the dominant stratum and lower case letters to provide an estimate of vegetation cover.

Vegetation Classification: Mapping notation and formulae,

- i) dominant genus and species — lower case letter on left;
- ii) physiognomy of dominant stratum — upper case letter in centre; and
- iii) projective vegetation cover — lower case letter on right.

i) Dominant genera and species

a	*Acacia*
b_2	*Banksia littoralis*
c	*Casuarina*
cl_1	*Baumea articulata*
cl_2	*Baumea juncea*
d	*Dryandra*
e_1	*Eucalyptus rudis*
e_2	*E. gomphocephala*
e_3	*E. marginata*
e_4	*E. calophylla*
e_5	*E. todtiana*
g	*Gahnia trifida*
h	coastal heath
j	*Juncus*
k	halophytes
l	*Leptocarpus*
m	*Melaleuca sp*
m_1	*M. rhaphiophylla*
m_2	*M. preissiana*
m_3	*M. laterita*
m_4	*M. teretifolia*
m_5	*M. cuticularis*
p	*Callitris*
s	*Scirpus*
t	*Typha*
w	weeds or introduced grasses
x	mixed or other

ii) Physiognomy of Dominant Stratum

T	Tall trees > 30 m tall
M	Medium trees 10-30 m tall
L	Low trees < 10 m tall
S	Shrubs > 1 m tall
Z	Dwarf shrubs < 1 m tall
R	Rushes and sedges > 1 m tall
V	Rushes and sedges < 1 m tall
G	Bunch grasses
H	Hummock grasses
F	Forbs
L	Lichens and mosses
C	Succulents

iii) Canopy Cover

d	Dense cover >70% foliage cover
c	Mid dense 30-70% foliage cover
i	Incomplete canopy-open, not touching
r	Rare but conspicuous foliage cover <10%
b	Vegetation largely absent
p	Scattered groups — no definite foliage cover

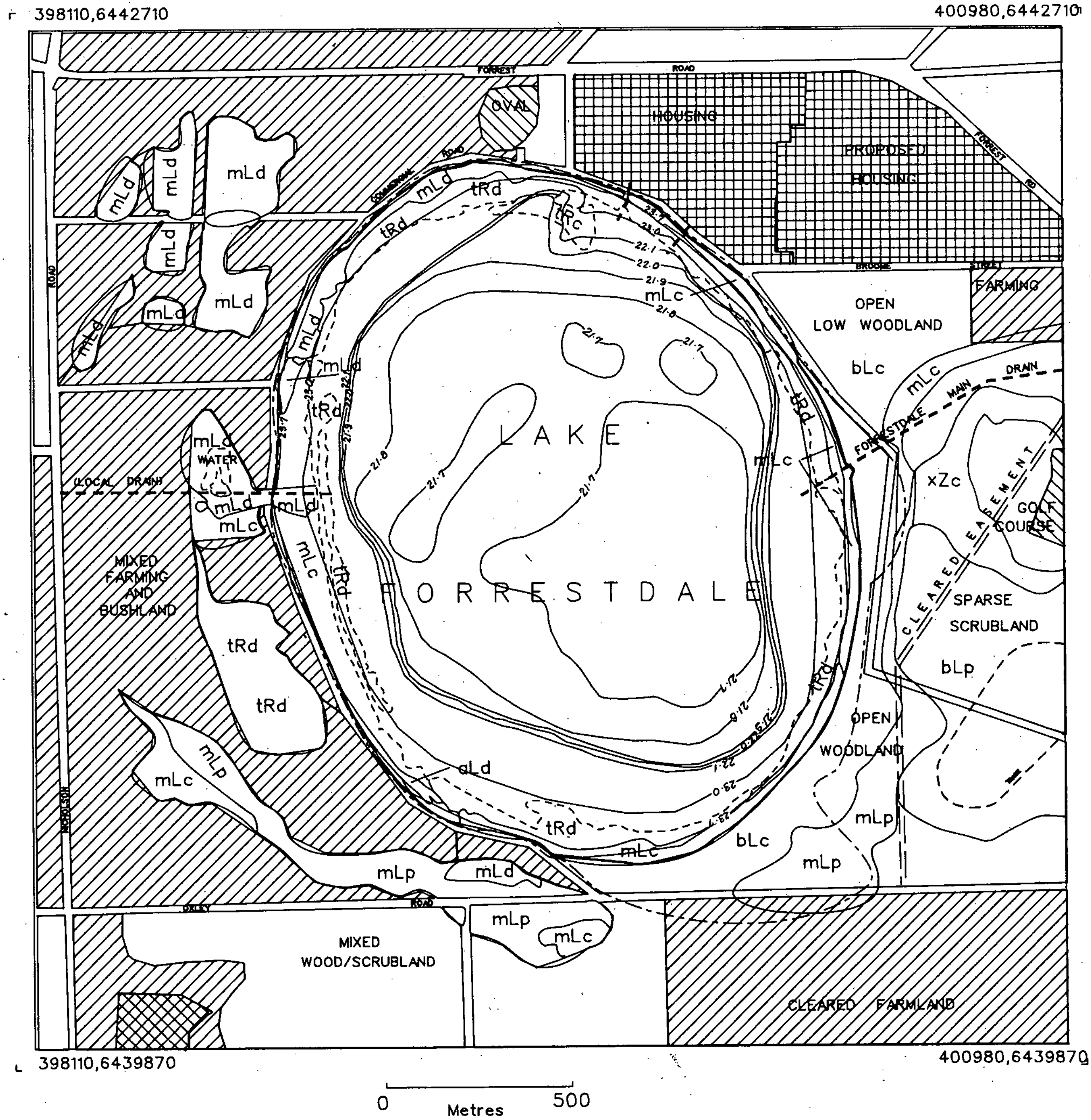


Figure A8.1 Bathymetry and vegetation for Forrestdale Lake.

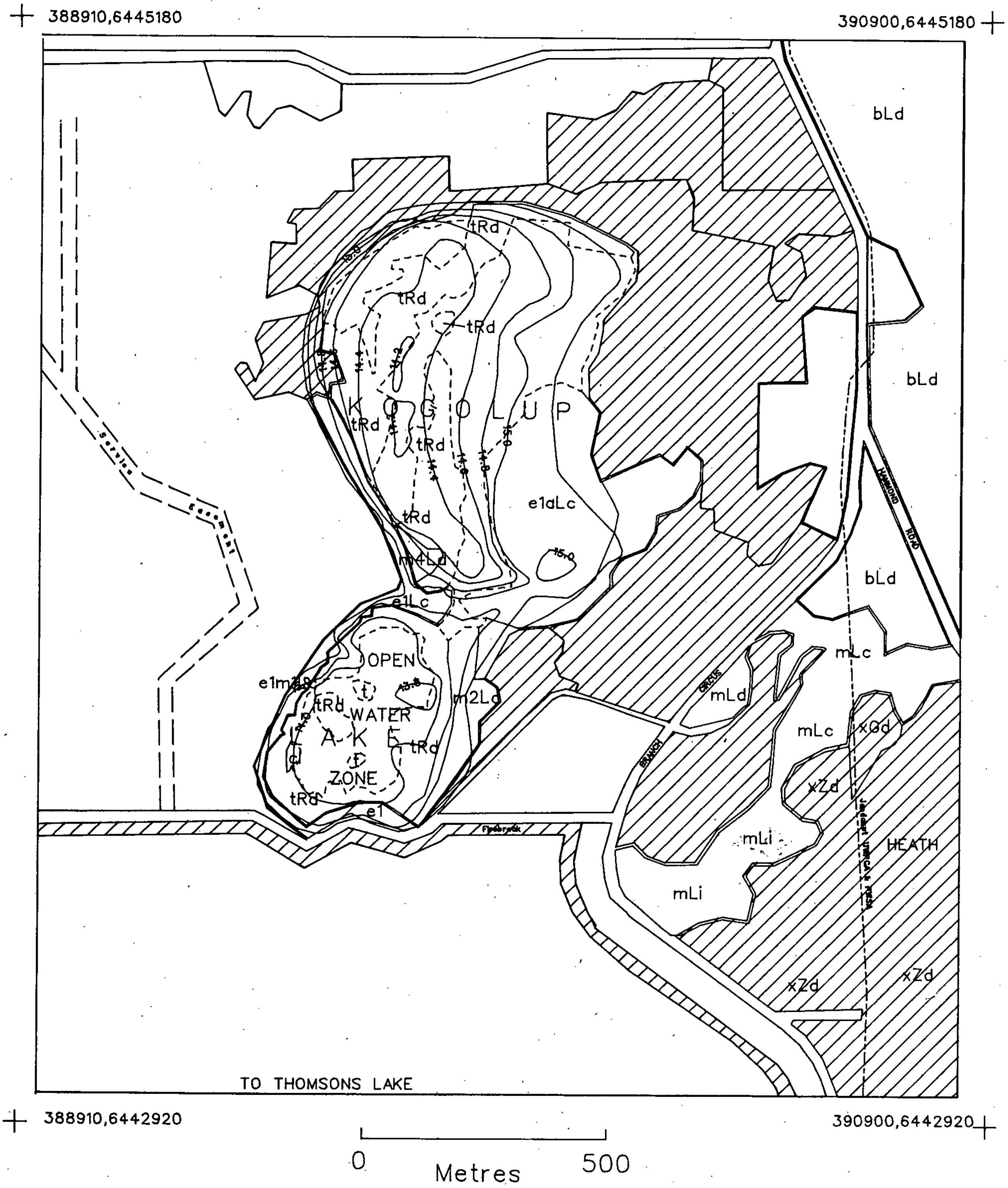


Figure A8.2 Bathymetry and vegetation for Kogolup Lake.

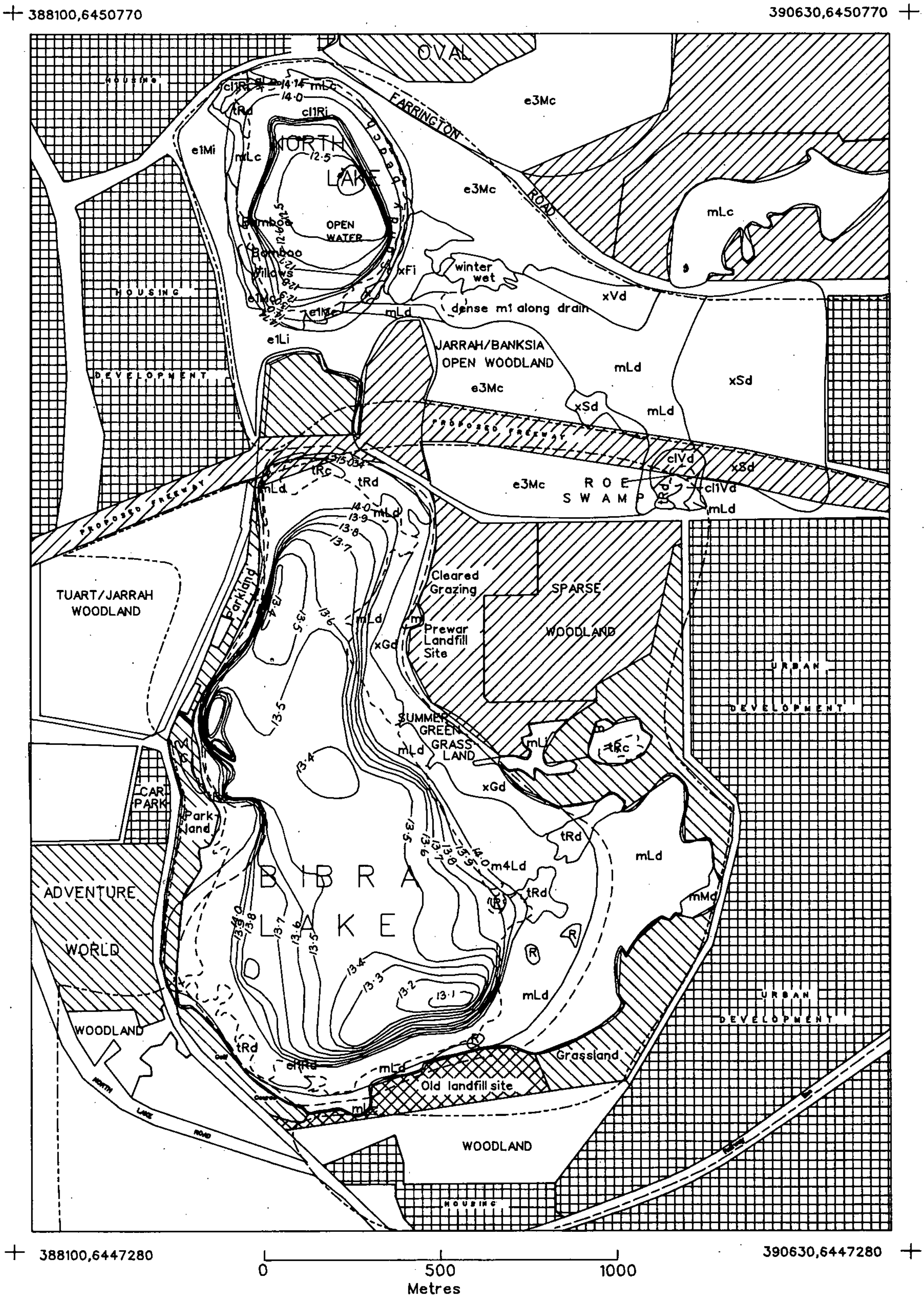


Figure A8.3 Bathymetry and vegetation for Bibra Lake.

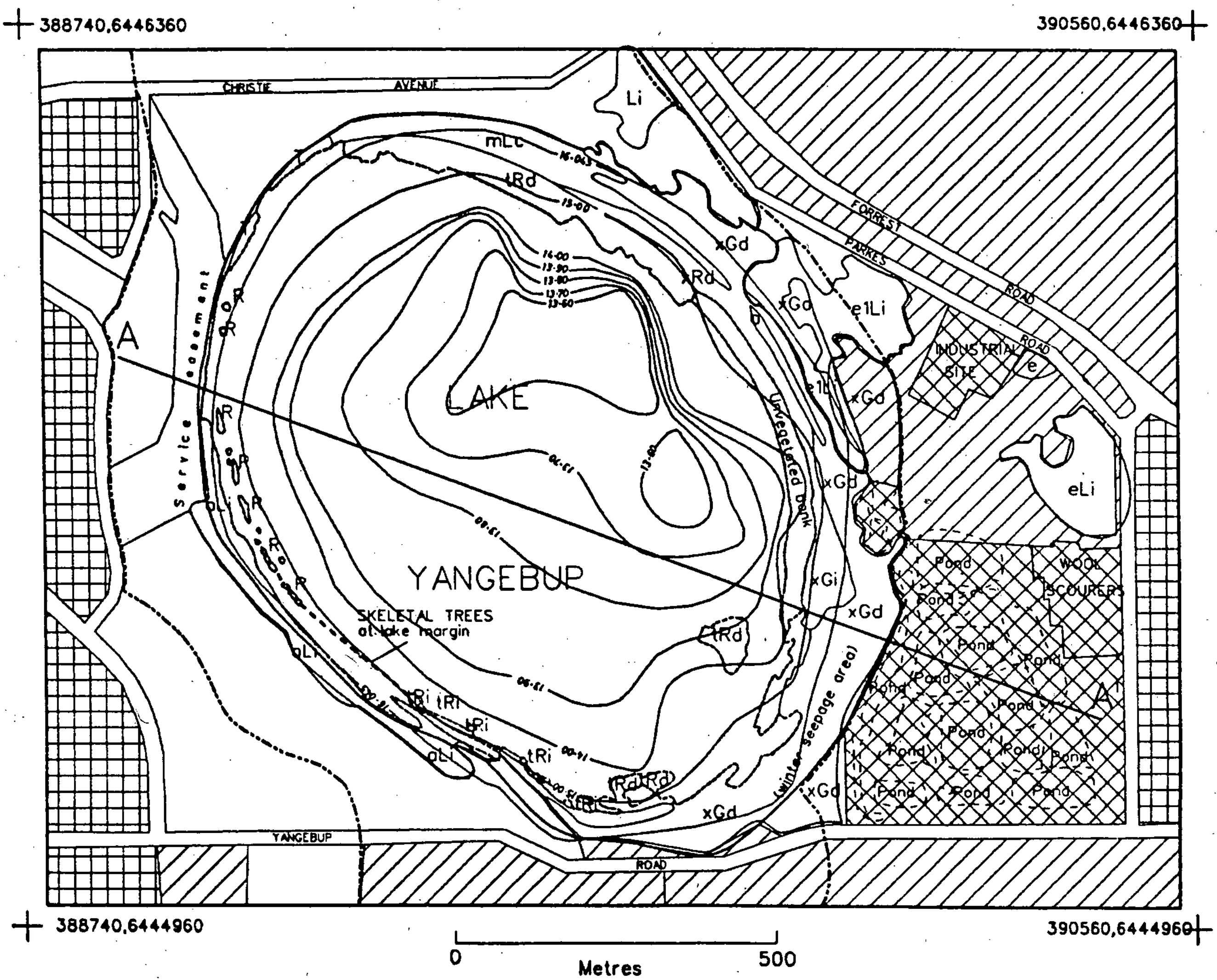


Figure A8.4 Bathymetry and vegetation for Yangebup Lake.

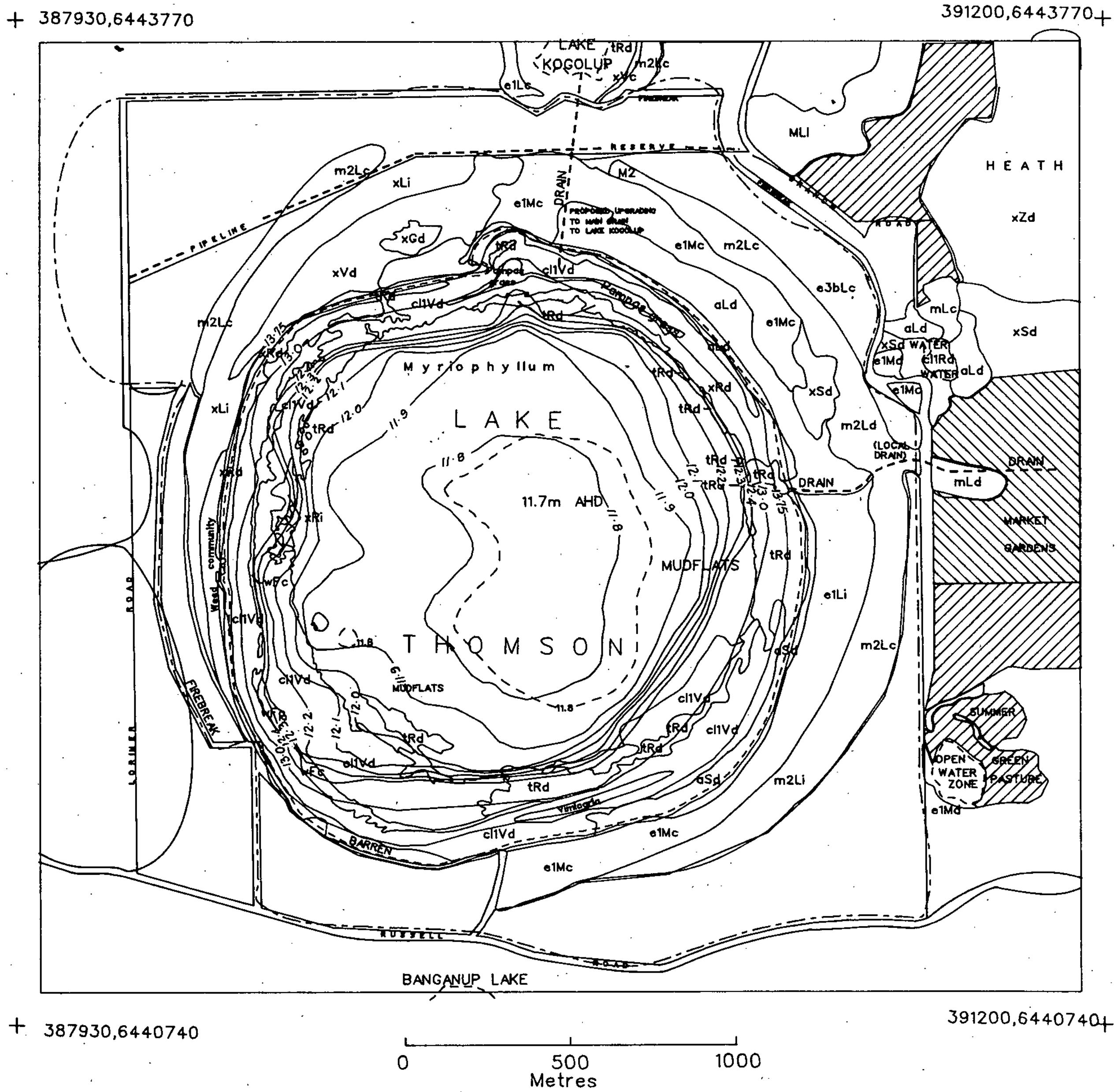


Figure A8.5 Bathymetry and vegetation for Thomsons Lake.

Appendix 9

Food webs in wetlands

Figure A9.1 shows a generalised diagram of energy pathways and trophic structures in a wetland ecosystem. The organisms at the various levels in the food web are (from EPA, 1987b):

Primary Producers	: Macrophytes (fringing reeds and submerged plants)	
	: Periphyton/Metaphyton	
	: Phytoplankton, Algae	

Invertebrate members of grazing and detrital food chains

First Order Consumers:	Zooplankton	*Chironomid* larvae
	Gastropods	(in part)
Second Order Consumers:	Dragonfly nymphs	Dysticid larvae
	Damselfly nymphs	Hydrophilid
	Water Mites	larvae
	Megalopterans	Corixid bugs
	Chironomid larvae (in part)	(water boatmen)
	Notonectid bugs	(backswimmers)
Decomposers:	Oligochaetes	Chironomid larvae
	Caddisfly larvae	(in part)
	Amphipods	Phreatiocids
	Freshwater shrimps	Ostracods
	Mayfly larvae	Corixid bugs (in part)
	Beetle larvae	

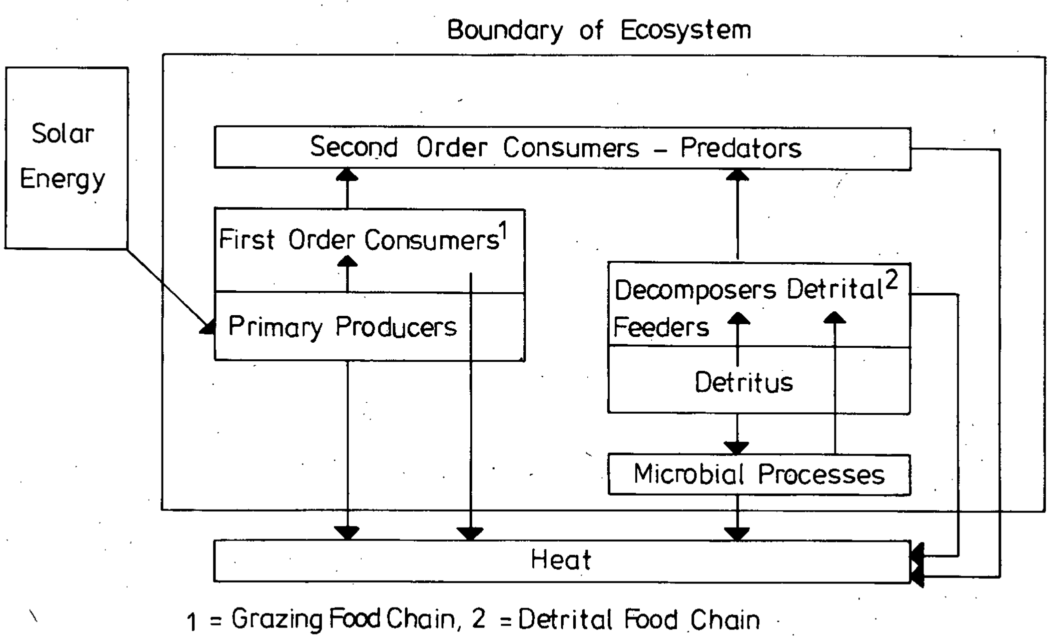


Figure A9.1 Generalised diagram of energy pathways and trophic structures in a wetland ecosystem.

Appendix 10

Bird species and habitats

The tables in this appendix were constructed using data from EPA (1989b) and Ninox (1988). The habitat types are listed in Appendix 7. The codings are as follows:

	S = status
F = feeding	U = uncommon
N = nesting	M = moderately common
L = loafing	C = common
	? = unknown status

Table A10.1 Habitats used by rare bird species (as cited in EPA, 1989b)

HABITAT TYPE	5	6	7	8	9	10	11	12	13	S
FRECKLED DUCK	L	L	L	FL	FL			L		U
CHESTNUT TEAL		L	L	FL	FL			L		U
CATTLE EGRET				F		F	F	L		U
LITTLE EGRET		F	L	F			F	L		U
GLOSSY IBIS		F	L	F			F	L		U
ROYAL SPOONBILL		L	L	F			F	L		U
MARSH SANDPIPER		FL					FL			U
BLACK-TAILED GODWIT		FL					FL			U
PECTORAL SANDPIPER		FL					FL			U
LONG TOED STINT		FL					FL			U
LESSER GOLDEN PLOVER		FL								U
AUSTRALASIAN BITTERN	FNL									U
HABITAT TYPE	5	6	7	8	9	10	11	12	13	S

Table A10.2 Habitats used by common species of birds (based on EPA, 1989b and Ninox, 1988)

HABITAT TYPE	5	6	7	8	9	10	11	12	13	S
GREAT CRESTED GREBE	N				FNL					U
HOARY-HEADED GREBEN			N	FNL	FNL		FNL			C
AUSTRALASIAN GREBE				FNL	FNL		FNL			C
AUSTRALIAN PELICAN		L			FL			L		U
GREAT CORMORANT			NL		F			L		U
LITTLE BLACK CORMORANT			NL	F	F			L		U
LITTLE PIED CORMORANT			NL	F	F			L		M
BLACK SWAN	FN	L		FL	FL	FL	FL			C
AUSTRALIAN SHELDUCK		L		FL	FL	FL	L	N		M
PACIFIC BLACK DUCK	NL	L	NL	FL	FL	FL	FL	L	N	C
MALLARD		L		FL	FL	FL				C
MUSCOVY		L		FL	FL	FL				C
GREY TEAL		L	NL	FL	FL	FL	FL	L	N	C
AUSTRALASIAN SHOVELER	NL	L	L	FL	FL	N	FNL	L	N	M
PINK-EARED DUCK	L	L	NL	FL	FL		FL	L	N	M
HARDHEAD	NL	L	NL	FL	FL	N		L	N	U
MANED DUCK		L		L	L	FNL	FL	L	N	M
BLUE-BILLED DUCK	NL		N		FL					M
MUSK DUCK	NL		N		FL					M
DUSKY MOORHEN	FNL	FL	FNL	FL	FL	F	F			M
EURASIAN COOT	FNL	L	FL	FL	FL		FL			C
SILVER GULL		FL		FL	FL	FL	FL	L		C
WHISKERED TERN		L		F	F			L		M
WHITE-WINGED TERN		L		F	F			L		M
CASPIAN TERN								L		?
CRESTED TERN								L		?
PACIFIC HERON		F	NL	F			F	L		U
WHITE-FACED HERON		F	NL	F		F	F	L		C
GREAT EGRET		F	L	F			F	L		U
RUFOUS NIGHT HERON	L	F	NL	F			F			M
SACRED IBIS	N	F	NL	F		F	F	L		M
STRAW-NECKED IBIS	N	F	NL	F		F	F	L		M
YELLOW BILLED SPOONBILL		L	L	F			F	L		U
MARSH HARRIER	FNL	F	L	F			F	L		U
BLACK WINGED STILT		FL		FL			FN			C
BANDED STILT		FL		FL						U
RED NECKED AVOCET		FL		FL			FL			M
BAR TAILED GODWIT		FL		FL						M
PURPLE SWAMPHEN		FL		FNL		F	F			M
BANDED LAPWING		FL				FNL				M
WOOD SANDPIPER		FL					FL	L		U
COMMON SANDPIPER		FL								U
GREENSHANK		FL					FL			U
SHARPTAILED SANDPIPER		FL					FL			M
RED-NECKED STINT		FL								U
CURLEW SANDPIPER		FL								C
RED KNEED DOTTERALL		FNL								U
BLACK-FRONTED PLOVER		FNL				FNL				M
BLACK TAILED NATIVE HEN		FNL	F	FNL			F	F		U
RED CAPPED PLOVER			FNL							C
BUFF-BANDED RAIL	FNL		FNL		FN		F			?
LITTLE BITTERN	FNL		NL							U
BAILLONS'S CRAKE	FNL		FNL				F			?
AUSTRALIAN CRAKE	FNL		FNL							?
SPOTLESS CRAKE	FNL		FNL							?
CLAMOROUS REED WARBLER	FNL		FNL							M
LITTLE GRASSBIRD	FNL									M
DARTER			NL					L		U
OSPREY			L					L		U
WHITE BELLIED SEA EAGLE			L	L	U					
PIED CORMORANT								L		U
WHIMBREL								L		?
FAIRY TERN								L		?
GREAT KNOT*		F								U
RED KNOT*		F								M
GREY PLOVER*		F				L				M
HOODED PLOVER*		F				L				U
LARGE SAND PLOVER*		F								U
WHITE FRONTED CHAT*		F				L				U
HABITAT TYPE	5	6	7	8	9	10	11	12	13	S

* there is some uncertainty about these codings.

Appendix 11

The groundwater computer model

As briefly described in section 8.3, the Water Authority operates a complex computer model as a tool for management of the Jandakot groundwater mound. This Appendix describes in greater detail: what is modelled, how the model is constructed and operated.

Modelling of hydrological processes involves a series of steps, these being:

- the development of an understanding of the physical processes and their interrelationships,
- representing the physical processes mathematically as a series of equations,
- using a computer to solve the equations. The computer program itself is usually referred to as a computer model, and
- calibrating the computer model for the particular system or area to which it is being applied.

Physical Processes

The various hydrological processes which need to be taken into account when modelling groundwater levels (ie the superficial aquifer) are:

- rainfall — characteristics such as intensity, duration and spatial distribution are all important,
- interception — the amount of water intercepted by roads, roofs and vegetation canopies depends on vegetation type, canopy cover, land use and rainfall characteristics,
- infiltration — the amount of water which enters the unsaturated soil profile (ie the soil above the water table) depends upon soil and rainfall characteristics and the distribution of moisture content in the soil,
- percolation — refers to the passage of water from the deep root zone to the water table and depends on the moisture distribution higher in the soil profile,
- surface runoff and drainage — occurs when water is unable to infiltrate and is dependent upon surface slope and roughness, soil moisture content at the surface as well as the rates at which additional water is supplied by rainfall and extracted by infiltration or evaporation,
- evaporation — occurs from open water surfaces, such as wetlands and directly from the soil. It depends on atmospheric conditions (solar radiation, wind speed, temperature and humidity) and on conditions within the body of water (temperature),
- transpiration — depends on vegetation characteristics (species, root depth and density etc.), atmospheric conditions and conditions within the soil (especially the distribution of soil moisture near the roots),
- saturated aquifer flows — (ie horizontal groundwater flows) occur beneath the water table in the direction of the slope of the water table. The rate of the aquifer flow depends on aquifer properties (such as permeability) and on the slope of the water table,
- leakage — is the vertical flow of water from one aquifer to another. Its rate depends on resistance to flow in the geological formation separating the two aquifers and the difference in water pressure between the two aquifers.

Details of how these processes are represented mathematically can be found in WAWA (1987c).

The Complete Model

The computer model basically consists of two linked models, one in the vertical direction and one in the horizontal direction. The area (ie the Jandakot Area) covered by the model is shown in Figure A11.1. The model boundary has been chosen to:

- be beyond the expected area of influence of pumping within the Jandakot PWSA, and
- include the major wetlands of the region, and the surrounding areas in which pumping is likely to influence them.

Details of the Computer Model

The two linked models forming the computer model are a vertical flux model and an aquifer flow model (see WAWA 1987c for more details). The term 'vertical flux' refers to the vertical movement of water to or from the superficial aquifer. Of the physical processes described above, all are vertical processes except for saturated aquifer flows. Included amongst the vertical processes is abstraction by wells. The aquifer flow model calculates horizontal flows and groundwater levels.

The aquifer flow model consists of a number of triangular and retangular cells (over 1200 for Jandakot — see Figure A11.1). A minimum number of cells are required to accurately model the physical processes. Some areas, such as wetlands, which have complicated flows require more cells than others.

To run the model, initial water levels need to be specified. However, these initial levels make very little, if any, difference for model runs in excess of a few years. The model is run by 'time steps'. This means that water level values are calculated for each time step of a simulation. Just as a minimum number of cells are needed for proper accuracy, the time step can only be so long. A time step of one month has proven to be suitable.

The model starts by calculating a vertical flux for each cell; the aquifer flow model then calculates horizontal flows and groundwater levels, which may in turn affect the vertical flux in the next time interval (ie one month later). Any feedback effect of groundwater levels on the calculation of the net vertical flux is greatest when the depth to the water table is small.

Further details on the computer model are contained in WAWA (1987a) and WAWA (1987c).

Output

Output from the model consists of monthly water levels at the corners of each cell. These water levels are presented in this PER as either hydrographs for major lakes or as water level difference contour plots over the Jandakot Area. The difference plots show the change in water levels for the Jandakot Area between different scenarios.

Calibration

The model was calibrated or matched to actual groundwater levels by estimating parameters from recorded data and varying these slightly until a simulation was reached which matched groundwater levels in the period 1975 to 1988.

A comparison of simulated water levels and recorded water levels for two monitoring wells and Bibra Lake is shown in Figure A11.2. It is considered that the model reliably simulates the actual groundwater behaviour and therefore provides accurate predictions of likely water levels under future scenarios.

Duration of Simulations

All model runs were for 75 years and used the actual climatic records from the last 75 years (1913 to 1988) unless stated otherwise.

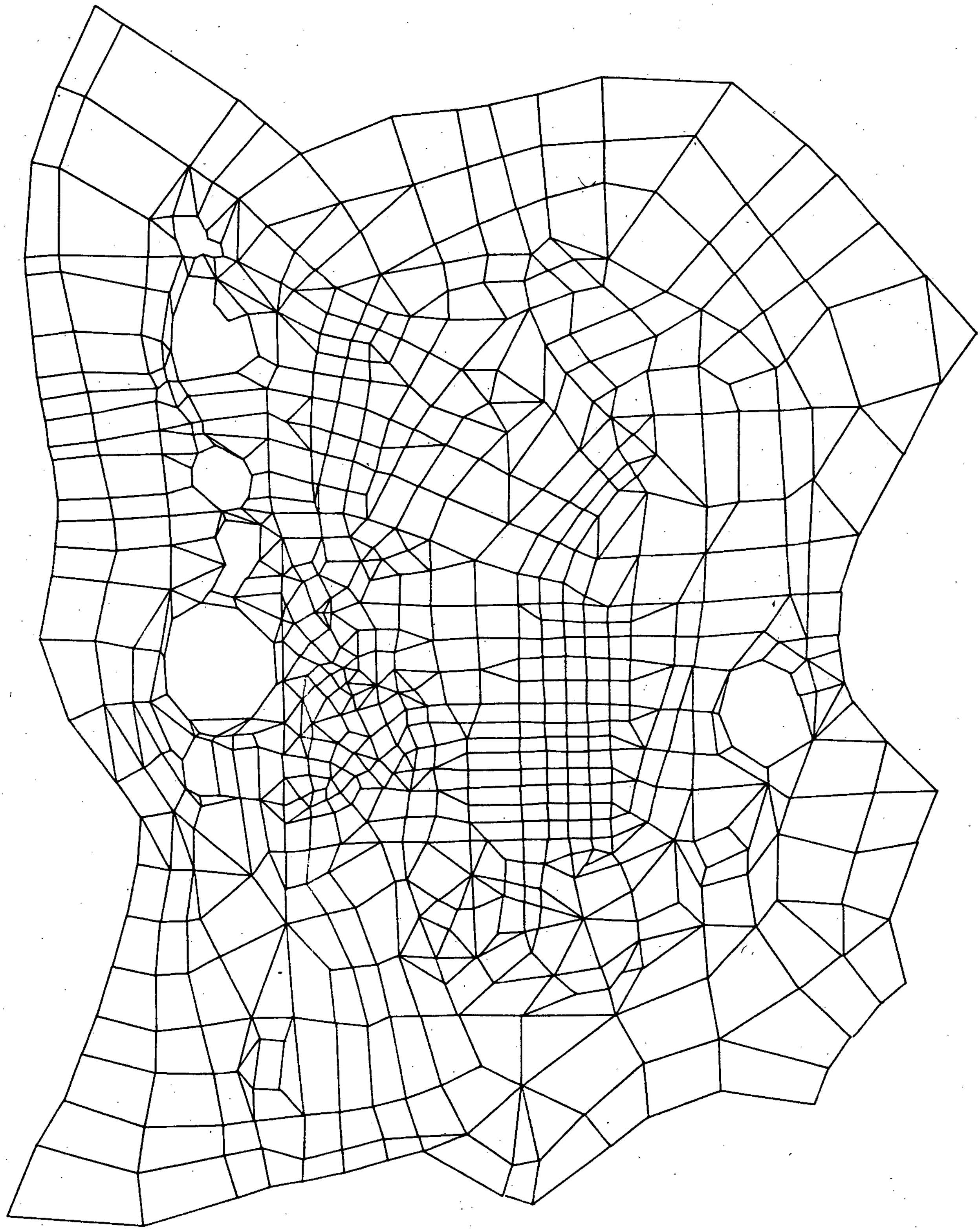


Figure A11.1 The area covered by the Water Authority's numerical groundwater model. The triangles show the cells (see text) used by the model.

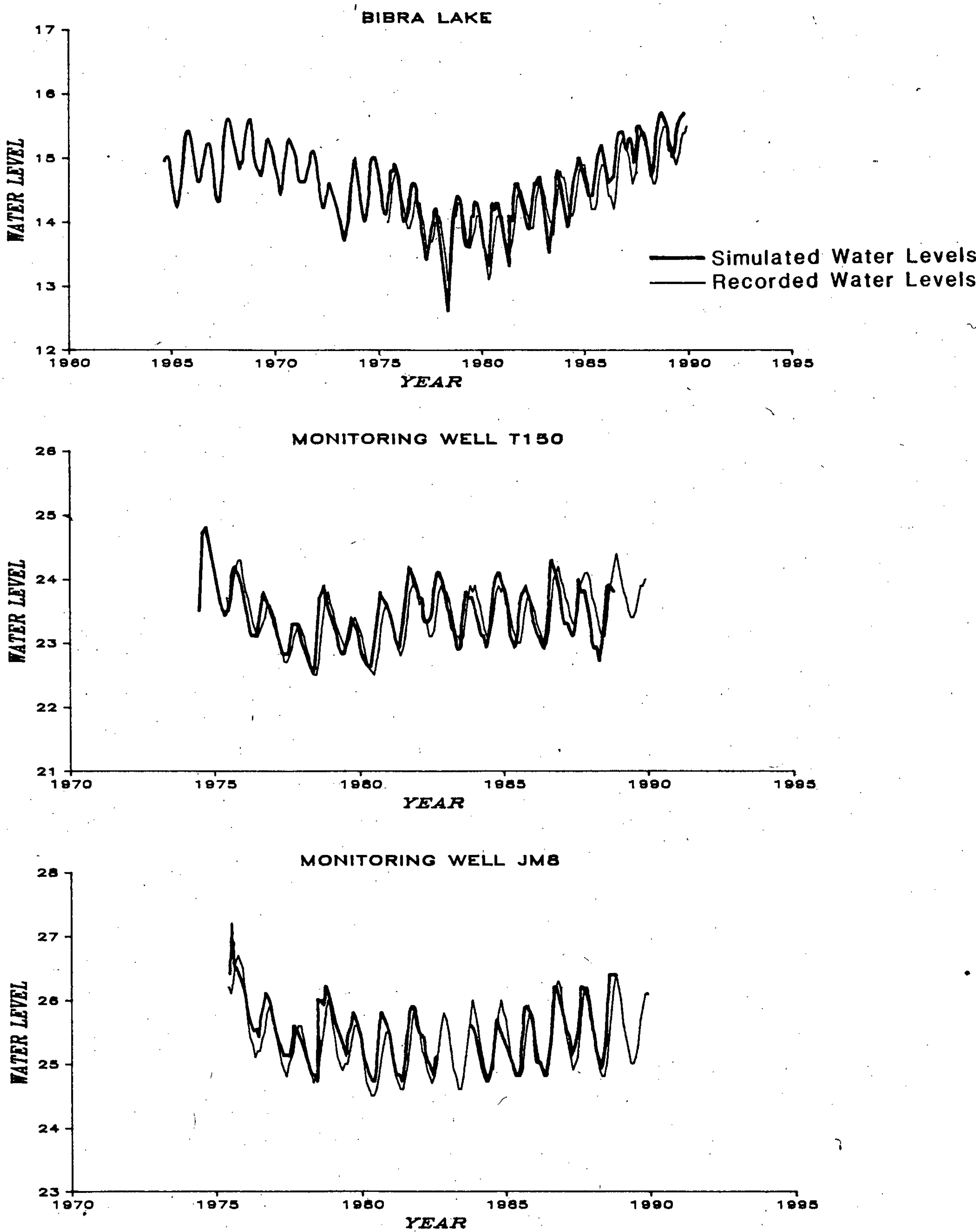


Figure A11.2 A comparison of simulated water levels and recorded water levels for two monitoring wells and Bibra Lake.

Appendix 12

Summary of Environmental Management Commitments

The environmental management commitments in this PER are summarised in Table A12.1. The criteria developed in Chapter 7 are summarised in Table A12.2.

Table A12.1 Environmental Management Commitments

No.	SECTION	COMMITMENT
1	10.1	To prepare a Management and Monitoring Programme, satisfactory to the EPA, prior to commissioning of the Stage 2 Scheme.
2	10.2	To ensure that groundwater abstraction satisfies the environmental criteria presented in this PER.
	10.5.1	To mitigate impacts associated with construction of the Stage 2 Scheme the Water Authority will ensure:
3		• clearing of vegetation at well sites will be restricted to the area of the enclosure (approximately 25 metres square) in non-urban areas, and the immediate area of the well head in the case of wells located in public open space in urban areas,
4		• where practical the collector main will be located within existing road reserves
5		• on Crown Land, top-soil from the collector main trench will be separately stripped, stock-piled and re-spread on completion of pipe laying,
6		• on private land, the collector main route will be left in a state agreed to by the land owner/occupier,
7		• where feasible, well site compounds will be used for the storage of materials and for contractors' facilities, in preference to the establishment of separate short-term sites,
8		• where temporary construction sites are established, the area will be returned either to its original state, in the case of Crown Land, or to a state agreed to by the land owner/occupier,
9		• all work on extensions to and modifications of the Jandakot Treatment Plant will be undertaken on existing cleared areas within the boundary of the Plant site, and
10		• all workers involved in project construction in natural areas will be instructed on environmental protection procedures before work proceeds
11	10.5.1	In the event that monitoring indicates that there will be significant impacts of a nature not predicted in this evaluation or a breach of the specified criteria, then as discussed in sections 6.9 and 7 the Water Authority must undertake one or more of the following:
		• demonstrate to the satisfaction of the EPA that the breach in criterion is not a result of groundwater abstraction, or
		• satisfy the EPA that the breach of criterion is transient and not of permanent significance, or
		• take the relevant action as specified in section 7:
		— modify pumping from any well where such changes can have a measurable effect (say raise water levels 1 centimetre or more), except in extenuating circumstances such as where significant economic hardship would occur, or CALM declare that the low water levels would be beneficial,
		— in the case of a wetland, artificially maintain the 'action minima' water level (see Table 7.5), and
		— implement a short-term detailed monitoring programme to establish the condition of agreed species in the affected area.
12	10.5.1	To modify the chlorine withdrawal system to a liquid process prior to commissioning of the Stage 2 line of wells.
	10.5.1	To operate the treatment plant with established buffer zones so that:
13		• the personal risk hazard of fatality associated with chlorine release is less than one in a million in any year, and
14		• hydrogen sulphide levels attributable to plant operation will be below noticeable levels of 5 parts per billion.
	10.5.2	To continue to manage private water abstraction by:
15		• regularly reviewing the bulk allocations for private abstraction, as part of the total water abstraction allocation for the Jandakot PWSA, with regard to the sustainable yield of the superficial aquifer, including consideration of the environmental impacts of that abstraction,
16		• restricting the issuing of licences for private water abstraction to the limits set by the bulk allocations, for both the Jandakot PWSA in its entirety and the licensing sub-areas, and
17		• investigating and implementing efficient mechanisms for groundwater allocation.
18		• Conduct pump tests on Stage 2 wells and liaise will nearby private users of groundwater prior to commissioning to assess the impact of Stage 2 wells on private wells.
	10.5.3	To protect the groundwater resource by active participation in:

19		• the development of Environmental Protection Policies to protect groundwater,
20		• the review of Regional Plans proposed by the Department of Planning and Urban Development, Local Government Town Planning Schemes, and rezoning and development applications, and
21		• review of development submissions to EPA.
22	10.5.3	To work with the Department of Planning and Urban Development to prepare an integrated Land Use and Water Management Strategy for the Jandakot Mound.
23	10.5.4	To actively pursue programmes in both supply and demand management. This includes ongoing public information programmes and, where appropriate, regulation for design changes and regular reviews of pricing to conserve water. Improvements in the Authority's supply system will also be pursued.
24	10.5.5	To actively participate in integrated management of the Jandakot catchment.
25	10.5.5	To review the management criteria and strategies, with the agreement of the EPA, as knowledge of the Jandakot environment and its interaction with groundwater improves.
26	10.5.5	To review opportunities for reducing the radius of the buffer zone required around the treatment plant to achieve acceptable personal risk and hydrogen sulphide levels.
27	10.6.1	To monitor water levels in groundwater monitoring wells and North, Bibra, Yangebup, Kogolup, Thomsons, Forrestdale Lakes, The Spectacles and Twin Bartram Swamp, as well as some other small wetlands.
28	10.6.2	To monitor vegetation transects on a triennial basis to establish significant changes in the condition, floristics or structure of vegetation communities.
29	10.6.2	To continue to fund the research projects 10.6.3 listed in Appendix 2 for the duration of the studies.
30	10.6.2	To use aerial photographs on a triennial basis to detect habitat shifts in North, Bibra, Yangebup, Kogolup, Thomsons and Forrestdale Lakes.
31	10.6.3	To develop a fauna monitoring programme, prior to the commissioning of the Stage 2 Scheme, which will focus on: • waterbird species diversity and breeding success, and • number of families of aquatic invertebrate and at infrequent intervals, species richness.
32	10.6.4	To hold meetings at least annually with a Jandakot Consultative Committee which will be established in consultation with the EPA. This Committee will be informed on the scheme's operation and will provide feed-back to the Water Authority.
33	10.6.4	To continue to monitor community response as reported by the media and maintain the current practice of public accessibility of Water Authority officers. Upon request and adequate notice, officers will address community groups on issues associated with groundwater management.
34	10.7	After the commissioning of the Stage 2 Scheme, written reports to the EPA will consist of: • annual reports addressing compliance with the environmental protection criteria, and • triennial reports including, in addition to a review of compliance with the criteria, an evaluation of the effectiveness of the criteria in meeting the environmental protection objectives.
35	10.7	To advise the EPA immediately upon becoming aware that specific environmental protection criteria might be breached. Details of the actions taken to avoid such a breach of criteria, or in the event of a breach occurring, its consequences, will be reported to the EPA at the earliest feasible date.
36	9.5.1	Undertake a study of Banganup Lake, in conjunction with CALM and the University of WA, to establish management criteria and consider the effectiveness of artificial maintenance of water levels.
37	9.5.7	Undertake a study of Twin Bartram Swamp to consider the feasibility and effectiveness of artificial maintenance of water levels.

Table A12.2 Summary of the terrestrial, wetland and air criteria.

TERRESTRIAL

Design criteria

1 Wells should not be placed closer than 300 metres to natural non-degraded sumplands (seasonally inundated wetlands) and preferably not closer than 500 metres.

2 Drawdowns must not exceed 1 metre in areas of phreatophytic native vegetation.

3 Wells shall not be placed closer than 200 metres to System Six area (M94) and preferably not closer than 400 metres as a design criterion.

Action and Operational criteria

4 Any well whose drawdown cone is estimated to be greater than 1.5 metres deep in environmentally sensitive areas will have its draw phased in evenly over a three year period.

5 Actual drawdowns should be less than 1 metre in areas of phreatophytic native vegetation and in no case shall exceed 1.5 metres.

6 In areas where rare species of orchids are known to occur, drawdowns should be less than 0.5 metres and must be less than 1.0 metres.

7 The Bartram Road Wetland Complex and Twin Bartram Swamp should preferably contain water until the end of January.

8 Water table drawdown in Beenyup Road Wetland and Solomon Road Wetland should preferably be less than 0.3 metres.

THOMSONS AND FORRESTDALE LAKES

Thomsons Lake

Design criteria

9 water levels in Thomsons Lake must satisfy those given in Table 7.2 for at least 30% of years (i.e. be an improvement on the present situation).

Operational and Action criteria

10 The average annual deviation over a four year period from the predicted water levels in Thomsons Lake must not be greater than 0.1 metres.

11 Should the deviation between the actual and predicted minimum water level in Thomsons Lake exceed 0.25 metres in any one year, this must be reported to the EPA as soon as possible, and

12 The minimum water level at Thomsons Lake must never go below 10.8 metres AHD.

Forrestdale Lake

13 At least 0.9 metre of water in the lake when water levels are at their annual maximum (the deepest point is at 21.6 metres AHD), and

14 A natural cycle of filling and drying should be allowed to continue.

15 Minimum water levels should be in the range 21.2 - 21.6 metres AHD,

16 Minimum water levels shall be greater than 21.1 metres AHD,

17 The preferred times of (earliest) drying are:

WET YEARS	dry by April
MEDIUM YEARS	dry by February-March
DRY YEARS	dry by January.

MAJOR WETLANDS

18 The recommended water level maxima, operational minima and action minima for the major wetlands are:

	RECOMMENDED MAXIMA	OPERATIONAL MINIMA	ACTION MINIMA
North	< 14.9	13.0-13.5	12.7
Bibra	< 15.0	13.6-14.2	13.6
Yangebup	< 16.5	13.9-15.5	13.8
Kogolup	< 14.8	13.1-14.0	13.1
Banganup		11.5	

THE WETLAND SYSTEM

19 The maximum allowable habitat reductions (as percentages in area) for the Jandakot Area (Thomsons Lake excluded) are:

HABITAT TYPE	WET YEAR	MEDIUM YEAR	DRY YEAR
I	5	10	15
II	8	13	18
III	12	17	22
IV	15	20	25

20 Increases of habitat shall be no more than 5% greater than the values given in the above table.

21 Bibra Lake must not dry out for more than 2 years in any 3 year period, and preferably not more than 1 in 3.

22 Either Bibra Lake or Yangebup Lake must contain 0.3 metre of water and preferably 0.5 metre.

AIR QUALITY

Chlorine

23 A buffer zone be maintained around the chlorine storage area of the treatment plant, and

24 The treatment plant and chlorine handling be operated in the manner described in section 4, resulting in a level of personal risk of fatality of no greater than one in a million in any year at the buffer zone boundary.

Hydrogen sulphide

25 A buffer zone be established with the distance defined by an anticipated hydrogen sulphide concentration of 5 parts per billion averaged over 30 minutes, as calculated for atmospheric conditions of Parquille class F and 2 metre per second wind velocity.