East Gnangara Environmental Water Provisions Plan

GOVERNMENT OF WESTERN AUSTRALIA

Public Environmental Review

Water and Rivers Commission

1997

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East Gnangara Environmental Water Provision Plan Public Environmental Review

Water and Rivers Commission
Policy and Planning Division

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Invitation to comment

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

The Public Environmental Review proposes groundwater allocations between the environment, a proposed public water supply scheme and private users.

In accordance with the Environmental Protection Act, a Public Environmental Review has been prepared which describes the proposal and its likely effect on the environment.

The Public Environmental Review is available for public review for up to 8 weeks from **27 October 1997,** closing on **22 December 1997**.

Comments from government agencies and from the public will assist the EPA to prepare an assessment report in which it will make recommendations to 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 an alternative approach. It is useful if you indicate any suggestions you have to improve the proposal.

All submissions received by the EPA will be acknowledged. Submissions will be treated as public documents unless provided and received in confidence subject to the requirements of the Freedom of Information Act, and may be quoted in full or in part in each report.

Why not join a group?
If you prefer not to write your own comments, it may be worthwhile joining with a group or other groups interested in making a submission on similar issues. Joint submissions may help to reduce the workload for an individual or group, as well as increase the pool of ideas and information. If you form a small group (up to 10 people) please indicate all the names of the participants. If your group is larger, please indicate how may people your submission represents.

Developing a submission
You may agree or disagree with, or comment on, the general issues, discussed in the plan or the specific proposals. It helps if you give reasons for your conclusions, supported by relevant data. You may make an important contribution by suggesting ways to make the proposal more environmentally acceptable.

When making comments on specific proposals in the plan:
- clearly state your point of view;
- indicate the source of information or argument if this is applicable;
- 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 issues raised are clear. A summary of your submission is helpful;
- refer each point to the appropriate section, chapter or recommendations;
- if you discuss different sections of the document, keep them distinct and separate, so there is no confusion as to which section you are considering;
- attach factual information you may wish to provide and give details of the source. Make sure your information is accurate.

Remember to include:

your name
address
date; and
whether you want your submission to be confidential.

The closing date for submissions is **22 December 1997**:

Submissions should be addressed to:

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Sharon Stratico	Water and Rivers Commission (Executive Officer)

Many other people who contributed to this project are also acknowledged

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Executive Summary

The East Gnangara Environmental Water Provisions Public Environmental Review has been produced by the Water and Rivers Commission and provides an overall approach to the management of groundwater allocations on the eastern side of the Gnangara Mound. The Public Environmental Review (PER) serves two main purposes.

1. It enables the Environmental Protection Authority (EPA) to assess the proposal and provide advice to the Minister for the Environment. The Minister then makes judgement on the environmental acceptability of the proposal.

2. It provides the public with detailed information about the proposal and the opportunity to comment. These comments give feedback to the Water and Rivers Commission on whether the needs of the environment, private and public users of water have been satisfactorily balanced to meet community expectations.

The Water and Rivers Commission has the role of managing the State's water resources. Its mission is to manage water resources for the benefit of future generations in partnership with the community.

Management of groundwater on the East Gnangara Mound aims to:

- ensure that environmental features are conserved;
- enable the development of a public water supply scheme for the north-east corridor; and
- provide groundwater for private users.

The study area for the Plan is shown in Figure A (see page xi).

The full scope and objectives of this Environmental Water Provisions Plan are to:

- identify the ecosystem components of the environment in the area which are considered to have the highest environmental and social values, are representative and are impacted by groundwater abstraction;
- determine Environmental Water Requirements (EWRs) for each ecosystem component;
- identify preferred public and private groundwater abstraction;
- conduct computer modelling to determine changes in water levels that are likely to result from proposed groundwater abstraction and other landuse activity; and to optimise well locations to minimise water level impacts;
- compare the predicted changes in water levels to EWRs to determine if conflicts are likely to result;
- propose management and mitigation strategies where necessary to protect the environment and propose Environmental Water Provisions (EWPs) (i.e. criteria in the form of water levels to define what is actually allocated to the environment);
- determine the quantity of water available for consumptive uses and allocate between the public and private users; and
- establish an ongoing management and monitoring programme for the area.

The East Gnangara environment and environmental criteria

There are three components of the environment which are dependent on groundwater within the study area. These are wetlands, springs/seepages and phreatophytic vegetation (vegetation which obtains water supply from roots in or near the water table). The East Gnangara Plan identifies a selection of wetlands and seepage areas for which environmental criteria have been determined. It also sets criteria in areas of native phreatophytic vegetation.

The selection of wetlands was based on environmental and social values such as:

- the EPA evaluation category;
- protection under the Swan Coastal Plain Lakes Environmental Protection Policy;

- System 6 identification;
- whether in existing/proposed nature reserves;
- recognition in other studies;
- national and international significance;
- aboriginal significance;
- representativeness of wetlands in the area; and
- the wetlands potential to be impacted by groundwater abstraction.

Springs and seepages were also selected based on their environmental and social values, in particular; vegetation and fauna, recognition by local people and others, and the potential to be impacted by groundwater abstraction.

To set environmental criteria in areas of native vegetation, a number of monitoring wells were selected in areas of intact native vegetation with a depth of 0 - 8 m to groundwater, and minimum water level requirements determined for each well.

Environmental criteria are presented in the form of Environmental Water Requirements (EWRs) and Environmental Water Provisions (EWPs). An Envrionmental Water Requirement (EWR) is the water regime required by the environment to maintain ecological values in their current state. EWRs include elements of quantity and duration and applies both spatially and temporally. An Environmental Water Provision (EWP) is that part of the EWR which can be met. The environment is given a high priority in the water allocation process and wherever possible the EWP is set equal to the EWR. However where social and economic requirements for water are found to conflict with environmental requirements and are considered to be of a higher value than meeting the full EWR, then the EWP will be set lower than the EWR. If the EWP is less than the EWR there will be some change to current environmental values. EWRs and EWPs are expressed as water table heights in wetlands and monitoring wells.

EWRs for wetlands and seepages were determined by identifying wetland characteristics and then identifying the wetland values (environmental and social) to set management objectives which reflect those values. A water level regime consistent with the management objectives has been determined.

An appropriate EWP is proposed after comparison of EWRs with groundwater abstraction impacts and consideration of the relative importance of environmental and social requirements for the water.

EWRs are criteria based on current scientific knowledge and should be updated as knowledge increases. Therefore EWRs will be reviewed on a regular basis and updated as further scientific research improves our understanding of water requirements of vegetation and fauna supported by wetlands and groundwater.

Figure B (see page xii) highlights all the points where environmental criteria have been determined and Tables A-C summarise the EWRs for each.

Table A. Environmental Water Requirements - terrestrial vegetation

Well	EWR
Melaleuca Park	
WM6	58.8 mAHD
WM8	65 mAHD
NR6C	58.5 mAHD
WM2	67 mAHD
NR11C	55 mAHD
Whiteman Park	
MM49B	24.7 mAHD
MM53	33.3 mAHD
MM55B	29.5 mAHD
MM18	38.6 mAHD
MM59B	36.3 mAHD
Native vegetation corridor	
MM12	43 mAHD
L30C	47.5 mAHD
L110C	57 mAHD
L220C	52.5 mAHD

mAHD = metres Australian Height Datum.

Table B. Interim Environmental Water Requirements for wetlands

Wetland	Management Objective	Interim Environmental Water Requirement	
		Minimum *	Absolute minimum
Lexia wetland 1 (94)	• Protect current vegetation assemblages.	1.5 m below ground (45.8 mAHD - well GNM17A)	1.8 m below ground (45.5 mAHD - well GNM17A)
Lexia wetland 2 (86)	• Protect current vegetation assemblages in and fringing the wetland. • Protect aquatic invertebrate fauna.	1m below ground (47.3 mAHD - well GNM16)	1.3 m below ground (47 mAHD - well GNM16)
Lexia wetland 3 (186)	• Protect current vegetation assemblages in and fringing the wetland. • Protect aquatic invertebrate fauna.	0.8 m below ground (47.5 mAHD)	1.1m below ground (47.2 mAHD)
EPP wetland 173	• Maintain existing areas of wetland and stream and the vegetation they support. • Protect invertebrate communities dependent on the wetland and stream. • Protect the fish, *Galaxiella nigrostriata*	0.1 m above ground (in the western sector)	
Dampland 78	• Maintain existing areas of wetland vegetation.	5.5 m below ground (65.4 mAHD - well GNM13)	5.8 m below ground (65.1 mAHD - well GNM13)

** Water levels can be below the minimum level at a rate of 2 in 6 years but should not fall below the absolute minimum level.*

Table C. Interim Environmental Water Requirements for seepages

Seepage	EWR in seepage	Minimum water level requirement in upstream bore B 10 (interim)	Minimum water level requirement in upstream bore B 25 (interim)
Edgecombe seepage	Permanent water flow	14.35 mAHD *	
Egerton seepage	Permanent water flow		39.29 mAHD

** Recommendation for management. The Water and Rivers Commission does not accept total responsibility for achieving the requirement given that removal of existing irrigation and urbanisation will have a greater influence than groundwater abstraction on the water level upstream of the seepage.*

Proposed groundwater abstraction

Public abstraction

Groundwater has been identified as an important component of Perth's future water supply. *Perth's Water Future Study* (WAWA, 1995) investigated many broad-ranging options for meeting the water requirements of Perth's growing population. The study concluded that 86 per cent of additional water supply to 2010 is likely to come from groundwater. Groundwater schemes were found to be the best alternative minimising environmental, social and economic costs (WAWA, 1995). Lexia and East Mirrabooka Stage 3 are schemes proposed to supply water to Perth's north-east corridor.

The proposed Lexia groundwater scheme consists of eleven Lexia superficial wells and one Mirrabooka Sands well and the East Mirrabooka Stage 3 scheme consists of two superficial wells. This provides a total quota of 11 x 10^6 kL/yr. Figure C (see page xiii) shows the scheme layout and Table D the breakdown of production well quotas.

Private abstraction

Private demand for groundwater on the East Gnangara Mound falls within two Groundwater Areas, the Swan Groundwater Area and the Mirrabooka Groundwater Area. The locations with sub-area boundaries are illustrated in Figure D (see page xiv). Sources of demand for groundwater are mainly for rural purposes with viticulture being dominant. There are requirements for the production of fodder crops, domestic and stock purposes. Other types of use include irrigation for parks and gardens and industrial use. Proposed private quotas are shown in Table E.

Impacts of the preferred abstraction and land-use scenario

The proposed public and private allocations were combined with other land-uses in the study area and a computer model was used to simulate the effects of future changes on groundwater levels to determine potential impacts on environmental areas. The land-use changes (in addition to public and private abstraction) included in the model were:

- the management of pine plantation to achieve an average basal density of 11m^2/ha; and
- full urbanisation of Ellenbrook and Egerton.

An average climate was also incorporated into the model. The impacts of the preferred abstraction and landuse scenario are illustrated in Figure E (see page xv) in the form of a contour plot. The predicted impacts in environmental criteria areas are:

- 0.25 m drawdown in the western Lexia wetlands;
- 0.25 m drawdown in dampland 78, Melaleuca Park;
- 0.5 m drawdown in the north of Whiteman Park;
- 0.5 - 2 m drawdown in the vegetation corridor; and
- minimal impact on the Egerton and Edgecombe seepages, the EPP wetland 173 in Melaleuca Park and in the remainder of Melaleuca Park.

These impacts have been compared to EWRs to determine their acceptability. The outcome is a set of EWPs. Where the EWRs were considered important to maintain and/or abstraction impacts did not interfere

Table D. Proposed public groundwater abstraction

Well Type	Abstraction	Number of wells	Total
Lexia - superficial	0.7 x 10^6kL/yr 1 x 10^6kL/yr 0.95 x 10^6kL/yr 0.9 x 10^6kL/yr	5 (L420, L620, L510, L430, L710) 4 (L700, L600, L500, L400) 1 (L490) 1 (L410)	3.5 x 10^6kL/yr 4 x 10^6kL/yr 0.95 x 10^6kL/yr 0.9 x 10^6 kL/yr
Lexia - semi-confined	0.45 x 10^6kL/yr	1 (L12)	0.45 x 10^6kL/yr
East Mirrabooka	0.6 x 10^6kL/yr	2 (M380, M390)	1.2 x 10^6kL/yr
Total		14	11 x 10^6kL/yr

Table E. Private groundwater sub-area allocations

Sub Area	Superficial/ Mirrabooka Sands Allocation Quota (kL x 10^6)		Unallocated availability (kL/yr x 10^6) (at November 1996)	
	Superficial	Mirrabooka	Superficial	Mirrabooka
Beechboro	1.0		0.556	0
Whiteman Park	1.3		1.019	0
Henley Brook	0.2		0.049	0
Ballajura	2.086		0	0
IP8	3		2.924	0
Landsdale	1.6		0	0
Plantation	0.7		0.097	0
State Forest	0.964	0	0	0
North Swan	3.3	0.25	0.3	0
South Swan	4.25	1.6	0.33	0.5
Neaves	3.8	0.5	0.588	0.5
Radar	3.4	1.2	2	1.147
Central Swan	1.7	0	0.024	0
East Swan	no limit set	no limit set		
Cockman Bluff	1.9		1.232	
Bandy springs	no limit set	no limit set		

with EWRs then the EWP is set equal to the EWR. Where proposed abstraction and the EWRs conflict the approach included both reducing abstraction and setting the EWP less than the EWR. The EWP is set lower than the EWR where groundwater supply to the north-east corridor is considered to have a higher priority than identified environmental values. For example in the native vegetation corridor.

Environmental Water Provisions

EWPs are summarised in Table F. The EWPs are criteria which must always be met. If necessary production wells will be turned off in dry periods to ensure EWPs are maintained. Table F gives an indication of how often production wells in the vicinity may need to be turned off.

EWPs have not been determined for wetlands at this stage as EWRs for the wetlands have not been finalised due to a lack of information on perching of the wetlands (and therefore degree of dependence on groundwater levels).

Although EWPs have not been determined for wetlands at this stage, the impacts on each wetland have been analysed using the groundwater contour outputs in comparison with interim EWRs (and assuming full dependence on groundwater). The impacts are minimal and the interim EWRs can be met. That is, drawdowns are within the regime that will maintain current wetland values even if the wetlands are found not to be perched.

The EWP has been set equal to the EWR in the Egerton seepage.

EWPs are lower than EWRs in Melaleuca Park as a result of predicted climatic impacts in the future. The EWR cannot be achieved even with no further groundwater abstraction. EWPs are set equal to EWRs in Whiteman Park as there should be no further impact on Whiteman Park from groundwater abstraction given the tree deaths which occurred in 1991. This is likely to mean that bores in Whiteman Park will not be operated at their design capacity at all times and some will need to be switched off when water levels in the Park are low. The EWPs in Melaleuca Park and

Table F. Environmental Water Provisions

Monitoring well	EWRs (mAHD)	EWPs (minimum level mAHD)	predicted % of years of years intervention required to ensure compliance with EWP
Melaleuca Park			
WM6	58.8	58.3	3
WM8	65	64.8	8
WM2	67	66.5	0
NR6C	58.5	58.5	0
NR11C	55	55	0
Whiteman Park			
MM18	38.6	38.6	0
MM59B	36.3	36.3	13
MM53	33.3	33.3	0
MM49B	24.7	24.7	0
MM55B	29.5	29.5	12
Vegetation corridor			
MM12	43	42	0
L30C	47.5	47.2	11
L110C	57	55.7	*
L220C	52.5	52.2	0
Egerton seepage			
B25	39.29	39.29	*

** model unable to predict absolute water levels due to complex hydrogeology.*

Whiteman Park have previously been approved through the Environmental Protection Authority's assessment of the *Gnangara Mound Groundwater Resources - Review of Proposed Changes to Environmental Conditions* (WAWA, 1995a).

EWPs are proposed to be lower than EWRs in the native vegetation corridor. The result will be a gradual loss of some mature banksia trees and their replacement by more drought tolerant seedlings. This type of gradual change to a drier community structure is considered an acceptable trade-off for a public water supply for the north-east corridor considering:

- The current status of the land. The land is set aside for basic raw materials in the North-East Corridor Structure Plan (DPUD, 1994) and a mining lease currently exists over the majority of the corridor. Therefore significant areas of vegetation are likely to be cleared over the next few years; and
- The scheme layout has been optimised, with abstraction reduced from that initially proposed by the Water Corporation to minimise impacts on the vegetation corridor. To meet EWRs in the vegetation corridor, abstraction would require further reduction. This could make the scheme unviable.

Management commitments

The Water and Rivers Commission has made a number of commitments which relate to the management and monitoring of groundwater levels on the East Gnangara Mound. The commitments relate to meeting the EWPs proposed in the document and monitoring to ensure that EWPs achieve the desired environmental protection objective.

The Water and Rivers Commission will report annually and submit more detailed triennial reports on the results of management and monitoring to the EPA. The Water consultative committee consisting of representatives from community interest groups and government agencies. Other commitments relate to conducting further research, providing advice and co-operating with other agencies in relation to water resource management.

The Water and Rivers Commission will license the Water Corporation's abstraction to ensure that its operating strategy will allow for compliance with the EWPs and enable directions to be given to adjust abstraction when there is a danger of non-compliance.

Water and Rivers Commission commitments

1.The Water and Rivers Commission will manage public and private groundwater abstraction to meet the water regime management objectives and Environmental Water Provisions summarised in Table G.

2. The Water and Rivers Commission will report on the management and monitoring of the East Gnangara Mound to the EPA as part of existing reporting for the Gnangara Mound. Triennial reports will include information on the operation of groundwater schemes by the Water Corporation and private groundwater use, compliance with EWPs and environmental conditions and outline any environmental impacts. Annual reports will provide information on compliance with environmental conditions.

3. The Water and Rivers Commission will investigate stratigraphy and water regimes in the Lexia wetlands, EPP wetland 173 and dampland 78 in Melaleuca Park. For wetlands displaying characteristics of perching the importance of groundwater to wetland water levels will be established and EWRs updated for the first triennial report to the EPA. EWPs will also be determined at this time.

4.The Water and Rivers Commission will support further research and investigations into EWRs of wetlands, vegetation and seepage areas as defined in Section 16.5 of the East Gnangara Environmental Water Provisions Plan.

5. EWPs will be reviewed every six years in triennial reports or as necessary. Feedback, through the monitoring programme, of any impacts of groundwater abstraction will be used to update EWPs and water allocations if necessary. Any update will involve consultation with the EPA and incorporate public involvement.

6.The Water and Rivers Commission will, after receiving environmental approvals, implement and undertake the following monitoring programme to the satisfaction of the EPA.

6.1 Continue monitoring the network of bores on the East Gnangara Mound, at a frequency of 1 - 3 monthly, depending on the well.

6.2 Monitor water levels in terrestrial vegetation monitoring wells with EWPs monthly.

6.3 Develop three new terrestrial vegetation transects on the East Gnangara Mound: one in Melaleuca Park and two in the Ellenbrook bushland near the Lexia wetlands. The transects will be established in Spring 1996 and monitored every 3 - 6 years.

6.4 Recommence monitoring of the terrestrial vegetation transect (established by the Water Authority (WAWA) in 1991) in Whiteman Park, on a shared cost basis with the Whiteman Park Board of Management. Monitoring will recommence in Spring 1996.

6.5 Continue monitoring the terrestrial vegetation transect in Melaleuca Park, established in 1966, every 3 - 6 years.

6.6 Select a range of species which provide an indication of vegetation composition at each of the terrestrial vegetation transects. The indicator species will be monitored in Spring every 3 - 6 years to assess any change towards a drier community. Parameters that will be assessed include: age (size), class distribution, vigour and recruitment.

6.7 Calculate a similarity index for each transect at each monitoring period with the aim of summarising spatial and temporal changes in vegetation composition.

6.8 Determine an 'acceptable' rate of change in vegetation composition for each terrestrial vegetation transect on the East Gnangara Mound. Rates of change will be measured using indicator species and similarity indices.

6.9 Monitor water levels once a month in wetlands and/or nearby monitoring wells for the following wetlands (see Figure B):

- Lexia wetland 94;
- Lexia wetland 186;
- Lexia wetland 86;
- Melaleuca Park Dampland 78;
- EPP wetland 173; and
- Lake Yakine (located east of Edgecombe seepage).

6.10 Develop vegetation transects in each of the wetlands listed in section 6.9 (with the exception of Lake Yakine). Monitoring will be undertaken in Spring of the first three years and reviewed in the first triennial report.

6.11 Conduct baseline monitoring on aquatic invertebrates and water quality in the Lexia wetlands in Spring 1996. Findings will be published in the first annual report.

6.12 Monitor aquatic invertebrate fauna and water quality in the wetlands (see Point 6.9) which contain open water in Spring each year.

6.13 Map wetland habitats along a regional transect in Melaleuca Park using large scale aerial photography in Spring of the first three years, then every following three years.

6.14 Monitor water levels in the Egerton and Edgecombe seepages and upstream of the seepages on a monthly basis (once access is granted).

6.15 Providing access is granted, conduct baseline monitoring of aquatic invertebrate fauna and water quality in the Egerton seepage. Results will be provided in the first triennial report.

6.16 Monitor aquatic invertebrate fauna and water quality in the Egerton and Edgecombe seepages annually in Spring (once access is granted).

6.17 Monitor water levels in wells with EWPs more frequently than once a month where necessary to determine compliance with EWPs.

7. By June 1998 the Water and Rivers Commission and the Department of Conservation and Land Management (CALM) will develop a Memorandum of Understanding (MOU) on pine management regimes in State Forest 65 which recognises the dual use of forests and optimises water and timber production, while minimising environmental impacts. The MOU will include agreements associated with the removal of the pine plantation over the next 20 years and the proposed establishment of Gnangara Park. In the process of developing the MOU, further modelling studies will investigate the impact of the various scenarios of pine removal on water tables. This will consider how the 'extra water' could be 'allocated' between consumptive and ecosystem protection uses.

8. The Water and Rivers Commission will provide advice on the impact of land-uses on groundwater resources of the Gnangara Mound to relevant agencies.

9. The Water and Rivers Commission will determine Environmental Water Provisions for new wells in the native vegetation corridor which have been installed at more appropriate places to replace wells MM12, L30C, L110C and L220C when sufficient monitoring data from the new wells is available.

10. The Water and Rivers Commission will continue to chair and to provide support for a Consultative Committee as a forum of information exchange and provide advice to the Water and Rivers Commission in relation to management of water on the Gnangara Mound. Some representatives from each of the East Gnangara and Gnangara Committees will be combined to form one Consultative Committee for the Gnangara Mound.

11. The Water and Rivers Commission will request that the Water Corporation, through licence conditions, phase in the production wells closest to phreatophytic vegetation to allow the vegetation to adapt slowly to the drawdown and minimise the overall impacts of drawdown.

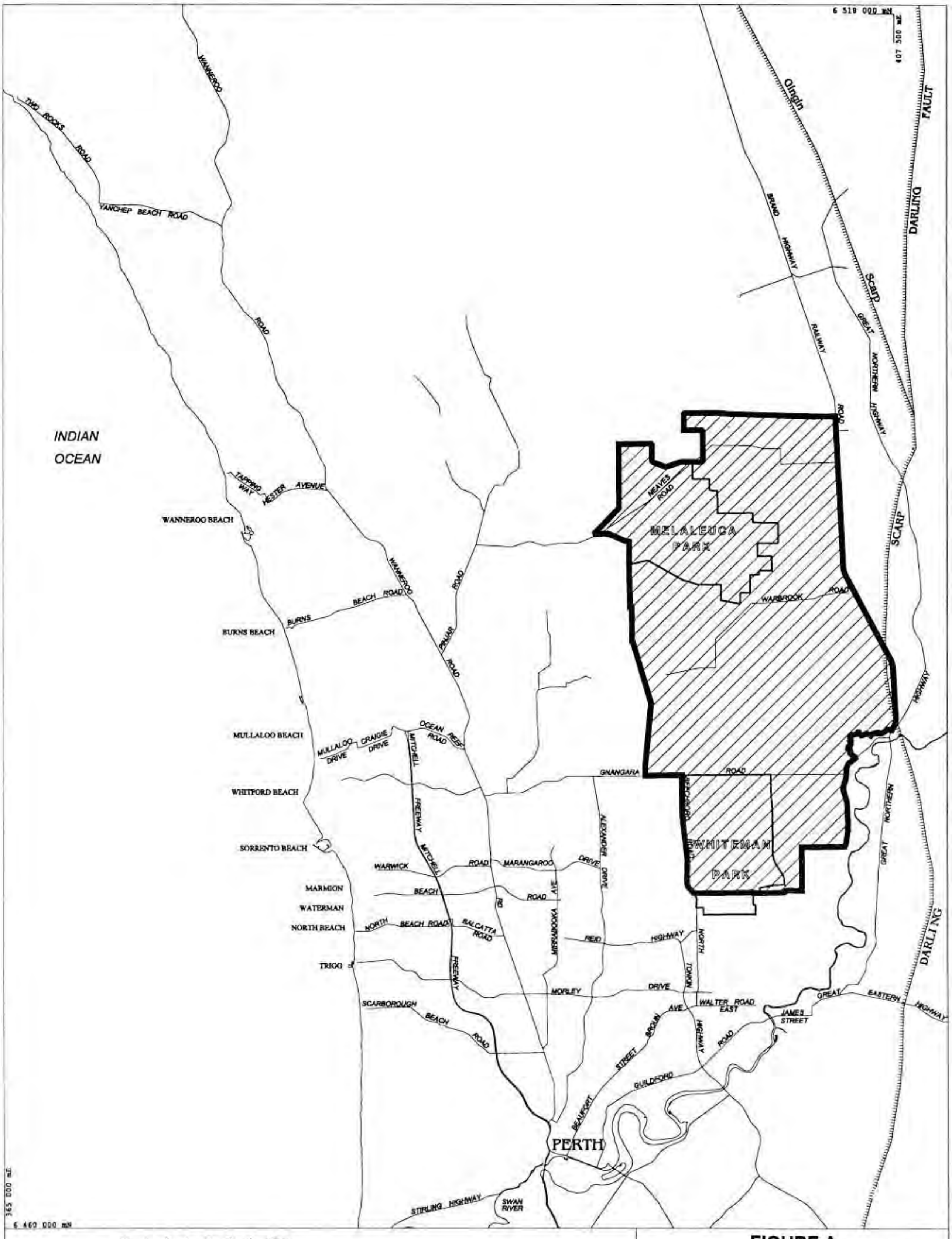
12. The Water and Rivers Commission will liaise with the Department of Environmental Protection (DEP), CALM and the Water Corporation with regards to an appropriate wetland mitigation strategy for the *Melaleuca rhaphiophylla* wetland in the pine plantation. The Water and Rivers Commission will then request that the Water Corporation, through licenceconditions, to implement the proposed strategy.

13. The Water and Rivers Commission will within six months of receiving environmental approval, require that the Water Corporation, through licence conditions, to update its operations plan to include the Lexia and East Mirrabooka groundwater schemes. This will include environmental management of the schemes and details of how abstraction will be managed to meet EWPs. As part of the operating strategy the Water Corporation will be required to submit annual production plans.

Table G. Environmental criteria

WELL	LOCATION	ENVIRONMENTAL WATER PROVISIONS (EWPs)		
		Management Objective	**Minimum water level (mAHD)**	**Absolute minimum water level (mAHD)**
WM6	Melaleuca Park	Protect native vegetation from any further groundwater abstraction impacts	58.3	*
WM8	Melaleuca Park	Protect native vegetation from any further groundwater abstraction impacts	64.8	*
NR6C	Melaleuca Park	Protect native vegetation from any further groundwater abstraction impacts	58.5	*
WM2	Melaleuca Park	Protect native vegetation from any further groundwater abstraction impacts	66.5	*
NR11C	Melaleuca Park	Protect native vegetation from any further groundwater abstraction impacts	55	*
MM49B	Whiteman Park	Protect native vegetation from any further groundwater abstraction impacts	24.7	*
MM53	Whiteman Park	Protect native vegetation from any further groundwater abstraction impacts	33.3	*
MM55B	Whiteman Park	Protect native vegetation from any further groundwater abstraction impacts	29.5	*
MM18	Whiteman Park	Protect native vegetation from any further groundwater abstraction impacts	38.6	*
MM59B	Whiteman Park	Protect native vegetation from any further groundwater abstraction impacts	36.3	*
MM12	Native vegetation	Protect native vegetation but allow a slow change to a drier community structure	42	*
L30C	Native vegetation	Protect native vegetation but allow a slow change to a drier community structure	47.2	*
L110C	Native vegetation	Protect native vegetation but allow a slow change to a drier community structure	55.7	*
L220C	Native vegetation	Protect native vegetation but allow a slow change to a drier community structure	52.2	*
GNM13	Dampland 78 - Melaleuca Park	Maintain existing areas of wetland vegetation	**	**
GNM14	EPP 173 - Melaleuca Park	* Maintain existing areas of wetland and stream * Maintain existing areas of wetland vegetation * Protect invertebrate communities dependent on the wetland and stream * Protect the fish, *Galaxiella nigrostriata*	**	**
GNM15	Lexia wetland 186	* Protect current vegetation assemblages in and fringing the wetland * Protect any aquatic invertebrate fauna dependent on the wetland	**	**
GNM16	Lexia wetland 86	* Protect current vegetation assemblages in and fringing the wetland * Protect any aquatic invertebrate fauna dependent on the wetland	**	**
GNM17A	Lexia wetland 94	Protect current vegetation assemblages in the wetland	**	**
B10	Edgecombe seepage	Maintain a permanent flow of water in the seepage	14.35 ***	*
B25	Egerton seepage	Maintain a permanent flow of water in the seepage	39.29 ****	*

** not applicable, ** to be determined, *** recommendation for management only, **** cannot be monitored until access to the land is granted.*



WATER AND RIVERS COMMISSION

LEGEND: Study Area

FIGURE A
EAST GNANGARA MOUND
Study Area

Drawn by	D.R.A	Date	10/02/96

Catchment and Waterways Management Branch

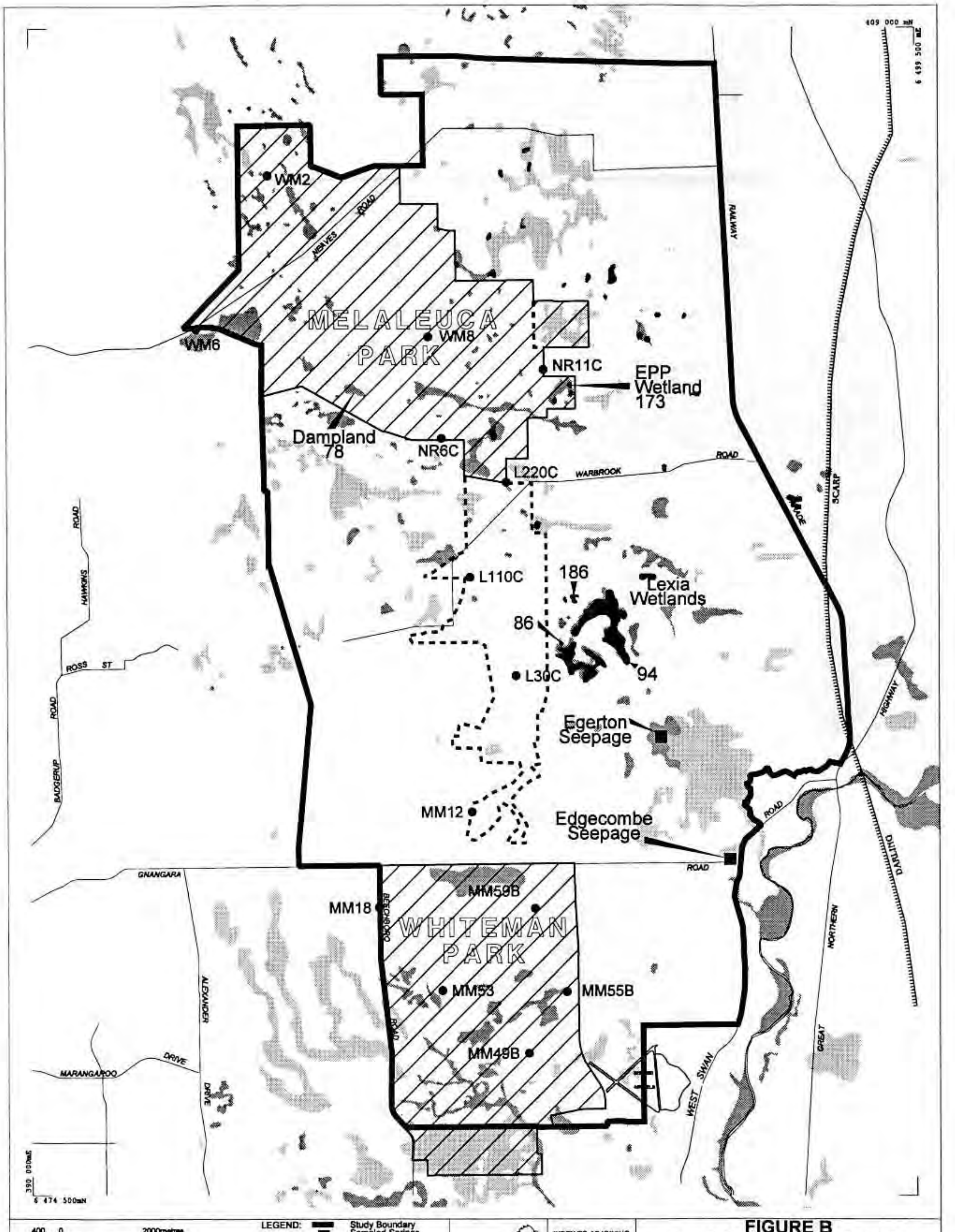
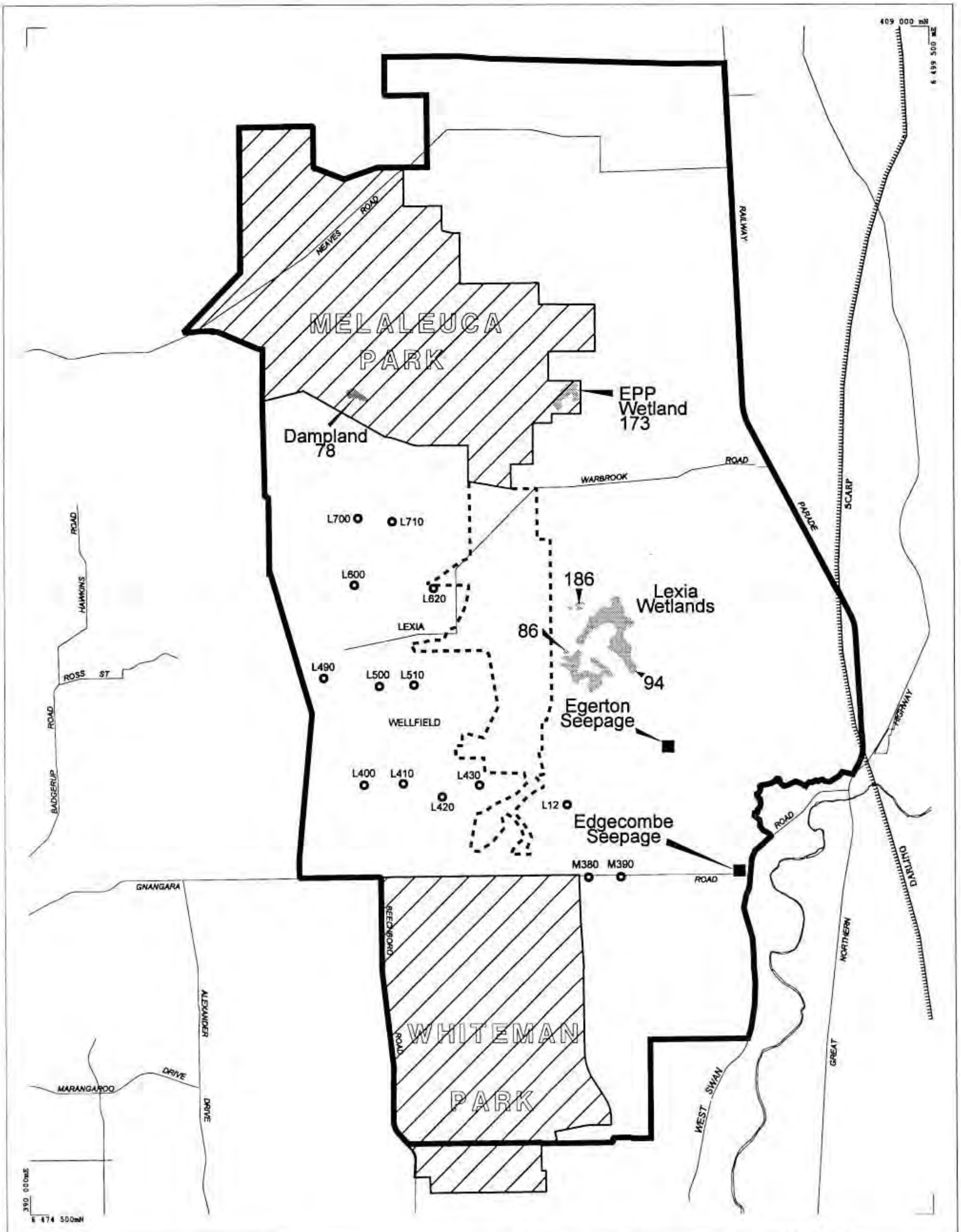


FIGURE B
EAST GNANGARA MOUND.
Areas selected for Environmental Water Requirements

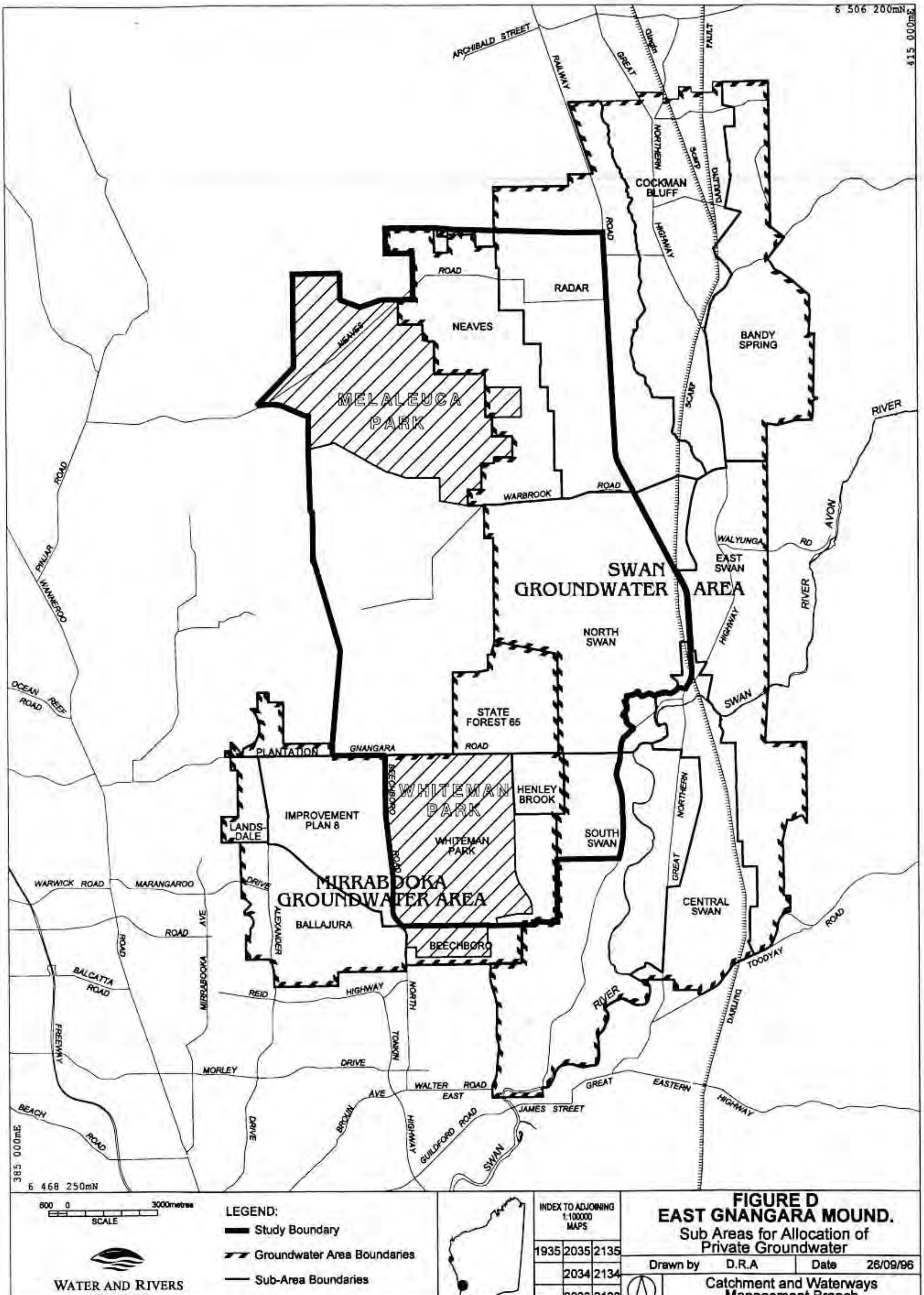
Drawn by	D.R.A	Date	09/09/96

Catchment and Waterways Management Branch

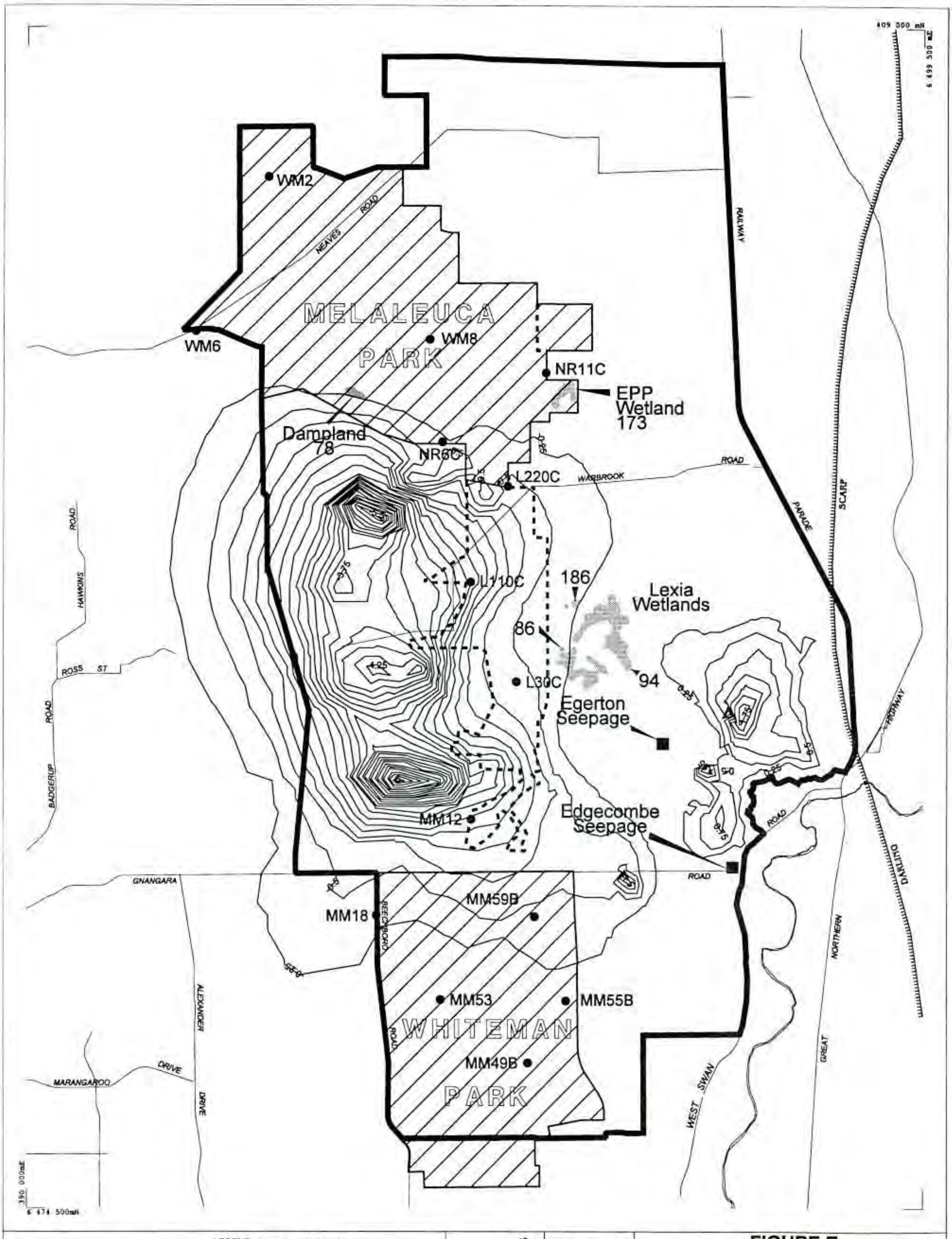


SCALE 400 0 2000metres	LEGEND: Study Area; Vegetation Corridor connecting Melaleuca Park & Lexia Wetlands; 78,86,94 173,186 Criteria Wetlands; Springs/Seepages; L400 Proposed Lexia and East Mirrabooka Wellfields	INDEX TO ADJOINING 1:100000 MAPS: 1935 2035 2135 / 2034 2134 / 2033 2133	FIGURE C EAST GNANGARA MOUND. Proposed Well Layout. Drawn by D.R.A Date 09/09/96. Catchment and Waterways Management Branch

WATER AND RIVERS COMMISSION



ARCHIBALD STREET
RAILWAY
GREAT
NORTHERN
HIGHWAY
ROAD
SCARP
FAULT
DARLING
COCKMAN BLUFF
RADAR
NEAVES
BANDY SPRING
MELALEUCA PARK
WARBROOK
ROAD
WALYUNGA
EAST SWAN
SWAN GROUNDWATER AREA
NORTH SWAN
STATE FOREST 65
GNANGARA
PLANTATION
WHITEMAN PARK
HENLEY BROOK
IMPROVEMENT PLAN 8
LANDS-DALE
SOUTH SWAN
MIRRABOOKA GROUNDWATER AREA
BALLAJURA
BEECHBORO
CENTRAL SWAN
WARWICK ROAD
MARANGAROO
ALEXANDER DRIVE
REID HIGHWAY
NORTH TONKIN HIGHWAY
MORLEY DRIVE
WALTER ROAD EAST
JAMES STREET
GREAT EASTERN HIGHWAY
GUILDFORD ROAD
BROUN AVE
SWAN RIVER
AVON RIVER
TOODYAY ROAD
PINJAR
WANNEROO
OCEAN REEF ROAD
BALCATTA ROAD
FREEWAY
BEACH ROAD
6 506 200mN
415 000mE
385 000mE
6 468 250mN
500 0 3000metres
SCALE
LEGEND:
Study Boundary
Groundwater Area Boundaries
Sub-Area Boundaries
WATER AND RIVERS COMMISSION
INDEX TO ADJOINING 1:100000 MAPS
1935 2035 2135
2034 2134
2033 2133
FIGURE D
EAST GNANGARA MOUND.
Sub Areas for Allocation of Private Groundwater
Drawn by D.R.A
Date 26/09/96
Catchment and Waterways Management Branch



400 0 2000metres SCALE	LEGEND:	
	———	Study Area
	1.25	Water Level Difference Contour from 1992 Baseline Levels
	– – –	Vegetation Corridor connecting Melaleuca Park & Lexia Wetlands
	78,86,94 173,186	Criteria Wetlands
	■	Springs/Seepages
WATER AND RIVERS COMMISSION	MM49B ●	Monitoring Well with Criteria

INDEX TO ADJOINING 1:100000 MAPS

1935	2035	2135
	2034	2134
	2033	2133

FIGURE E
EAST GNANGARA MOUND.
Impact of Preferred Abstraction and and Land-use Scenario

Drawn by	D.R.A	Date	20/08/97

Catchment and Waterways Management Branch

1. Introduction

The East Gnangara Environmental Water Provisions Plan was initiated to determine and manage groundwater allocations on the eastern side of the Gnangara Mound. Groundwater management is important to ensure that environmental features in the area are conserved, to enable the development of the Lexia groundwater scheme and to allow provision of groundwater to private users.

The Gnangara Mound is a large source of fresh groundwater in the superficial formation north of Perth. It is bounded by; Gingin Brook and Moore River in the north, Ellen Brook in the east, the Swan River in the south, and the Indian Ocean to the west. This report is concerned only with part of the Gnangara Mound (the eastern edge). The study area for the project is described in Section 1.3 and illustrated in Figure 1.

The East Gnangara Mound supports a variety of important environmental features including wetlands, springs and seepages and native vegetation dependent on groundwater.

Private groundwater users also rely on water from the Gnangara Mound. They abstract groundwater for agricultural, recreational and domestic uses. The groundwater of the East Gnangara Mound will also become an important source for the proposed Lexia and East Mirrabooka Stage 3 public groundwater schemes to be operated by the Water Corporation.

This means that groundwater in the area will need to be managed in a sustainable manner to ensure optimal community benefit in terms of environmental values and consumptive uses.

As managers the State's water resources the Water and Rivers Commission has the responsibility of planning and managing the allocation, protection and use of these resources on a sustainable basis for the continuing benefit of the community, with regard to environmental and social considerations.

Before 1996, the Water Authority of Western Australia (WAWA) had the role of managing the State's water resources. WAWA also provided water related services to the community. In 1996 WAWA was restructured and these functions were separated. The Water Resources Division of WAWA joined the Waterways Commission and the Hydrogeology Section of the Department of Minerals and Energy to form the Water and Rivers Commission. The remainder of WAWA formed the Water Corporation whose role is to provide water related services to the State.

In providing water related services the Water Corporation requires water allocations to allow it to supply water for the community. The development of water supplies is carried out with the objective of minimising long term financial and environmental costs.

This document has been prepared by the Water and Rivers Commission. It is concerned with the planning and management of water allocations in East Gnangara. It focuses on how the groundwater will be allocated and managed to ensure that the environment is protected. In particular it describes the rationale, process and outcome of identifying Environmental Water Requirements (EWRs) and proposed Envrionmental Water Provisions (EWPs). The Environmental Protection Authority (EPA) will consider the proposed planning and management of groundwater allocations on the East Gnangara Mound through the setting of EWPs and make recommendations to the Minister for the Environment.

In addition to identifying EWPs, the document proposes allocations that will be available for the Water Corporation to abstract water for the Lexia scheme and East Mirrabooka Stage 3 scheme and also allocations that will be available for private users.

Section 15 deals with allocations between public water supply and private users and will not be assessed by the EPA. This is because it relates to the split of water available for consumptive use and the setting of groundwater quotas following the setting of environmental allocations (EWPs). It is the role of the Water and Rivers Commission to determine allocations.

The EPA will only assess the environmental allocations and the impacts of abstraction and its management. However, the Water and Rivers Commission considers the proposed allocations to be of interest to the community and that there should be an opportunity for public comment.

Approvals to construct the Lexia Groundwater Scheme and East Mirrabooka Scheme will be obtained separately by the Water Corporation after it is determined what allocation is available following the outcome of this EWPs Plan.

The objectives of this Public Environmental Review (PER) are to:

- determine EWRs for the environment dependent on groundwater from the East Gnangara Area;
- determine water allocations that will be available for the environment, private groundwater users and the Water Corporation's public water supply schemes on the East Gnangara Mound; and
- establish a management programme to minimise the impacts of groundwater abstraction on the environment and establish a monitoring programme to ensure management objectives are achieved in the long term.

1.1. Background

Significant development is currently occurring in the north-east corridor which requires the development of a water source in order to provide a public water supply to the new growth areas. The development of a local groundwater resource has been found to be the most cost effective method of meeting this requirement (WAWA, 1995c).

The Ellenbrook estate land is in the Shire of Swan approximately 20 km north-east of the Perth central business district. In 1992 a PER document was produced by the proponent, Ellenbrook Management Pty Ltd, for submission to the EPA. The document required environmental impact assessment before the land could be transferred from an 'urban deferred zoning' to an 'urban zoning'. The document has been assessed by the EPA (EPA, 1993b) and environmental approval was obtained from the Minister for the Environment on the provision that certain conditions were met. Conditions were initially set in October 1992. A change to conditions occurred and was finalised in 1993 (EPA, 1993b).

Following environmental approval, development of the Ellenbrook estate has recently commenced. It is intended that development will progress over a period of 15 years. The Ellenbrook estate urban development area was initially 1,797 ha (to accommodate 20,000 households with 58,000 people) (Feilman Planning Consultants, 1992). However 300 ha has now been withdrawn from development and another 240 ha will be reserved for conservation (EPA, 1993b).

The Egerton property which is adjacent to and east of the Ellenbrook estate will also become an 'urban estate' (see Figure 2). The Egerton Structure Plan was submitted to the EPA in early 1994 and environmental approval including ministerial conditions, were given by the Minister for the Environment in late 1994 (Minister for the Environment, 1994).

The Egerton property is 495 ha of which 395 ha will be converted to housing. There will be 3,650 lots which will house a population of 11,800 people (Alan Tingay and Associates, 1994).

Because of these developments and other North-East corridor growth, a long term water supply will be required in the Ellenbrook area in the near future. The Lexia groundwater scheme has been determined as the most economical method of providing this requirement. The rationale for the development of the Lexia groundwater scheme rather than other alternatives, is discussed in *Perth's Water Future Study* (WAWA, 1995c). The Lexia groundwater scheme will be located close to the area of demand which will save on the cost of transporting water from other areas through trunk mains.

In the short term, before the operation of the groundwater scheme, the Water Corporation will supply new lots in the Ellenbrook subdivision from the Greenmount Reservoir via a pipeline to an on-site tank. Developer projections are that the Ellenbrook area will reach approximately 2,700 lots during 1997-98 and 3200 lots in 1998-99 including the Egerton subdivision (WAWA, 1994). Supply via the Greenmount reservoir can serve up to approximately 3,000 lots. Assuming a take-up rate equivalent to 85 per cent of developer projections, water will be needed for the additional lots by the summer of 1999. Therefore it is important for the Lexia groundwater scheme to be operating by summer 1999.

Other groundwater schemes in the area are, the Wanneroo and Mirrabooka Groundwater schemes to the west and south of the proposed Lexia Groundwater Scheme. In addition to the proposed Lexia Groundwater Scheme, it is proposed that two wells be added to the Mirrabooka Groundwater Scheme. These are the East Mirrabooka wells (East Mirrabooka Stage 3) which are proposed along Gnangara Road. Figure 2 illustrates the location of the proposed Lexia and East Mirrabooka wells in relation to existing wells and Ellenbrook, Egerton and the study area. The wells illustrated in Figure 2 show the proposed final layout following Water and Rivers Commission assessment of the impacts of many different scheme layouts.

1.2 Scope and objectives of the EWPs Plan

The scope of the East Gnangara EWPs Plan will be to:

- identify the ecosystem components of the environment in the area which are considered to have the highest environmental and social values and most likely to be impacted by groundwater abstraction;
- determine EWRs for each ecosystem component;
- identify preferred public and private groundwater abstraction;
- conduct computer modelling to determine changes in water levels that are likely to result from proposed groundwater abstraction and other land-use activity; and to optimise well locations to minimise water level impacts;
- compare the predicted changes in water levels to EWRs to determine if any conflicts are likely to result;
- propose management and mitigation strategies where necessary to protect the environment and propose EWPs (criteria in the form of water levels will be used to define what is actually allocated to the environment); and
- establish an ongoing management and monitoring programme for the area.

1.3 The study boundary

Groundwater abstraction from the Lexia wells will result in a local drawdown in groundwater levels. The study area was established to take into account the region where some groundwater drawdown may occur. The boundary was determined from preliminary computer modelling of proposed initial well locations and abstraction rates. Cadastral boundaries were then imposed on the modelling boundary to determine a study boundary which was easy to identify.

The study area is bounded in the north by the northern boundary of Melaleuca Park and the proclaimed Groundwater Area boundary. It is bounded to the east by the Midland railway line and Ellen Brook; to the south by Whiteman Park; and to the west by the Gnangara Pine Plantation, Melaleuca Park and Whiteman Park boundaries (see Figure 1).

The western region of the study area has previously been investigated and EWPs recommended as part of the *Gnangara Mound Groundwater Resources-Review of Proposed Changes to Environmental Conditions, Section 46* (WAWA, 1995a), hereafter referred to as the *Gnangara Section 46 Report*, which has been assessed by the EPA. However, that part of the study area is still included in the East Gnangara EWPs Plan study boundary. This is because the Lexia Groundwater Scheme has the potential to effect these areas and more detailed investigation to identify these impacts and how they can be managed is required.

1.4 The proponent

The proponent for the East Gnangara EWPs Plan is the Water and Rivers Commission. The proponent will have the responsibility of managing groundwater allocations and associated impacts in East Gnangara. The Water Corporation as a water supply utility is not the proponent for the plan, but will be licensed by the Water and Rivers Commission to enable it to abstract water for public water supply.

1.5 The environmental impact assessment process

The East Gnangara Environmental Water Provisions Plan was referred to the EPA in December 1994 (then titled *East Gnangara Water Resource Allocation and Management Plan*). The level of assessment was set at a PER. Guidelines which outline the issues which must be addressed in the PER were received from the EPA in April 1995 (see Appendix 1).

A draft PER is submitted to the EPA for comment. Appropriate changes are made to the document before it is released for public review. A PER has a public review period of up to 8 weeks. Once the public review period has been completed and submissions have been received, the DEP summarises the issues raised and the proponent has the opportunity to respond to these issues. The EPA then formally assesses the proposal taking into consideration the issues raised in public submissions and produces a Report and Recommendations document for submission to the Minister for the Environment. The Report and Recommendations are available to the public. The proponent and the public have 14 days to appeal. The Minister will then determine the acceptability of the proposal and may attach conditions. The conditions are legally binding on the proponent.

1.6 The public participation process

In April 1995 a pamphlet introducing and outlining the scope of the project was made available to the public and concerned groups in the vicinity of the study area. There have been newspaper articles published in the West Australian and local papers, the Wanneroo Times, the Echo, the Midland Reporter and The Hills Gazette. A Chart Report was also published in the *Ecoplan* newsletter produced by the Department of Environmental Protection (DEP).

A consultative committee was formed in April 1995 and consists of representatives from: Department of Conservation and Land Management (1); Department of Environmental Protection (1 observer); Shire of Swan - one councillor and one shire officer (2); Private groundwater-users in the Swan Groundwater Area (1); Ellenbrook Conservation Group (1); Ministry for Planning (1); Ellenbrook Management Pty Ltd (1); Mt Lawley Pty Ltd (1); Swan Region of the Water and Rivers Commission (1 observer); Water Corporation (1); Swan Valley Ratepayers Association (1); and the Conservation Council (1).

This committee has met on several occasions throughout the project to determine the nature of the public participation process and to allow for the exchange of information and views. Some of the issues that the committee discussed were: the methodology for selection of wetlands and terrestrial vegetation areas for the setting of EWRs; the determination of EWRs; the modelling process; the EWPs; private abstraction issues; and monitoring issues. The committee's suggestions have been taken into consideration throughout the development of the EWPs Plan. The committee will continue to meet for the duration of the project and then possibly combine in some reduced form with the Gnangara Community Consultative Committee to discuss continuing environmental commitments and issues concerning Gnangara Mound groundwater.

In addition to the meetings of the Consultative Committee a presentation was given to the Grapegrowers Association and a community workshop was held in November 1995. The workshop provided a general overview of the East Gnangara Project and how the Lexia groundwater scheme fits into the total planned future water supply for Perth. It also outlined research used in determining EWRs and presented the proposed EWRs.

Twenty people including representatives from Whiteman Park; the Swan Valley Tourism Council; The National Trust, the Grapegrowers Association, Scientists from UWA; local landholders, conservation groups and members of the Consultative Committee attended the workshop.

The final stage of the public participation process is the public review of this document.

2. The regional physical environment

2.1 Climate

Perth has a Mediterranean climate with warm to hot, dry summers and mild, wet winters. The Perth region experiences 5 - 6 dry months between mid October and the end of March. During this period rainfall is lower and temperature and pan evaporation are higher than other times in the year (Dames and Moore, 1986).

Annual average rainfall is 869 mm with 90 per cent falling between April and October (Dames and Moore, 1986; WAWA 1995a). Temperatures vary from the hottest recorded average maximum in February of 34°C to the coldest average maximum of 18°C in August. Annual average pan evaporation is 1,819 mm. Annual evaporation exceeds annual rainfall. Rainfall only exceeds evaporation between May and August. This is the period where groundwater recharge occurs in the shallow aquifer and soil moisture is replenished (WAWA, 1995a).

Annual average rainfall has varied in different periods. There were a number of years with above average rainfall between 1920 and 1940 and there has been a period of below average rainfall for the past 20 years (1975 -1995). A graph of Perth's annual rainfall since the late 1870s and the long term and ten-year-average is shown in Figure 3.

2.2 Geology

Figure 4 illustrates the geology of the Swan Coastal Plain. In the Perth region the Swan Coastal Plain overlies the Perth Basin. The Perth Basin consists of sedimentary rocks up to 13 km thick which were formed 286 million years ago. The youngest formations within this basin were formed in the Late Tertiary and Quaternary period (25 million years ago) and are 10-100 m thick (WAWA, 1995a). These are termed superficial formations.

The superficial formations are made up of sand and limestone with some areas of silt and clay. Significant volumes of groundwater are stored in and move through the superficial formations due to the porous nature of the sediments (WAWA, 1995a).

In the region of the study area the superficial formation overlies the Mirrabooka Formation. The Mirrabooka Formation is semi-confined and significant groundwater leakage occurs from the superficial formation.

Underlying the Mirrabooka Formation is the Osborne Formation. This is a layer of black shale and green-black sandy shale and has small beds of clayey, course-grained sand (Dames and Moore, 1986). The Osborne Formation restricts the flow of groundwater downwards from the Mirrabooka Formation. The regions of sand within the Formation are allowing some groundwater leakage to occur in these particular areas (WAWA, 1995a).

The Leederville Formation underlies the Osborne Formation. The Leederville Formation is made up of interbedded sandstone, siltstone and shale (Dames and Moore, 1986; Davidson, 1995). The Leederville Formation also stores large volumes of groundwater. This Formation is recharged by leakage through the Osborne Formation or in areas where the Leederville Formation comes into contact with the superficial formation (WAWA, 1995a).

A confining layer made up of mainly siltstone and shale lies beneath the Leederville Formation. This layer is termed the South Perth Shale. The siltstone and shale is grey to black with some minor thin sandy beds and local thin calcareous beds (Davidson, 1995). Below the South Perth Shale is the Yarragadee Formation which is similar to the Leederville Formation. It consists of similar materials and also stores large volumes of groundwater (Davidson, 1995; WAWA, 1995a).

2.3 Geomorphology

Aeolian and alluvial deposition has resulted in a series of distinct landforms on the Swan Coastal Plain near Perth.

Nearest to the coast lies the youngest of a series of dune systems running in a north-south direction. These are the Quindalup dunes. Further east the Spearwood dunes form a 10 km band followed by the Bassendean dune system which forms a 20 km wide band. Then nearest to the Darling Scarp is the Pinjarra Plain (WAWA 1995a, Alan Tingay and Associates, 1994).

The East Gnangara study area lies within the Bassendean dune system. Dunes rising to over 100m above sea level exist in the north of the study area.

2.4 Landforms

Within the Bassendean dune system there are several smaller landform units. Bassendean sands are common to the Bassendean dune system. Bassendean sands have a light grey sand near the surface and yellow sand at depth. They are fine to medium grained and contain some subrounded, well sorted quartz (Allan Tingay and Associates, 1994).

In the western Section of the study area the Bassendean sands are split into the Jandakot and Gavin units (Dames and Moore, 1990). The Jandakot unit occurs were there are hills or ridges with greater than 5m relief. These hills or ridges are commonly 10-15m relief. The soil within the Jandakot unit consists of iron podzol with a grey surface, a white sub-surface and a yellow sub-soil (Dames and Moore, 1986).

Conversely the Gavin unit occurs where the terrain is flat or gently undulating. The relief in these areas is less than 5m. The Gavin unit occurs throughout the Gnangara pine plantation. The soil consists of an iron humus podzol with a dark grey surface, grey sub-surface and a dark brown sub-soil. Iron concretions may also be present (Dames and Moore, 1986).

There are also smaller units occurring within the depressions of the Bassendean dunes. These are the Joel landform and the Seasonal Swamps.

The Joel areas are swampy regions (damplands) that become wet during the winter months. The water table in these areas is commonly within 2 m of the surface. The soils are a humus podzol with a dark surface, grey subsurface and dark brown indurated subsoil (Dames and Moore, 1986).

The Seasonal Swamp areas (sumplands) have free shallow water in the winter months and dry or turn into moist areas by the end of summer. The substrate of these swamps consists of peat, organic stained soil and diatomite.

The eastern Section in the middle of the Study area has an area of Yanga Alluvial Terrain. This is a drainage area for the Gnangara Mound. The area is associated with drainage lines running from damplands towards Ellen Brook and the Swan River. The Alluvial Terrain is swampy consisting of variable soils. These may be sand over heavy clay or sand over deep sand. Some of the Alluvial soils have ferruginous pans. Salts can build up in patches in this region.

There are also several other drainage lines occurring in the eastern regions of the study area which carry surface water from the Gnangara Mound to Ellen Brook and the Swan River during winter.

The south-eastern parts of the study area contain Guildford formation landforms or Bassendean sands over Guildford Formation. The Guildford Formation is derived from sediment deposits associated with Ellen Brook and the Swan River. The soil is a pebbly strong brown silt with occasional laterite quartz course grains and weathered granite pebbles, and fine to medium grain quartz sand (Alan Tingay and Associates, 1994).

2.5 Hydrology

The study area lies on the eastern fringe of the Gnangara Mound. The Gnangara Mound is a term used for the large source of fresh groundwater that lies within the superficial formations of the Swan Coastal Plain, north of Perth. The Gnangara Mound is bound by Gingin Brook and the Moore River in the north; by Ellen Brook in the east; by the Swan River in the south and by the Indian Ocean in the west (WAWA, 1995a).

Soils on the Gnangara Mound are porous allowing rainfall that is not recycled to the atmosphere through evapotranspiration to drain through the soils and recharge the aquifer (WAWA, 1995a). The groundwater in the aquifer eventually discharges to the Indian Ocean and rivers which surround the Mound.

The water table height at any particular position on the Gnangara Mound reflects the general topography in the region. The water table is highest, at 75m above sea level, in an area 6 km west of Muchea (WAWA, 1995a). Figure 5 illustrates water table contours over the study area.

The flow of groundwater is from the top of the Mound towards the ocean and river boundaries. The groundwater flow in the study area is generally in a south-easterly direction from the top of the Mound towards Ellen Brook and the Swan River (see Figure 5). The flow of groundwater varies between 10 and 100 m per year in the sandy soil areas and 0.01m per year in clay areas (WAWA, 1995a). The total groundwater storage in the Gnangara Mound is estimated at 19,500 x 10^6 m^3 (WAWA, 1995a).

Groundwater in the study area affects the formation of wetlands, springs and seepages in the region. Springs or seepages in the eastern part of the study boundary are formed where the water discharges to the land surface at the edges of the Gnangara Mound. In some cases the seepages flow strongly enough to establish creeks which discharge to Ellen Brook.

Wetlands occur where there are low areas in the landscape. At these points the groundwater rises above, or in the case of damplands, comes close to the land surface. Some of the wetlands in the study area do not reflect the water table but are perched above it. This means that impermeable ferricrete or clay layers have been laid down above the superficial aquifer so that rainfall accumulates in these areas rather than draining into the superficial aquifer. Perching within the study area makes some of the hydrology relatively complex (V & C Semeniuk Research Group, 1992, 1993).

2.6 Water quality

In general, Gnangara Mound water is of excellent quality. The longer the groundwater remains in the aquifer, the more it acquires the characteristics of the host material. The quality of the groundwater is best in the recharge areas at the Gnangara Mound and declines with depth and with distance towards discharge areas (WAWA, 1995a).

Salinity generally varies between 140 mg/L and 550 mg/L. Measurements of up to 12,000 mg/L have been recorded in wetlands at the end of summer due to the concentration of salts by evaporation (see glossary for definitions of salinity classes). Plumes of more saline groundwater occur down gradient of many wetlands (WAWA, 1995a).

The groundwater at the centre of the Gnangara Mound has a pH of 4.5 - 6.5 due to the presence of organic acids (leached from wetland areas) and reactions involving dissolved iron. By contrast, in coastal areas the host limestone results in the pH of groundwater between 6.5 and 8.0. The limestone also causes the water to be hard to very hard, whereas towards the middle of the Gnangara Mound hardness varies between moderately soft to slightly hard (WAWA, 1995a).

Dissolved iron varies from less than 1 mg/L - 10 mg/L and averages around 2 mg/L. Higher iron concentrations are found in areas of groundwater discharge such as near the coast and stream boundaries (WAWA, 1995a).

Nitrate levels are generally low but can exceed 5 mg/L-N in groundwater below urban areas and 10 mg/L-N below horticulture areas. Total phosphorus concentration is generally less than 0.1 mg/L, except for a few isolated locations and a trend to slightly higher concentrations along the eastern margin of the Gnangara Mound (WAWA, 1995a).

Heavy metal concentrations are low with the exception of localised occurrences of elevated concentrations attributed to point sources of contamination (WAWA, 1995a).

The temperature of groundwater varies between 18°C and 24°C. It may be coloured by organic acids and locally have a high turbidity. In some areas odours resulting from the presence of hydrogen sulphide may occur, and dimethyl trisulphide is also present in some areas imparting a swampy taste to the water (WAWA, 1995a).

There is one small area of groundwater within the East Gnangara study boundary which has been contaminated. A plume of ammonia currently exists downstream of the old Gnangara liquid waste disposal site. The site is located 1 km west of Lord street and 0.65 km north of Gnangara Road. The Gnangara liquid waste disposal site was opened in November 1971 and operated until January 1989, except for 5 years between 1982 and 1987 (WAWA, 1995b).

The result of dumping domestic and some industrial waste over this period is an ammonia plume 1 km long and 0.6 km wide. Concentrations directly downstream and adjacent to the site are greater than 10 mg/L^{-1} and decrease with distance. Concentrations in the region of Gnangara Road are between 5-10 mg/L^{-1} (WAWA, 1995b). The plume will not impact upon water quality in any of the existing or proposed production wells.

3. The regional biological environment

3.1 Terrestrial vegetation

Within the East Gnangara study area there are five main areas of native vegetation. These are Melaleuca Park; the Ellenbrook bushland; the vegetation corridor between them; Whiteman Park and small remnants of vegetation within the pine plantation. The vegetation found within each of these areas is discussed below with regards to the vegetation complexes identified by Heddle *et al.*, (1980) and community types identified by Gibson *et al.*, (1994). The representation of each complex and community type is provided within a regional context. Locations of the native vegetation areas in relation to the vegetation complexes and community types is provided in Figure 6.

The vegetation complexes identified by Heddle *et al.* (1980) were defined and mapped as part of an atlas of natural resources for the Darling System, commonly known as System 6. The area mapped was divided into five geomorphological provinces, one of these being the Swan Coastal Plain. Within the Swan Coastal Plain there are 29 vegetation complexes identified. Each vegetation complex is grouped according to shared features such as growth form dominance, species dominance, structure and species composition (Heddle *et al.*, 1980). The vegetation complexes were defined in relation to landform soil units (Churchward and McArthur, 1980) and average annual rainfall. The East Gnangara study area falls within the Swan Coastal Plain unit and contains representatives of six of the vegetation complexes.

Gibson *et al.*, (1994) conducted a regional floristic based survey of the southern Swan Coastal Plain and identified 30 community vegetation groups based on floristic data. Within these community groups finer sub-divisions could be made to define sub-groups, giving a total of 43 individual community types. The East Gnangara study area contains three community types identified from the sites surveyed (Gibson *et al.*, 1994) and an additional five identified from recent work for Bushplan (see Section 4.2.1 for explanation of Bushplan) (G. Whisson, pers. comm., 1997). A summary of the community types within the study area are provided in the table in Appendix 2. Appendix 2 also provides details on the community's reservation status and conservation status as determined by Gibson *et al.*, (1994).

Melaleuca Park contains representative vegetation of the Bassendean Complex-North. This complex is defined to consist of a range of vegetation from low open-forest and low woodland of *Banksia* spp and *Eucalyptus todtiana* to low woodland of *Melaleuca* spp and moister sites being occupied by sedgelands (Heddle *et al.*, 1980). The Bassendean Complex - North also occurs outside the study area as far north as Moore River National Park. In terms of Community types (Gibson *et al.*, 1994) Melaleuca Park contains representatives of Community types 23b (Northern *Banksia attenuata - Banksia menziesii* woodlands) and 22 (*Banksia ilicifolia* woodlands). Both community types are represented outside the study area . Community type 22 has been surveyed further north-east and south of the Swan River and Community type 23b is found south-west of Gingin. Melaleuca Park has been recommended for conservation through *The Northern Forest Region Regional Management Plan* (CALM, 1987). Recently the Western Australian government has been assessing areas of remnant bushland in the Perth region in the process of developing Perth's Bushplan. Refer to Section 4.2.1 for a discussion of Bushplan and its aims. Bushplan has not been finalised and is proposed to be released in late 1997. As a part of the assessments of vegetation Melaleuca Park has also been identified as containing representatives of the Yanga Complex and Bassendean Complex-North Transition (these complexes are discussed below) and Community types 4 (*Melaleuca* preissiana damplands), 21c (low lying *Banksia attenuata* woodlands or shrublands) and 23a (Central *Banksia attenuata - Banksia menziesii* woodlands) (G. Whisson, pers. comm., 1997). These Community types are also present outside the study area. Melaleuca Park has been recognised as a regionally significant area of bushland and is being considered for inclusion in Bushplan (G. Whisson, pers. comm., 1997).

Whiteman Park contains representatives of the Southern River Complex and the Bassendean Complex-Central and South. The Southern River Complex is defined as open woodland of *Eucalyptus calophylla - Eucalyptus marginata* and *Banksia* spp with fringing woodland of *Eucalyptus rudis* and *Melaleuca rhaphiophylla* along creek beds. The complex is not confined to the East Gnangara study area. There are occurrences as far south as the Bunbury/Busselton area (Heddle *et al.*, 1980). However, Whiteman Park contains the only reservation of Southern River Complex (Semeniuk, 1992). The Bassendean Complex-Central and South is defined as vegetation ranging from woodland *of Eucalyptus marginata - Allocasuarina fraseriana - Banksia* spp to low woodland of *Melaleuca* spp and sedgeland (moister sites). The Bassendean Complex-Central and South also occurs to the south of the study area with occurrences as far as the Bunbury area. The floristic Community type of Gibson *et al.* (1994) represented in Whiteman Park is Community type 23a (Central *Banksia attenuata - Banksia menziesii* woodlands). This Community type is also reserved outside Whiteman Park (Gibson *et al.*, 1994). Whiteman Park was initially recognised in System 6 (Department of Conservation and Environment, 1983). As part of the assessments of bushland in Perth (discussed in Section 4.2.1) Whiteman Park has also been found to contain Community type 4 (*Melaleuca preissiana* damplands), 21c (low lying *Banksia attenuata* woodlands or shrublands) and 22 (*Banksia ilicifolia* woodlands). These Community types are found outside the study area (Gibson *et al.*, 1994). Whiteman Park is also considered regionally significant and is being considered for inclusion in Bushplan (G. Whisson, pers. comm., 1997).

The central western part of the study area would have supported vegetation of the Bassendean Complex North and a small Section of Bassendean Complex North-Transition. It now only contains very small remnants which were left uncleared when the pine plantation was established. These remnants have been effected by the pine plantation through clearing, groundwater drawdown (from use of water and reduced recharge by pines), and weed invasion including pine invasion. A definition of the Bassendean Complex-North is provided above. Within the East Gnangara study area the complex is also represented in Melaleuca Park and the strip of native vegetation between Melaleuca Park and the Lexia wetlands, commonly referred to as the vegetation corridor. One of the remnants in the pine plantation contains a very small patch of *Melaleuca rhaphiophylla* closed forest which is a community type recently identified to be limited in its distribution on the Bassendean Complex-North or North Transition (B. Keighery, pers. comm., 1997).

The vegetation corridor contains representative vegetation of the Bassendean Complex North and Bassendean Complex North-Transition. A description of the Bassendean Complex North is provided above and it is also represented in Melaleuca Park. The Bassendean Complex North - Transition is defined as a transition complex of low open forest and low woodland of *Banksia* spp - *Eucalyptus todtiana (*Heddle *et al.*, 1980). It is limited in distribution in the study area mainly to the vegetation corridor but does occur outside the study area, although also limited in distribution outside the study area. Community types represented in the vegetation corridor are 22 (*Banksia ilicifolia* woodlands) and 23a (Central *Banksia attenuata* and *Banksia menziesii* woodland). Both of these types are represented outside the study area with 22 occurring further north and south and 23a further south. They are also reserved outside the study area (Gibson *et al.*, 1994). The vegetation corridor has been recognised as regionally significant bushland and is being considered for inclusion in Bushplan (G. Whisson, pers. comm., 1997).

The Ellenbrook bushland contains representatives of the Yanga Complex, Bassendean Complex North and North Transition. The Yanga Complex consists predominantly of closed scrub of *Melaleuca spp* and low open forest of *Casuarina obesa* on the flats subject to inundation. On drier sites vegetation reflects adjacent vegetation complexes (Heddle *et al.*, 1980). Remnant vegetation of the Yanga complex occurs near Sawpit Gully. It is considered to have high conservation value as less than 10 per cent of the complex is left uncleared and less than 5 per cent is secured in reserves (Dames and Moore, 1992). As discussed above the Bassendean Complex North and North Transition are represented in other parts of the study area and outside the study area. Through the recent assessments of bushland in Perth the Ellenbrook bushland has been identified as representing Community types 4 (*Melaleuca preissiana* damplands); 5 (mixed shrub damplands), 18 (shrublands on calcareous silts); 21a (Central *Banksia attenuata-Eucalyptus marginata* woodlands); 21c (Low lying *Banksia attenuata* woodlands or shrublands); 22 (*Banksia ilicifolia* woodlands); and 23b (Northern *Banksia attenuata-Banksia menziesii* woodlands) (G. Whisson, pers. comm., 1997).These Community types are also represented in areas outside the East Gnangara study area (Gibson *et al.*, 1994). In general, the Ellenbrook bushland is one of the most floristically rich remnants of native vegetation on the Swan Coastal Plain with a total of 427 different species occurring (Weston, Griffin, Trudgen: 1993). It has been listed by The National Trust (J. Blake, pers. comm.); entered onto the interim list of The National Estate (Australian Heritage Commission, 1994); identified as regionally significant; and is being considered for inclusion in Bushplan (G. Whisson, pers. comm., 1997).

The East Gnangara study area contains a number of important areas of native vegetation particularly Melaleuca Park, Whiteman Park and the Ellenbrook bushland. Other vegetation includes the vegetation corridor linking the Ellenbrook bushland and Melaleuca Park and a small stand of remnant *Melaleuca rhaphiophylla* closed forest.

3.2 Rare flora

Several investigations have been carried out within the study area for rare flora. Investigations conducted as part of the PER for the Ellenbrook Development by Dames and Moore (1990, 1992) found *Restio stenostachyus* (Priority 3), *Drosera pulchella* (uncommon on the Swan Coastal Plain), *Aotus cordifolius* (restricted to Perth flora region and Priority 3) *Caladenia huegelii* (declared rare flora) *Conostephium minus* (Priority 3) and *Cartonema philydroides* (Priority 3). (see Appendix 3 for definitions of Declared Rare Flora (DRF) and each priority classification).

A further investigation for rare flora in spring/summer 1992 which revised previous investigations concluded that the *Caladenia huegellii* identified earlier was actually *Caladenia paludosa*. However the occurrence of *Caladenia huegelii* in the area can not be definitely ruled out as there is suitable habitat in the area (Western, Griffin, Trudgen, 1993). In this investigation 15 priority species were identified (see Table 1).

Table 1. Priority species in the East Gnangara study area identified in *'Flora and Vegetation Conservation Values of the Ellenbrook Estate'*

Species	Priority
Anthotium junciforme	4
Aotus cordifolia	3
Cartonema philydroides	3
Conostephium minus	3
Daviesia physodes	2
Eryngium pinnatifida spp *palustre ms*	1
Eryngium subdecumbens ms	1
Gonocarpus pithyoides	3
Grevillea curviloba	1
Macarthuria apetala	2
Pericalymma floridum	2
Restio stenostachyus	3
Stachystemon axillaris	4
Stylidium longitubum	1
Stylidium utricularioides	4

In the review of rare and priority flora at Ellenbrook and the Lexia wetlands two species, *Cassytha micrantha* and *Schoenus clandestinus*, previously recorded have since been taken off CALM's DRF list. The botanists who assessed the area found *Darwinia species A* which is not currently on any priority or rare flora list. The botanists however believe it to be rare enough to have declared rare flora status. Other species also found on the Ellenbrook property which are significant because they are at the end of their geographical ranges are *Cassytha micrantha, Caladenia longicauda, Hibbertia perfoliata* and *Stylidium striatum*. A large number of the priority and rare flora species found are mainly located in or near the Lexia wetlands or in the Sawpit Gully area (Weston, Griffin, Trudgen, 1993)

An investigation of the Egerton property has also been carried out as part of the Egerton Structure Plan. Two priority three species, *Aotus cordifolia* and *Conostephium minus* have been identified on this property. No declared rare flora were found on the property (Alan Tingay and Associates, 1994). However there are two species which are considered rare or restricted which have been identified on the land. These are a club moss and liverwort species living in a seepage on the western Section of the property (Weston, Griffin, Trudgen, 1993). These species occur at their northern limit (Jasinska and Knott, 1994).

The Department of Conservation and Land Management has databases listing rare and priority flora and their locations. These databases provide an indication of whether a particular species occurs in an area. An investigation of these databases found six additional species which have previously been recorded within the East Gnangara study area (see Table 2).

Table 2. Priority species in the East Gnangara area identified from the Department of Conservation and Land Management's database

Species	Priority
Myriocephalus appendiculatus	3
Schoenus capillifolius	2
Haemodorum loratum	3
Hydatella dioicia	2
Verticordia serrata	1
Cynicula ixioides	4

Flora listed in Table 2 may also be present in the study area. The most likely locations indicated by CALM's database are mainly to the east of the Lexia wetlands or at the north or eastern boundary of the study area.

3.3 Wetlands

3.3.1 Wetland vegetation

Approximately 135 wetlands including palusplain, floodplain, dampland and sumpland areas (as classified by Semeniuk, 1987a) have been identified within the East Gnangara study area from Water Authority wetland map sheets (WAWA, 1993) (see Figure 7).

Investigations of the wetland vegetation in the area have found a diversity of species. The wetlands exhibit a plant succession from the lowest to highest point which has been described by Muir (1983) and Dames and Moore (1990) and presented in Section 9. The succession results in a series of concentric bands of vegetation. Where there is free water in the centre of the wetland *Baumea articulata* dominates.

Other vegetation supported by the wet areas include *Typha orientalis, Villarsia albiflora, Astartea species*, other species of Baumea, *Lepidosperma species, Juncus* and *Leptocarpus, Kunzea, Regelia* and *Jacksonia species* (Dames and Moore, 1990; Muir, 1983; Alan Tingay and Associates, 1995a, R. Froend, pers. comm.). *Banksia littoralis, B. attenuata, B. ilicifolia, Melaleuca preissiana, M. rhaphiophylla* and *Eucalytptus rudis* also occur in wetland or damp woodland areas (Dames and Moore, 1990; Ray Froend, pers. comm.). Damp woodland areas form a succession from wetland areas to dry woodland areas. Damp woodland areas also support understoreys of heath and shrub vegetation.

3.3.2 Wetlands previously investigated within the East Gnangara study area

Included within the collection of wetlands in the study area is Mussell Pool and Horse Swamp in Whiteman Park. These wetlands support low open woodland of Moonah paperbark and low closed forest of paperbark and flooded gum with an understorey of sedge and some shrub vegetation (Department of Conservation and Environment, 1983). Whiteman Park is classified as a Regional Park important from a recreational perspective. Mussell Pool attracts picnickers from urban areas nearby (Department of Conservation and Environment, 1983). Mussell Pool has been largely degraded however, due to the removal of its buffer vegetation. There is little fringing vegetation remaining with some Melaleuca but no emergent macrophytes (Davis *et al.*, 1993).

A study of physiochemical characteristics of wetlands on the Swan Coastal Plain included sampling of Mussell Pool. It was found to be highly coloured and undergoes temperature stratification in the spring and summer months. It was also found to be light-limited due to its high colour and to have a total filterable solids concentration of 765 mg/L^{-1} (Davis *et al.*, 1993).

An investigation of invertebrates in wetlands on the Swan Coastal Plain identified 80 species in total in Mussell Pool over three sampling occasions in 1989-90 (Davis *et al.*, 1993). Seven species of waterbird have been observed at Mussell Pool (Storey *et al.*, 1993a).

There are also several wetlands present in Melaleuca Park, most of them damplands and sumplands. These wetlands are dominated by paperbark and *Hypocalymma angustifolium* (White Myrtle) vegetation (Department of Conservation and Environment, 1983). One wetland in Melaleuca Park has been observed as part of the studies for the *Wetlands of the Swan Coastal Plain* series. This is a seasonal swamp north of Neaves Road. This wetland was found to be highly coloured and turbid and to have a high nutrient concentration (Davis *et al.*, 1993; Storey *et al.*, 1993a). In a survey of invertebrate fauna in 1989-90 twenty-nine species were recorded (Davis *et al.*, 1993).

Investigations have also been carried out in an EPP wetland on the south-eastern boundary of Melaleuca Park (wetland 173) by Knott and Jasinska (1996, unpublished data), at the request of the Water and Rivers Commission. This sumpland was sampled in November 1995 and found to contain temperature and salinity gradients. It is a highly coloured wetland with low salinity and nutrient concentrations and low primary productivity. Forty-two species of invertebrates were recorded including cladoceran crustaceans previously only found between Walpole and Windy Harbour. An outlier population of the fish, *Galaxiella nigrostriata,* was also found in this wetland.

Many of the wetlands in Melaleuca Park have become drier in previous years due to low rainfall over the last 20 years and in some areas, groundwater abstraction.

Within the East Gnangara study area there are also several wetlands scattered throughout the Gnangara pine plantation. However, the majority of these have been largely degraded due to the clearing of native vegetation and planting of pine trees. An assessment by a botanist from the Water and Rivers Commission found that although these wetlands still have significant vegetation cover they are suffering from significant weed invasion, including invasion by pine trees. One wetland contains *Melaleuca rhaphiophylla* closed forest recently identified to be limited in distribution in a comparable geomorphological setting (B. Keighery, pers. comm.).

One of the most significant areas of wetlands within the study boundary is the Lexia wetlands. These are mainly damplands and some sumplands located to the east of the Gnangara pine plantation between Melaleuca Park and Whiteman Park. These wetlands are in relatively pristine condition with diverse undisturbed vegetation and are classified *conservation* using the EPA's Bulletin 686 (EPA, 1993a). They were sampled in August 1990 and found to have a low pH, low total dissolved solids concentration and to be naturally high in nutrients (Dames and Moore, 1992).

3.4 Springs and seepages

An investigation of springs and seepages in the Ellenbrook/Muchea area was conducted by Jasinska and Knott (1994), at the request of WAWA. This survey was conducted between Gnangara Road and Muchea and included the following types of spring as defined by Williams (1983);

Helocrene:	Water issues gently from the soil.
Rheocrene:	Water which flows along a horizontal channel intersects the ground surface producing a stream.
Limnocrene:	Water wells up vertically through the ground and water emerges.

See Figure 7 for the locations of springs/seepages sampled.

Vegetation at the springs/seepages sampled included reeds, sedges, eucalyptus, banksia and melaleuca. One seepage which is at Egerton contained pristine vegetation and supported bog club moss, liverworts and other species which are at the northern limit of their distribution. Some of these are rare to the area, only found in springs/seepages (Jasinska and Knott, 1994). The liverwort and club moss species were recognised as significant when discovered at other springs at Muchea nearby and reported in *Conservation Reserves for Western Australia as recommended by the EPA: The Darling System- System 6* (Department of Conservation and Environment, 1983).

All sites sampled except 1L (Lake Yakine) had low conductivities reflecting their location in Bassendean Sands and most were acidic reflecting high levels of humic acids associated with the peaty deposits in these areas. None of the sites sampled had high concentrations of nutrients (Jasinska and Knott, 1994).

From the 13 sites sampled a total of 147 invertebrate species were identified. This number was an underestimation due to the inability to identify some classes and genera to species level. Of these 147 species collected, 91 had not been found in previous studies of wetlands of the Swan Coastal Plain (Davis *et al.*, 1993), south west wetlands (Storey *et al.*, 1993b; Edward *et al.*, 1994) or the Darling Scarp (Bunn *et al.*, 1986) (Jasinska and Knott, 1994). Invertebrate species assemblages were found to be quite different at different sites sampled in the study and at each site there was found to be at least 3 species endemic to that site (Jasinska and Knott, 1994). Amphipods of a new genus were found in the seepage at Egerton (Jasinska and Knott, 1994).

One of the main differences found between wetlands and seepages sampled and the wetlands of the western Gnangara Mound was the lack of amphipods collected (Jasinska and Knott, 1994). Of the sites sampled the springs/seepages were found to be absent in insects except for dipteran larvae (ceratopogonids and chironomids) in comparison to the surface waters (Jasinska and Knott, 1994). All of the sites were observed to support frogs and waterfowl including ducks, geese, ibis and heron. Some of the sites supported tortoises and gilgies (Jasinska and Knott, 1994). One of the main conclusions of the study is that there were three sites with a 'high conservation' value. These were 1s/1L (Edgecombe seepage and Lake Yakine), Eg (Egerton seepage) and the springs on Lot 11, Archibald Street, Muchea. The springs on this lot have since been reserved by CALM. Sites 1s/1L and Eg are in the south-eastern area of the East Gnangara study boundary; 1s/1L (Edgecombe seepage) located near the junction of Gnangara Road and West Swan Road and Egerton seepage located in the north-eastern area of the Egerton Property. Each of these sites has a mosaic of habitats of which only a few were sampled and it is thought that each of these habitats would support different aquatic faunal species (Jasinska and Knott, 1994).

3.5 Fauna

A comprehensive fauna survey of the Gnangara Mound area was conducted in 1977-78 by the West Australian Museum. In this survey it was confirmed that 12 mammal species were present in the area and that an additional three were considered to possibly occur. There could be up to 33 native mammal species occurring in the area according to a review of West Australian museum records by Kitchener *et al.*, (1978).

Seventy species of amphibians and reptiles were recorded in the 1977-78 survey and 17 of these are considered to be rare or scarce in the area due to insufficient suitable habitat on the Swan Coastal Plain (Dames and Moore, 1986).

Storr *et al.*, (1978) compiled a list of birds in the Gnangara Mound region. There were a total of 233 on this list. There are several bird species which have since become rare in the region or no longer present due to the loss of habitat, or introduction of predators or DDT (Dames and Moore, 1986, 1992). On the other hand other species have benefited from the clearing of vegetation and introduction of exotic plants.

Waterbird occurrence in the area was observed more recently by Storey *et al.*, (1993a) as part of an investigation of waterbird usage of wetlands on the Swan Coastal Plain. Two wetlands within the East Gnangara study area were included in this study. Observations were made of a wetland in Melaleuca Park just north of Neaves Road and Mussell Pool in Whiteman Park. Eight surveys of the wetlands were conducted between April 1990 and January 1992. No waterbird species were observed at the swamp in Melaleuca Park, however 7 species were found occurring at Mussell Pool in the survey period. Waterbird occurrence at Lake Yakine, near Edgecombe seepage in the south-east of the study area has also been observed for waterbird occurrence in 1994 by the Western Australian Naturalists Club. Twenty nine species were observed at this location (V & C Semeniuk, 1994).

In the 1977-78 survey by the WA Museum 13 species of freshwater fish from 10 families were found. Seven of these were endemic to the South West. Ellen Brook is considered to be important in terms of aquatic habitat for fish because these habitats support native species which have disappeared from other water bodies in the area due to the introduction of exotic species which compete with them (Dames and Moore, 1986). As discussed in Section 3.3.2, a rare species of fish only previously found in the Walpole area, has also recently been discovered in an eastern Melaleuca Park wetland by Knott and Jasinska (1996, unpublished data).

Surveys of aquatic invertebrate fauna are limited on the East Gnangara Mound. As discussed in Sections 3.3 and 3.4 there has been sampling in Mussell Pool and swamps in Melaleuca Park and also in springs and seepages in the East Gnangara area.

The Southern Brown Bandicoot *(Isoodon obesulus)* occurs in the wetland and dampland habitats in the area. This species is gazetted as rare, however it is found to commonly occur in other regions throughout the South West (Dames and Moore, 1992).

The Western Swamp Tortoise *(Pseudemydura umbrina)* is rare and in risk of extinction and only occurs in the reserves Ellen Brook and Twin Swamps which are both just outside the eastern boundary of the East Gnangara study area. Ellen Brook Wildlife Sanctuary has continued to support a wild producing population and therefore was set aside for tortoise protection. Twin Swamps Nature Reserve is also set aside for their preservation.

In the 1960s approximately 100 tortoises occurred in Twin Swamps. By 1985 the tortoises had almost disappeared due to fox predation and a series of dry winters since the 1970s and particularly in the 1980s.

To re-establish the population a fox-proof fence and a groundwater abstraction well for artificial maintenance have been established. WAWA provided the funding to establish the well which was completed in November 1993. The well is required to keep water levels in the swamps at appropriate depths for 5 - 6 months to allow the tortoises to feed. The tortoise has now been successfully reintroduced at Twin Swamps Reserve.

Investigations for Western Swamp Tortoise habitat were conducted at the Ellenbrook development area for the Ellenbrook Public Environmental Review and Egerton for the Egerton Consultative Environmental Review but none were found.

4. Regional social environment

4.1 Current land-use

The study area is currently divided into the following land-uses:

- a large conservation area;
- a large parks and recreation area;
- the Gnangara pine plantation;
- the Vines resort and estate;
- urban development at Ellenbrook;
- remnant vegetation areas;
- rural land (broadacre and 'Special Rural Zone'); and
- sand mining.

See Figure 8 for the locations of each land-use.

4.1.1 Conservation and recreation areas

The conservation and recreation areas within the study boundary were recommended to be reserved as part of the System 6 *Redbook* and/or *The Northern Forest Region Regional Management Plan, 1987-1997* (CALM, 1987). Melaleuca Park (M9) in the northern region of the study area is recommended to be reserved as a Nature Reserve for the conservation of flora, fauna and landscape and is currently managed for this purpose. It contains representative vegetation of the Bassendean Complex North (Department of Conservation and Environment, 1983).

Whiteman Park (M13), in the south of the study area covers approximately 2,605 ha (Department of Planning and Urban Development, 1994) and is reserved for Parks and Recreation (Department of Conservation and Environment, 1983). Whiteman Park is an important area of Regional Open Space in the North East corridor, providing a range of recreational activities. It contains a picnic area around Mussell Pool, a miniature aircraft sports centre, youth camp, international shooting complex, railway, bridle and cycle trails, train and tram trails, village and an equestrian centre. Approximately 300,000 people are estimated to have visited the park in 1993. Whiteman Park will be further developed as a recreational area for the north-east corridor in the future (Department of Planning and Urban Development, 1994). In March 1997, the Whiteman Park Concept Plan was released for public comment. The concept plan outlines proposed future management of Whiteman Park. It includes proposals to introduce new facilities; possibly including a heritage park with natural and aboriginal heritage components; an exhibition square to demonstrate cultural heritage including forestry and mining components; a heritage farm; more picnic areas; sports fields; a concert venue; wildlife park; botanic garden; an aboriginal heritage centre; and a golf course and accommodation facilities (Western Australian Planning Commission, 1997).

Particular areas of the Park are also set aside for conservation. This includes protection of Bennett Brook and wetlands from the Bennett Brook suite only found in two other areas of the Swan Coastal Plain (V & C Semeniuk, 1992). Whiteman Park also contains one of the few remnants of vegetation from the Southern River Complex on the Swan Coastal Plain (Department of Conservation and Environment, 1983). The Whiteman Park Concept Plan outlines proposals to rehabilitate some areas of the Park (Western Australian Planning Commission, 1997).

4.1.2 Forestry areas

The Gnangara pine plantation in the western Section of the study area is a part of State Forest 65 managed by CALM.

4.1.3 Rural areas

Rural land occurs in the north- east and south-east of the study area. These areas consist of small rural land holdings which are used for a variety of activities. A special rural zone also occurs in East Gnangara in the south-east of the study area at Henley Brook (Department of Planning and Urban Development, 1994).

4.1.4 Mining areas

The north-east corridor contains two priority resource areas, one of which is in the East Gnangara study area. This resource area is set aside for sand extraction, occurring north of Gnangara Road over the native vegetation corridor between Melaleuca Park, the Lexia wetlands and southwards to Gnangara Road (see Figure 8). Sand is currently being mined in the southern portion of this area and is likely to continue over the mining lease for the next two years (Department of Planning and Urban Development, 1994).

4.1.5 Urban development

Construction of the first village within the Ellenbrook development area began in October 1994. More details on the development are discussed in Section 4.2.2.

4.2 Future land-use

4.2.1 Conservation and recreation

Gnangara Park

CALM has recently proposed that much of State Forest 65, including the Gnangara pine plantation, become part of *Gnangara Park.* It is intended that the pine plantation will be gradually cleared over the next 20 years and rehabilitated with various types of native vegetation to create a park extending over 50,000 ha for conservation, recreation and groundwater protection.

Perth Bushplan

The DEP, Ministry for Planning, Water and Rivers Commission and CALM are currently developing Perth's Bushplan. Bushplan assesses remnant bushland (including wetlands) in the Swan Coastal Plain portion of the Perth Metropolitan area to determine which areas are regionally significant. Bushplan then makes various recommendations for the areas identified as important with the aim of achieving their ongoing protection. Bushplan aims to protect a 10 per cent area of each of the original ecological communities (G. Whisson, pers. comm., 1997). Remnant vegetation in the Perth metropolitan region is currently being investigated to identify Bushplan proposals. There are several potential Bushplan Sites within the East Gnangara study area (see Section 3.1) . A draft Perth Bushplan will be released in late 1997.

4.2.2 Urban development

There are two areas within the study boundary which will become urban estates. These are the Ellenbrook and Egerton properties. The Ellenbrook property was initially intended to include 1,797 ha of land to accommodate 20,000 households and a population of 58,000 people (Feilman Planning Consultants, 1992). It now excludes 300 ha of Mt Lawley Pty Ltd land in the north-west of the area concerned (EPA, 1993b). This area contains the Lexia wetlands and will be set aside for conservation. Of the 1497 ha left another 240 ha will be reserved for conservation purposes and vested in the National Parks and Nature Conservation Authority (EPA, 1993b). This area encompasses land adjacent to the Mt Lawley Pty Ltd property and the Sawpit Gully region. This leaves approximately 1200 ha for housing.

The Egerton property is 495 ha and will be developed into 3,650 lots housing approximately 11,800 people. Wetland areas within the Egerton property will be converted to public open space areas. The total area of public open space will be 84 ha (Alan Tingay and Associates, 1994).

4.3 Groundwater use

4.3.1. Public Water Supply

Public Water Supply Areas (PWSA) were proclaimed by WAWA under the *Metropolitan Water Supply Sewage and Drainage Act 1909.* This allowed WAWA to abstract groundwater and license private groundwater use in these areas. Public Water Supply Areas have now been proclaimed or in the process of being proclaimed as Groundwater Areas by the Water and Rivers Commission. Within Groundwater Areas the Water and Rivers Commission now licences water utilities such as the Water Corporation and private users to abstract groundwater. The Water and Rivers Commission proclaims Groundwater Areas under the *Rights in Water and Irrigation Act 1914.*

Parts of the Gnangara Groundwater Area (previously the Wanneroo PWSA and Gnangara PWSA) and the Mirrabooka Groundwater Area (previously the Mirrabooka PWSA) lie within the East Gnangara study boundary (see Figure 9).

The portion of the Gnangara Groundwater Area which overlaps the East Gnangara study area contains no public groundwater schemes in current operation. However, the Wanneroo Groundwater Scheme is nearby with the eastern leg of the wellfield abutting the western boundary of the East Gnangara study area. Groundwater drawdown from this scheme has some impact on East Gnangara groundwater levels. Table 3 shows the current quota for the Wanneroo groundwater scheme and production in the 95-96 year. Figure 9 shows the locations of the Wanneroo wells.

The Mirrabooka Groundwater Area is located to the south of the Gnangara Groundwater Area. The Mirrabooka public water supply scheme (currently operating) is located within the Mirrabooka Groundwater Area. Well locations are shown in Figure 9 and quotas in Table 3.

4.3.2 Private Groundwater use

Private groundwater users can also be licensed to abstract water from the Gnangara Groundwater Area and the Mirrabooka Groundwater Areas as discussed. The portion of the Gnangara Groundwater Area which lies within the East Gnangara study area has only a few small private allocations. The portion of the Mirrabooka Groundwater Area which lies within the East Gnangara study area contains the Whiteman Park, Henley Brook and State Forest sub-areas. Locations of the sub-areas in relation to the study area are shown in Figure 10. Table 4 shows the allocations for these areas current in November 1996 [Quotas are those proposed as a result of the outcome of this document (see Section 13.2)].

Quotas and allocations in the Mirrabooka Groundwater Area outside of the East Gnangara Study area are shown in Table 5.

The majority of private groundwater abstraction in the East Gnangara study area is within the Swan Groundwater Area. This area was proclaimed in 1975 by the Public Works Department to licence private groundwater abstraction. The Swan Groundwater Area will now be managed by the Water and Rivers Commission. It is also undergoing an amendment and will occupy an area of 27,144 ha extending from 3 km south of Muchea townsite southwards to just above Guildford and Midland; the eastern and western boundaries being the Darling Ranges and the Gnangara and Mirrabooka Groundwater Areas (WAWA, 1995d).

The Swan Groundwater Management Area has changed from the area in the Swan Groundwater Area Management Plan of 1991 (WAWA, 1991). Changes include the addition of the Bullsbrook Groundwater Area which virtually doubles the Swan Groundwater Area and also includes the Swan Valley Planning Area and excludes the area south of Toodyay Road which is urbanised. An additional change in the Swan Groundwater Area is the reduction in a number of sub-areas. The reason for amalgamating with the Bullsbrook Groundwater Areas and reducing the number of sub-areas is due to similarities in hydrogeology (WAWA, 1995d).

Some of the sub areas of the old Swan Groundwater Area described in the management plan of 1991 were over-allocated. However in these areas no stress on the groundwater system was evident from the over-allocation. It has since been found that the old sub-areas were not allocated along hydrogeological boundaries and the result of this was that under-allocated areas were compensating over-allocated areas (WAWA, 1995d). Relocation of sub-areas along hydrogeological boundaries has resulted in additional groundwater from the superficial aquifer being available for private use (WAWA, 1995d).

In addition to extraction from the superficial aquifer, groundwater can also be extracted from the semi-confined Mirrabooka aquifer and mostly confined Leederville aquifer. Only the Mirrabooka aquifer is considered here as abstraction from this aquifer can affect water levels in the superficial aquifer. Affects of abstraction from the Leederville aquifer is currently being investigated by a consultant. Results of this investigation will be given to the DEP.

Table 3. Abstraction from the Mirrabooka and Wanneroo Public Water Supply Schemes

Scheme	Commissioning Date	No Superficial Wells	Current Quota (kL x 10^6/ yr)	Production 95/96 (kL x 10^6/ yr)
Mirrabooka	1971	33	16	15.375
Wanneroo	1976	24	12	11.889
TOTAL		57	28	27.264

Table 4. Private Groundwater Allocations for sub-areas of the Mirrabooka groundwater area within the East Gnangara study area

Allocation million kL/yr	Sub-Area		
	Whiteman Park	Henley Brook	State Forest
Current Quota			
Superficial	1.3	0.2	0.964
Current Allocation			
Superficial	0.281	0.151	0.964
Unallocated Availability			
Superficial	1.019	0.049	0

Table 5. Private groundwater allocations for sub-areas in the Mirrabooka groundwater area outside of the East Gnangara study area

Allocation million kL/yr	Sub- Area				
	Ballajura	IP8	Lansdale	Plantation	Beechboro
Current Quota					
Superficial	2.086	3	1.6	0.7	1
Current Allocation					
Superficial	2.086	0.076	1.646	0.603	0.444
Unallocated Availability					
Superficial	0	2.924	0	0.097	0.556

Table 6. Proposed allocations in the Swan groundwater area sub-areas within the East Gnangara study area

Allocations million kL/yr	Sub - Area			
	North Swan	South Swan	Neaves	Radar
Current Quota				
Superficial	3.3	4.25	3.8	3.4
Mirrabooka	0.25	1.6	0.5	1.2
Current Allocation				
Superficial	3.042	3.922	3.212	1.343
Mirrabooka	0.212	1.122	0	0.053
Unallocated Availability				
Superficial	0.3	0.33	0.588	2.06
Mirrabooka	0	0.5	0.5	1.147

Figure 10 illustrates the new sub area boundaries of the Swan Groundwater Area and Table 6 provides an overview of proposed allocation limits and current allocations for sub-areas within the East Gnangara study area. These are Neaves, Radar, North Swan and South Swan (Quotas are those proposed as a result of the outcome of this document (see Section 13.2).

Table 7 shows the proposed groundwater allocations in the other sub-areas of the Swan Groundwater Area.

Groundwater in the Swan Groundwater Area is used to support rural activity with viticulture being the most significant use in this area. The breakdown of groundwater use in this area is 51 per cent to horticultural pursuits, 19 per cent to fodder crops, 14 per cent for parks and garden use, 7 per cent for industrial use and 9 per cent for domestic stock purposes (WAWA, 1995d).

Future groundwater allocations will preferably be given to increasing economic viability of existing projects rather than providing water for new projects. Future approvals for licences for horticultural development will require consideration of nutrient discharge to Ellen Brook (WAWA, 1995d).

Proposals for private groundwater allocation in the Swan Groundwater area are considered by the Swan Groundwater Advisory Committee using the management plan for guidance. Their function is to advise the Water and Rivers Commission on whether or not an application should be approved. The committee consists of government officers from departments relevant to management considerations and private individuals representing local landholders and interest groups (WAWA, 1995d).

The Water Resource Allocation Committee guides the Water and Rivers Commission on the development of policies and operation in relation to allocation and management of water resources.

4.4 Aboriginal Heritage

Wetland areas are extremely important to Aboriginal people living on the Swan Coastal Plain. There is evidence that Aboriginal people gathered in large numbers around wetlands in the summer period where they found food and water. Wetlands were rich in fish, waterfowl, tortoise, frog and vegetable foods (Anderson, 1984). Seasonal drying of some wetlands aided in the capture of some species residing in these wetlands. Some of the wetland plant species were collected for eating and paperbark made a good building material (Balla, 1994). This illustrates the wetland's importance due to their high productivity in their natural state (Balla, 1994). The Upper Swan was rich in resources and was therefore an important area for hunting and gathering by Aboriginal people (Feilman Planning Consultants, 1992).

Within the East Gnangara study boundary there are several sites identified as important to Aboriginal people. One of these sites located to the east of the Egerton property is termed Yakine, or Turtle Swamp (V & C Semeniuk, 1994). The East Gnangara area is believed to have been important for the hunting of

Table 7. Proposed allocations in the Swan groundwater sub-areas outside of the East Gnangara study area

Allocations million kL/yr	Sub - Area			
	Central Swan	East Swan	Cockman Bluff	Bandy Springs
Current Quota				
Superficial	1.7	no current limit	1.9	no current limit
Mirrabooka	0		0	
Current Allocation				
Superficial	1.676	0.725	0.668	0.307
Mirrabooka	0.039	0.025	0	0
Unallocated Availability				
Superficial	0.024		1.232	
Mirrabooka	0		0	

turtles (Feilman Planning Consultants, 1992). Yakine Swamp is also believed to have cultural and spiritual significance to the Nyungah Aboriginal people (V & C Semeniuk, 1994).

An archaeological and ethnographic survey of the Egerton property has been carried out to provide information for the Egerton Structure Plan Consultative Environmental Review. These surveys identified three sites of significance. Two of these sites were camping areas associated with a sumpland, the other site containing a scattering of stone artefacts is in close proximity to these camping sites (Allan Tingay and Associates, 1994).

Archaeological and ethnographic surveys have also been conducted on Ellenbrook Management land for the Ellenbrook PER (Feilman Planning Consultants, 1992). There were two sites on this land which were important to Aboriginal people as areas of resource procurement. One of these sites was located on the eastern edge of what is now a sand quarry in the south west corner of the Ellenbrook land. This has been destroyed by pine plantation (Feilman Planning Consultants, 1992). The other site to the south of Gnangara Road has been destroyed by quarrying (Feilman Planning Consultants, 1992).

Ethnographic and archaeological investigations were conducted for WAWA in June 1995 (Harris, 1995; O'Connor, 1995). The sites investigated were in the vicinity of the sites proposed as potential treatment plant sites for the Lexia groundwater scheme, the site which will become the reservoir and the access road for the scheme (which is also the access road for sand mining by Amertek/Rocla). Locations are illustrated in Figure 11. The investigations did not find any ethnographic sites in these areas, however the archaeological survey identified three sites within 3 km (Harris, 1995: O'Connor, 1995) of the survey area.

These appear to be the same two sites disturbed by quarrying found in the Ellenbrook investigation and an additional site near a creek. This site, believed to have been a small habitation camp was also disturbed (Harris, 1995).

In relation to the East Gnangara EWPs, Plan the Water and Rivers Commission also wrote to the Aboriginal Affairs Department requesting a list of ethnographic and archaeological sites within the East Gnangara study area which are on the Department's register. Five sites were found on the database which occurred within the study area. Four of these appear to be the same sites found by the surveys in the Ellenbrook and Egerton properties and surveys conducted for WAWA discussed above. The fifth site is on the perimeter of the study area.

Mussel Pool is a wetland within the study area which is of mythological importance to aboriginal people. This wetland is associated with the Waugal. It also became a seasonal camping area in the period of early settlement of Europeans. Aboriginal people camped here while they were employed by families in the region during the Swan Valley Grape Harvest (O'Connor, Quartermaine, Bodney, 1989).

In general the East Gnangara area was important for its swamps which were used for turtle hunting. Several of the swamps were used as dinner camps. Food was caught, cooked and eaten at the site and then aboriginal people returned to their permanent camps (Feilman Planning Consultants, 1992).

Ellen Brook and Bennett Brook are also important to Aboriginal people as mythological sites, being associated with the Waugal (O'Connor, Quartermaine, Bodney, 1989; Feilman Planning Consultants, 1992). The central resting place of the Waugal is found at the confluence of Bennett Brook with the Swan River; there is also a site associated with an evil and dangerous spirit and camping areas located along Bennett Brook. Memory of habitation in this area dates back approximately 100 years and the first women inhabitant of the Bennett Brook camping area is also remembered (O'Connor, Quartermaine, Bodney, 1989).

4.5 European Heritage

There are four sites identified to have European cultural significance within the East Gnangara study boundary. One of these is a small dam which has been constructed on a streamline crossing the Egerton property nearby to Ellen Brook. This dam dates back to the early period of occupation of the Swan River Colony (Alan Tingay and Associates, 1994).

There is also an historical stock watering trough (The Barnard Springs Trough and Wetland) located in the middle eastern region of the study boundary on private property. This trough which is associated with a spring was built by an early pioneer. The area has recently been listed on the National Trust (K. Tullis, pers. comm.).

The other features of historical significance are a collection of old forestry buildings in the Gnangara pine plantation which is in an area now zoned for urban development. The Ellenbrook estate is to be developed in this area.

There is also 980 ha in the central eastern area of the study boundary which has been registered on the National Trust for its features of natural significance. The area encompasses the Ellenbrook bushland (J. Blake, pers. comm.). A larger area of 2,000 ha which also encompasses the National Trust declaration has been put onto the interim list of the National Estate (Australian Heritage Commission, 1994). This area includes the Lexia wetlands and is shown in Figure 12.

5. Environmental Water Requirements and Environmental Water Provisions - philosophy and approach

This Section discusses the philosophy and approach adopted by the Water and Rivers Commission to manage groundwater systems, particularly how the principles of ecologically sustainable development (ESD) have been applied in determining EWRs. EWRs are specific criteria required to sustain ecosystem components which are considered to be beneficial or valuable. There are two primary sources which have provided a framework for the development of the Water and Rivers Commission's philosophy and approach.

The first is *The National Strategy for Ecologically Sustainable Development* (Commonwealth of Australia, 1992). This contains three core objectives and a set of guiding principles for the achievement of ecologically sustainable development in Australia. The three core objectives are:

- to enhance individual and community well-being and welfare by following a path of economic development that safeguards the welfare of future generations;
- to provide for equity within and between generations; and
- to protect biological diversity and maintain essential ecological processes and life support systems.

The second are *The National Principles for the Provision of Water for Ecosystems* which were published by the Agricultural and Resource Management Council of Australia and New Zealand (ARMCANZ) and the Australian and New Zealand Environment Council (ANZECC) in 1996. The document states that *the overall objective for providing water for the environment is to sustain and where necessary restore ecological processes and biodiversity of water dependent ecosystems*. There are twelve national principles that address the following issues:

- the basic premise of the inevitability of adverse effects resulting from regulation/diversion;
- the basis for determining EWRs;
- in providing water for ecosystems, the need to:
  - legally recognise environmental water
  - recognise the existing rights of other water users
  - take action where water is overcommitted
  - protect the environment in future water allocation decisions;
- in managing EWPs, the need for:
  - clear accountability mechanisms
  - responsiveness to new information;
- that managment of water for other uses be efficient and recognise ecological values;
- the need for further research; and
- the need for community involvement in decision making.

In East Gnangara the proposed management of water quantity is based on a water resources allocation process which includes the determination of EWRs. EWRs are determined by identification of values and/or beneficial uses of water dependent components of the environment, and the establishment of water levels for ecosystem protection. The water levels then define the EWR.

In this project, the specific approach to defining the EWR has been:

- identification of groundwater dependent ecosystem components (wetlands, springs/seepages, dependent terrestrial vegetation);
- selection of representative ecosystem components for which environmental water level requirements will be set to ensure appropriate protection for the region;
- identification of values (beneficial uses) of those parts including social and environmental aspects;
- determination of management objectives based on values/beneficial uses; and

- establishment of water level regimes for each ecosystem component that satisfy the identified management objectives and define the EWR.

The EWR identified in this manner is the optimal level of water provision for the environment. The actual water provisions that have been made also take into consideration other requirements for the groundwater. EWPs are therefore actual water allocations made to the environment taking into consideration all environmental and social requirements for groundwater. Where allocations to the environment conflict with other requirements such as public groundwater abstraction required to sustain the population, the environment may be allocated a water provision lower than the optimal water requirement. There will be a trade-off to what the community considers is an appropriate balance of the beneficial uses of the groundwater. It may be that groundwater will be managed to provide groundwater to two conflicting uses, or mitigation strategies will be put into place to ensure the environment is given a high level of protection.

The three aspects of the environment within the study boundary which are dependent on groundwater and for which EWRs and EWPs have been determined are:

- wetlands, including seasonal and intermittent wetlands;
- springs and seepages which emerge from the Gnangara Mound; and
- Banksia woodlands which are dependent on root access to the groundwater.

6. Environmental Water Requirements - methodology for terrestrial vegetation

To protect terrestrial vegetation groundwater levels must be maintained to give plants access to water which is required for their survival. In areas with a shallow depth to groundwater, experience has shown that groundwater drawdown, under terrestrial vegetation has the potential to impact on the vegetation (WAWA, 1992).

Water level fluctuations can result from climatic factors, groundwater abstraction and land-use changes. For example the clearing of native vegetation leads to a rise in the water table due to reduced evapotranspiration. The establishment of pine plantation will cause a decrease in groundwater levels as rapidly growing pine trees intercept rainfall and compete for soil moisture (Mattiske and Associates, 1989). Other catchment activities which can impact groundwater levels include agriculture and urbanisation. Urbanisation will cause an increase in water table levels due to reduced evapotranspiration from the initial clearing of vegetation, and concentrated runoff due to the presence of impervious surfaces and importation of water from other areas for water supply purposes (WAWA, 1995a).

Groundwater abstraction results in a drawdown of the water table. The potential impact of abstraction ranges from gradual changes in plant community composition to more drought tolerant species, to sudden and extensive death of vegetation in some instances. The aim of establishing EWRs is to determine water levels which will avoid death of native vegetation. It is more difficult to determine an appropriate water level which avoids long term changes in community structure. For example towards a more drought tolerant species composition because a range of environmental factors, including climate, interact to collectively determine community structure (Mattiske and Associates, 1989).

A drier climate over the past 20 years has resulted in gradual changes in community composition to more drought tolerant species in several areas over the Gnangara Mound not subject to groundwater abstraction (Mattiske and Associates, 1981-1995).

In the past, groundwater abstraction from production wells has on a few occasions lead to death of vegetation in the immediate vicinity of wells (within the drawdown cone). Under extreme climatic conditions (drought and high temperature) the abstraction from production wells adds to the water stress on vegetation. Previously vegetation deaths have mainly occurred within a 200 m radius of the wells on the Jandakot and Gnangara Mounds. Vegetation deaths in the immediate vicinity of wells is a cost of water supply production which should be recognised by the community.

It is estimated that water table drawdowns within the drawdown cones of the superficial Lexia production wells will be approximately 1.3 m at 100 m radius, 1m at 200 m and 0.5 m at 500 m from each well. All wells in combination will cause a regional drawdown in groundwater levels. The modelling discussed in Section 13 predicts these drawdowns. The EWRs will define what level of drawdown phreatophytic vegetation will tolerate before impacts result. The methodology used in determining EWRs follows. Where conflicts arise between EWRs and these drawdowns in groundwater, one of the following approaches is taken:

- proposed abstraction is reduced to the point where EWRs can be met;
- EWPs are proposed to be less than the EWRs; or
- there is some combination of these two approaches.

EWPs define the actual allocation of groundwater that will be made to vegetation. If less than the EWR, they represent a trade-off between the EWRs of native vegetation and social requirements for public water supply.

6.1 Research on the effects of groundwater drawdown on terrestrial vegetation - *The Gnangara Mound Vegetation Stress Study*

Where there has been significant reductions in soil moisture and water table drawdowns they have shown significant impacts on native vegetation. The Gnangara Mound vegetation stress study investigated the cause of stress and deaths of vegetation on the Gnangara Mound in 1991. The study was initiated in response to observations of drought stress in trees in Whiteman Park in the summer of 1990-91. Investigations involved: observations of groundwater level changes due to WAWA activities; climate; root excavations to determine the relationship between tree roots and groundwater levels at different topographies; vegetation monitoring along transects and the use of a geographic information system to examine relationships between tree deaths, species, topography and depth to groundwater (WAWA, 1992).

The study's main conclusion was that vegetation deaths occurred due to low soil moisture and lower water levels after the extended period of below average rainfall between 1979 and 1991, particularly between 1985 and 1991. The justification for this conclusion is that stressed vegetation and vegetation deaths were observed over several areas of the Gnangara Mound and not just where production wells were abstracting groundwater. Vegetation stress has also been observed in other areas of the State such as Kings Park and on the coast near Albany (with deaths being observed in summer, 1991). Both of these locations are remote from groundwater abstraction activity. In both locations death appeared to be associated with high temperatures and low soil moisture (WAWA, 1992). In 1991, trees that died on the Gnangara Mound, Kings Park, Albany and the Wheatbelt were exposed to record maximum temperatures in addition to low water levels.

However, the study also concluded that groundwater abstraction exacerbates the effects of reduced recharge and can therefore influence the intensity of tree deaths in an area. There is evidence to show that tree deaths have been more concentrated in areas of groundwater abstraction.

Due to below average rainfall since 1975 some trees have compensated for lowered soil moisture by relying on access to groundwater. A decline in groundwater levels beyond where their roots extend can therefore be detrimental for this vegetation. (WAWA, 1992).

Other factors found to contribute to vegetation stress were:

- Depth to groundwater
  - vegetation which occurs where the depth to groundwater is less than 6 m appears to be adapted to having shallow groundwater near their roots. Falls in the groundwater table will effect this vegetation more than vegetation in areas where the depth to groundwater is greater.
- Tree species
  - *Banksia ilicifolia* is less drought tolerant and is therefore more susceptible to groundwater drawdown than *Banksia menziesii* (WAWA, 1992).
- Temperature
  - Tree deaths have tended to occur when high average daily temperatures are reached. An increase in temperature increases the moisture requirements for plants. If moisture is limited when temperature increases, a plant may not be able to regulate its cell temperature effectively and this leads to stress.
- Topography
  - In areas of flat topography there have tended to be a greater aerial extent of vegetation deaths. In addition, vegetation associations which are associated with particular topographies have different susceptibility to declines in water levels.

Further investigations by WAWA on water uptake of banksia vegetation using sapflow sensors supports this observation (R. Froend, pers. comm.). Vegetation on flatter areas was found to be more dependent on groundwater than vegetation upslope (greater depth to groundwater) which demonstrated more response to rainfall events (ie soil moisture) (R. Froend, pers. comm.).

Over time a gradual drop in soil moisture under native vegetation results in a shift from tree species which tolerate moister soil conditions to those that tolerate dry soil conditions or are not site specific in their occurrence (Mattiske and Associates, 1989). Tree species such as *Banksia menziesii* and *Banksia attenuata* can exist as either xerophytes (accessing soil moisture) or phreatophytes (accessing the water table). Phreatophytes can become xerophytic. However, phreatophytes which experience a rapid change in water table levels will die.

6.2 Methodology for determining EWRs for terrestrial vegetation

To determine EWRs for terrestrial vegetation the following approach was taken:

- native vegetation areas susceptible to groundwater drawdown were identified;
- monitoring wells were selected which best represent water table levels and can be used to monitor compliance with water level requirements; and
- rates of change in groundwater levels and minimum groundwater levels which are unlikely to lead to vegetation deaths due to water stress were determined.

6.2.1 Areas of susceptible vegetation

The *Gnangara Mound Vegetation Stress Study* (WAWA, 1992) undertook an investigation into what vegetation is likely to be susceptible to drawdown in groundwater levels. As discussed, the study found that *Banksia* trees in areas of less than 6 m depth to groundwater were most effected by drawdowns.

The study also identified acceptable rates of change in water levels and minimum levels that were acceptable before vegetation deaths occurred from water stress. It indicated that *Banksia* species can tolerate a water table drawdown of 1.5 m in total, and that this drawdown could be tolerated at no more than an average rate of 0.2 m per year. These requirements of *Banksia* vegetation have been applied in determining EWRs in this document. This approach is considered to be conservative.

To identify susceptible vegetation areas within the East Gnangara study boundary all areas with a depth to groundwater of 0-8 m were mapped. The 0-8 m range was used to allow for inaccuracies in mapping. Within these areas, intact native vegetation was identified using aerial photography. Figure 13 shows the native vegetation areas occurring at a depth to groundwater of 0 - 8 m.

6.2.2 Selecting monitoring wells

Existing Water and Rivers Commission monitoring wells within the native vegetation areas were selected to represent groundwater levels. In selecting monitoring wells an attempt was made to locate them in important areas such as Melaleuca Park, Whiteman Park, the vegetation corridor between Melaleuca Park and the Lexia wetlands, and upstream of rare flora locations. The locations of selected monitoring wells are given in Figure 13.

In some areas additional monitoring wells have been established to ensure comprehensive representation of native vegetation areas which are susceptible to drawdown. Where asterisk is shown in Figure 13 new monitoring wells have been drilled. Because limited monitoring data is available, wells L220C, L110C, L30C and MM12 will be used in the interim to set EWRs.

In Whiteman Park and Melaleuca Park the monitoring wells chosen are the same monitoring wells as used for the *Gnangara Section 46 Report* (WAWA, 1995a). These wells are considered appropriate in representing water levels within these areas.

6.2.3 Determining groundwater level requirements

To determine a minimum groundwater level requirement the historical monitoring records for existing monitoring wells were analysed (hydrographs for each of the monitoring wells selected are provided in Appendix 7). A 'normal' minimum groundwater level was identified. 'Normal' is defined as the average minimum groundwater level occurring in the early 1970s (1970-1975) before the drought period occurring over the last 20 years.

Where monitoring data were available from the early 1970s the 'normal' minimum groundwater level was taken as an average level occurring at the end of summer periods in the early 1970s.

Where groundwater level data was only available from the early 1980s, the groundwater level on the hydrograph that appeared to be an average minimum since then, was identified. A figure of 0.5 m was added to the minimum to allow for drawdown over the dry climatic period since the mid 1970s. The Figure arrived at was considered to be the 'normal' groundwater level.

Once a 'normal' minimum groundwater level was identified an absolute minimum groundwater level was determined. The absolute minimum groundwater level was determined by subtracting 1.5m from what was considered to be the 'normal' groundwater level.

A figure of 1.5 m was used to subtract from the 'normal' groundwater level to establish the EWR due to the findings in the *Gnangara Mound Vegetation Stress Study* (WAWA, 1992) discussed in Section 6.2.1.

The other component of the terrestrial vegetation EWR, determined through the findings of the *Gnangara Mound Vegetation Stress Study* (WAWA, 1992), is that drawdown must be slow, at a rate of approximately 0.2m per year. Together with the minimum level this defines the EWR. Rates of drawdown will be kept slow by phasing abstraction for production wells where they are in close vicinity to native vegetation.

In areas where vegetation deaths have been observed in the past, EWRs were set above the minimum levels associated with tree deaths by at least 0.2 m.

7. Environmental Water Requirements for terrestrial vegetation

7.1 Previously proposed EWRs for Melaleuca Park and Whiteman Park

In the *Gnangara Section 46 Report* (WAWA, 1995a) EWRs were determined and EWPs proposed for terrestrial vegetation in Melaleuca Park and Whiteman Park (which are also within the East Gnangara study boundary).

Also in the Report, EWRs in Melaleuca Park and Whiteman Park were determined using previously recorded information on minimum groundwater levels and the observed effect these levels had on phreatophytic vegetation. The philosophy used in determining the EWRs was to have no further impact on groundwater levels or vegetation where groundwater has already been drawn down due to the development of the Wanneroo and Mirrabooka wellfields. Therefore, where previously recorded minimum water levels have resulted in tree deaths in Whiteman Park, EWRs were set above this minimum groundwater level (by at least 0.2 m). In Melaleuca Park the Wanneroo wellfield has drawn down groundwater levels at the western edge of the park but no significant tree deaths have been observed. Therefore the minimum water level requirement in WM6 was set at the previously lowest recorded water level. For the remainder of the wells in Melaleuca Park which had EWRs determined (WM8, NR6C and WM2), the methodology used was the same as outlined in Section 6.2.3.

Table 8 lists the monitoring wells selected in the *Gnangara Section 46 Report* (WAWA, 1995a) and their minimum water level requirements. Monitoring well locations are illustrated in Figure 13 and hydrographs for each in Appendix 7.

7.2 Role of the East Gnangara Plan in determining EWRs

The EWRs determined in the *Gnangara Section 46 Report* (WAWA, 1995a) will be adopted as EWRs for East Gnangara as they are based on current information.

The monitoring well network and the minimum water level requirements proposed for Whiteman Park are believed to be sufficient for protecting the terrestrial vegetation in Whiteman Park from the impacts of groundwater drawdown from the Lexia and East Mirrabooka groundwater schemes. However, an additional monitoring well is required in Melaleuca Park. The additional well chosen (NR11C) and the

Table 8. EWRs for monitoring wells in Melaleuca Park and Whiteman Park. [Established in the 'Gnangara Mound Groundwater Resources - Review of Proposed Changes to Environmental Conditions' (WAWA, 1995).]

Observation Well	Minimum level recorded (Year)	Minimum Water Level Requirement (EWR)	Depth to groundwater
Whiteman Park			
MM49B	24.3 mAHD (1986)	24.7 mAHD	4 m
MM53	33.0 mAHD (1991)	33.3 mAHD	4 m
MM55B	29.2 mAHD (1986, 1991)	29.5 mAHD	3 m
MM59B	36.1 mAHD (1991)	36.3 mAHD	4 m
MM18	38.4 mAHD (1991)	38.6 mAHD	5 m
Melaleuca Park			
WM6	58.8 mAHD (1991, 1995)	58.8 mAHD	8 m
WM8	65.5 mAHD (1990, 1991)	65.0 mAHD	6 m
NR6C	59.7 mAHD (1991, 1995)	58.5 mAHD	2 m
WM2	67.6 mAHD (1991, 1995)	67.0 mAHD	6 m

minimum water level requirement determined is given in Table 9. The location is illustrated in Figure 13 and the hydrograph in Appendix 7. The minimum water level requirement was determined using the methodology in Section 6.2.3 which allows a 1.5 m drawdown of groundwater in total at a gradual rate.

7.3 Additional wells with EWRs

In addition to the need for another monitoring well with a minimum water level requirement in Melaleuca Park, wells are also required to protect other areas of terrestrial vegetation within the East Gnangara study boundary, which were not covered by the *Gnangara Section 46 Report* (WAWA, 1995a). The only other region of terrestrial vegetation dependent on groundwater is the native vegetation corridor between Melaleuca Park and the Lexia wetlands and extending below the Lexia wetlands. The groundwater monitoring wells with minimum water level requirements determined for protection of this vegetation are listed in Table 9 and includes the additional well proposed for Melaleuca Park. Locations are illustrated in Figure 13 and hydrographs in Appendix 7.

The status of vegetation health near the wells in Table 9 was observed during the two periods of minimum water levels in 1991 and 1995. Airborne remote sensing imagery was taken over the area in April 1991 after vegetation deaths had been observed in Whiteman Park. In the images dead vegetation was easily identified. The lowest minimum water levels recorded were prevailing in wells MM12, L220C and L30C at this time. The imagery shows there were no vegetation deaths in the vicinity of these wells at that time.

Vegetation was also observed in the field after low water levels in April 1995, during which the lowest water level for NR11C and L220C were recorded. No vegetation near monitoring wells in the corridor or near NR11C appeared to be stressed at this time.

The monitoring wells located in the vegetation corridor, MM12, L30C, L110C and L220C will act as temporary wells for the EWRs and EWPs and for the monitoring of water levels. New monitoring wells which are in more appropriate locations have recently been installed. They are shown in Figure 13 (see asterix). As more detail becomes available EWRs and EWPs will be determined for these wells and will replace MM12, L30C, L110C and L220C. The new monitoring wells are located further from production well drawdown cones and will be more appropriate in reflecting regional groundwater levels. They are also outside mining lease areas.

Table 9. EWRs for monitoring wells in the vegetation corridor and Melaleuca Park [Not included in 'Gnangara Mound Groundwater Resources-Review of ProposedChanges to Environmental Conditions' (WAWA, 1995).]

Observation well	Minimum water level recorded (year)	Assumed 'normal' minimum level	Minimum water level requirement (EWR)	Depth to groundwater
Vegetation corridor				
MM12	43.14 mAHD (1991)	44.5 mAHD	43 mAHD	3 m
L30C	48.14 mAHD (1986, 1991)	49 mAHD (48.5 + 0.5)	47.5 mAHD	4 m
L110C	57.72 mAHD (1986)	58.5 mAHD (58 + 0.5)	57 mAHD	6 m
L220C	53 mAHD (1991, 1995)	54 mAHD (53.5 + 0.5)	52.5 mAHD	1.5 m
Melaleuca Park				
NR11C	55.6 mAHD (1993, 1995)	56.5 mAHD (56 + 0.5)	55 mAHD	2 m

8. Environmental Water Requirements methodology for wetlands

To protect representative and significant wetland ecosystems within the study boundary the following approach was taken to determine water level requirements.

8.1. Selection of wetlands

All wetlands within the study boundary were identified from WAWA's wetland map sheets (WAWA, 1993). There are 135 in the area. Wetlands from this group were then selected to represent the collection of wetlands within the study boundary. It is neither practical nor necessary to set EWRs for all wetlands. It is more appropriate to set EWRs for a representative group of these wetlands with the highest values.

The following factors were taken into consideration when selecting the group of wetlands for EWRs:

- the natural and human-use attributes of the wetlands as determined through the application of EPA Bulletin 686-*A Guide to Wetland Management* (EPA, 1993). All wetlands which have a 'High Conservation' and 'Conservation' preliminary evaluation category were considered important {now all classified 'Conservation' with the removal of the 'High Conservation' category (Hill *et al.*, 1996)};
- wetlands protected by the *Environmental Protection (Swan Coastal Plain Lakes) Policy 1992* (EPP) were identified.

Table 10. Wetlands selected for Environmental Water Requirements

Wetland	**78**	**173**	**86 (Lexia)**	**94 (Lexia)**	**186 (Lexia)**
Co-ordinates easting northing	 39,695 649,172	 40,146 649,172	 40,136 648,637	 40,256 648,635	 40,164 648,730
Preliminary Management Category	C	C	C	C	C
EPP	No	Yes	No	Yes	Yes
System 6	M9	M9	No	No	No
Existing/ proposed nature reserve	Yes	Yes	Yes	Yes	Yes
Proximity to proposed Lexia scheme	3.9 km	4.8 km	1.8 km	3 km	3.4 km
Type	Dampland	Sumpland	Sumpland	Dampland	Sumpland
Suite	B.3	B/P.3	B.3	B.3	B.3
Vegetation classification	Maculi	Hetero	Peri	Maculi	Maculi
Other	Perth to Bunbury study	Perth to Bunbury study	Other regional studies, NE corridor audit, Ellenbrook studies, National Trust listing	Other regional studies, NE corridor audit, Ellenbrook studies, National Trust listing	Other regional studies, NE corridor, audit Ellenbrook studies, National Trust listing

SOURCE: Wetland type = Semeniuk, 1987a; Consanguineous suite = Semeniuk, 1987b; Vegetation classification = Semeniuk et al., *1990.*

- wetlands within System 6 areas were identified;
- wetlands in existing or proposed nature reserves were identified;
- wetlands recognised in other studies to have high conservation value were identified.
- other wetland values such as RAMSAR listing, Aboriginal significance, and nominations for listing on the National Estate and The National Trust were identified;
- wetlands most likely to be effected by groundwater abstraction were given priority; and
- the representativeness of the wetlands in reflecting the range of wetlands existing in the study area was taken into consideration. [Representativeness was assessed using the Semeniuk's geomorphic classification (Semeniuk, 1987a), consanguineous suite identification (Semeniuk, 1987b) and vegetation classification (Semeniuk *et al.*, 1990)].

8.1.1 Wetlands selected for EWRs

Using the above criteria a group of wetlands were identified which were to be used in developing EWRs. These wetlands and the information considered in their selection are shown in Table 10. Figure 14 shows the locations of these wetlands.

In addition to the wetlands in Table 10, two seepages in the south-east of the study area which are downstream of the groundwater scheme and have high conservation value, were selected for EWRs. The selection of the springs is discussed in Section 10. Locations are provided in Figure 14.

Although EWRs have been set for only five of the 135 wetlands in the study area, they are considered to provide the necessary protection for the majority of wetlands and for all wetlands with high values because:

- The wetlands selected are in relatively close proximity to the proposed groundwater scheme. Therefore in setting EWRs and limiting the drawdown in wetlands in relatively close vicinity to the scheme protection for the wetlands located further from the scheme, is also provided. This is because drawdown from abstraction is reduced with distance.
- The wetlands and seepages selected for EWRs form a semi-circle of protection from groundwater abstraction impacts on the upstream and downstream sides of the proposed groundwater scheme. Protection in the north is provided by setting EWRs for two wetlands in the southern region of Melaleuca Park (one in the west and one in the east). Protection in the east will be provided through setting EWRs at the Lexia wetlands and protection in the south-east by having EWRs for the Egerton and Edgecombe seepages.
- Although no wetlands have been selected for EWRs in Whiteman Park, EWRs have been set for native vegetation in Whiteman Park (see Section 7 and WAWA, 1995). This will also limit drawdown in wetlands in this area. Many of the wetlands in this area have already adapted to a lower water regime due to the operation of the Mirrabooka groundwater scheme since 1979. Any additional groundwater drawdown will be at the north of Whiteman Park where wetland areas have been degraded due to past clearing and grazing practices.
- EWRs were not set in wetlands in the pine plantation as the wetlands have generally been degraded by the establishment of the plantation. These wetlands have already adapted to a drawdown in water levels caused by the pines use of groundwater and many have been cleared and/or suffer from weed invasion including invasion of pine trees. There is one wetland in the area which contains a small patch of *Melaleuca rhaphiophylla* closed forest which is a vegetation association identified to be limited in distribution within a comparable geomorphological setting (B. Keighery, pers. comm., 1997). The predicted impacts on these wetlands and proposed actions in response to this are discussed in Section 13.2.6.2.

8.2 Development of wetland criteria

The following approach was taken to identify wetland water level requirements.

8.2.1. Identify characteristics of the wetland

Wetland characteristics were identified with the use of information from all available research and monitoring on the wetlands. This included information on physical setting, water level regimes, stratigraphy, vegetation, aquatic fauna, avian fauna, water quality, Aboriginal significance and historical significance. For the majority of wetlands little information was available. Therefore additional investigations have been undertaken or are proposed. For example, a botanist assessed wetland vegetation and monitoring wells were installed to monitor water levels.

8.2.2. Identify the values of the wetland (environmental and social)

The wetland values considered important are social and environmental. Identification of the value of the wetlands relied upon information from scientific research, information from community members and further assessment of the wetlands by a botanist. Issues considered in identifying environmental values of wetlands included degree of disturbance, the abundance and diversity of flora and fauna, and the uniqueness of the characteristics.

Identification of social values was undertaken largely through discussions with the local community and through the Consultative Committee and public participation activities.

8.2.3. Determine management objectives to reflect wetland values (particularly those achievable through management of water levels)

After identification of wetland values, management objectives were determined to ensure protection. Management objectives are then expressed as water regimes which define the EWRs.

8.2.4. Develop a water level regime consistent with the management objectives with water levels to describe that regime

The final stage in determining an EWR for a wetland is to determine water regimes which will ensure the sustainability of the values of the wetlands. Management of water regimes will not achieve all aspects of wetland management. However they are fundamental in determining vegetation distribution, species habitat availability and species diversity. Water levels also have implications for water quality. EWRs indicate both minimum and maximum water levels required to protect important wetland characteristics. Groundwater abstraction activities have no impacts leading to increased water levels and therefore will not influence maximum levels. The maximum requirements are provided however, as the Water and Rivers Commission has a responsibility to provide advice to other agencies in its role as a water resource manager. Activities which may influence maximum water levels include urban development, clearing for mining and harvesting of pines.

8.3 Key research on wetlands

8.3.1 The effect of altered water regimes on wetland plants *(Wetlands of the Swan Coastal Plain, Volume 4)*

Among other factors, the distribution of wetland vegetation is dependent on water regime. The distribution of vegetation is a reflection of abiotic factors such as nutrient availability, water regime and sediment composition, and biotic factors, such as competition from other species. Water regime is thought to be the principal abiotic determinant in the development and distribution of wetland plant communities (Gosselink and Turner 1978).

Water regime is a term which encompasses variability in water levels as well as average water levels. Wetland plant communities are dependent on the variation in water levels which occur in wetlands of the Swan Coastal Plain. Water levels vary over the long term (to follow climatic cycles); the medium term (yearly) and over the short term (seasonally) with maximum water levels occurring in Spring (September-October) and minimum water levels occurring in Autumn (March-April).

Wetland plant communities are a reflection of past and current water regimes. Individual species respond to changes in water regimes which in turn influences community response. It is beneficial to maintain a water regime which supports existing conservation values.

The study by Froend *et al.* (1993) *The Effect of Altered Water Regimes on Wetland Plants* found within wetlands there was a zonation of typical vegetation that coincides with the gradient of the landscape as you move away from the wetland. At highest elevations typical species included *Melaleuca preissiana* and *Eucalyptus rudis* and at lower elevations emergent macrophytes such as *Typha orientalis* and *Baumea articulata* were dominant. This zoning in vegetation is related to the water regime gradient which follows the gradient of the landscape.

At the lower ends of the gradient, water levels are higher and further up the gradient, water levels fall. Within this gradient water levels vary seasonally as groundwater levels rise and fall over the year. Those species found at the base of the water regime gradient are able to withstand inundation for long periods while those at the upper end of the water regime gradient are more tolerant to drier conditions and prefer waterlogged soil rather than prolonged flooding. Species living in between these two extremes are able to withstand the stresses associated with inundation and drier conditions.

Froend (1993) found that *B. articulata* and *T. orientalis* occurred in a range where the average maximum depth of groundwater was approximately 1m above the ground surface to a minimum average water depth of 1 m below the ground surface. The range of duration of inundation for *B. articulata* was found to be from 5.8 per cent of the year at the dry end of the water regime gradient to 74.2 per cent of the year at the wettest end of the gradient. The range for *T. orientalis* was 7.2 - 81.3 per cent of the year. Therefore these species can tolerate a wide variation in duration of inundation.

Froend *et al.*, (1993) investigated how altered water regimes affect the growth and reproduction of particular species. Those at the extreme ends of the elevation gradient were found to have reduced growth and reproductive rates. Timing of maximum productivity and reproductive activity was found to vary along the water regime gradient.

Long term changes in water regime will affect wetland plant communities. If average water levels rise then it is likely that there will be a gradual shift of vegetation up-gradient and a lowering of the water table is likely to result in a gradual shift of vegetation down gradient.

Water regimes in wetlands may be affected by abstraction of groundwater, clearing of the catchment or drainage into or out of the wetland. These are typical impacts on wetlands adjacent to or within urban catchments (Froend and McComb, 1994).

8.3.2 Managing Perth's wetlands to conserve the aquatic fauna *(Wetlands of the Swan Coastal Plain, Volume 5)*

This report by Balla and Davis (1993) studied the effect of changing water levels and nutrient enrichment in wetlands on aquatic invertebrates to determine how best to manage Perth's wetlands to conserve their fauna.

Wetlands on the Swan Coastal Plain have a predictable seasonal variation in water levels in response to climate. Water levels are greatest between August and November due to rises in groundwater with winter rainfall. In seasonal wetlands drying then occurs for 4-5 months between December and April. The period of drying may be longer if rainfall has been low in previous years.

Invertebrate fauna are adapted to these seasonal variations. Balla and Davis (1993) found that the lifecycles of invertebrates are synchronised so that they are completed while the seasonal wetlands contain water, and within this period are staggered, so that different species do not compete with each other. Those species which complete their lifecycles in late summer, autumn or winter are most vulnerable to the timing of drying and refill. If drying occurs early for example, a species may die before it reproduces.

Balla and Davis (1993) found that features of both permanent and seasonal wetlands are required by aquatic fauna. Some mobile fauna disperse from seasonal wetlands to permanent wetlands when seasonal wetlands are dry; others migrate from permanent to seasonal wetlands to reproduce; some have adapted to drying by evolving a desiccation resistant phase; some species rely on the cues associated with the drying of seasonal wetlands to stimulate stages in their life histories and some non-mobile fauna require permanent water and complete their lifecycles in permanent wetlands.

Balla and Davis (1993) concluded that a mosaic of wetland types must be maintained and that within the two broad wetland types a variety of different characteristics should be conserved. Impacts on wetlands should be managed so that seasonal fluctuations are maintained. The most detrimental impacts include drainage and runoff into wetlands which can cause seasonal wetlands to become permanent. Groundwater abstraction can also impact on seasonal fluctuations in wetlands by causing earlier drying or an increased rate of drying.

Balla and Davis (1993) recommended seasonal wetlands not to dry before December and the rate of drying not to exceed 2 cm/day. The study also recommends autumn minimum water levels not to fall below previous minimums for a period greater than one year and that if a wetland is to be artificially maintained it should be topped up in Spring rather than in Autumn to follow the normal pattern of wetland flooding. The flooding of fringing vegetation in Spring provides the food source and shelter aquatic fauna require

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8.3.3 Waterbird usage of wetlands on the Swan Coastal Plain *(Wetlands of the Swan Coastal Plain, Volume 7)*

Storey *et al.* (1993a) investigated the relationship between environmental characteristics in wetlands of the Swan Coastal Plain and their relationship with waterbird usage. A range of wetland types were used in the study including permanent and seasonal swamps, winter wet areas, river sections, drains, estuaries and artificial wetlands.

The eight surveys conducted over two years were insufficient to produce complete species lists for half the wetlands. The study recorded 79 species of which 39 were recorded breeding.

Wetlands found to be important as drought refuges and to support large numbers of birds have also been found to be important in previous studies (Jaensch *et al.*, 1988; Van Delft, 1988). However in the study the wetlands found to be most important for breeding were not already known to be important. It is thought that there are sites on the Swan Coastal Plain which are important for breeding which have not yet been identified.

The data collected in the study on the breeding and abundance of waterbird species at each wetland were used to classify the wetlands into groups supporting the same types of waterbirds. A list of environmental variables found to positively correlate with waterbird groups and species was identified. However, generally wetland classifications based on environmental characteristics were not found to be completely successful in predicting waterbird usage, nor were wetland types. The few generalisations that can be made are:

- bigger wetlands support more birds;
- wetlands with complex vegetation and high primary productivity support more waterbirds;
- most species prefer freshwater; and
- for breeding water levels greater than 0.5 m and wetlands with complex vegetation and fish are favoured sites.

Because only broad general relationships between waterbird usage and wetland characteristics could be identified, it was recommended that any wetland management with the aim of supporting waterbirds should be done on a wetland by wetland basis. Management of each wetland should incorporate all available information on waterbird biology and wetland processes.

8.3.4 Wetland classification on the basis of water quality and invertebrate community data *(Wetlands of the Swan Coastal Plain, Volume 6)*

In a study by Davis *et al.*, (1993), 41 wetlands on the Swan Coastal Plain were classified and ordinated to obtain groups of wetlands with similar assemblages of invertebrates. These groups were related to chemical and environmental variables. The study found the main environmental factors which effect invertebrate fauna to be eutrophication, colour, salinity and seasonality. The study produced some water quality management objectives and monitoring suggestions.

8.3.5 Interaction between lakes, wetlands and unconfined aquifers *(Wetlands of the Swan Coastal Plain, Volume 3)*

The interaction between wetlands and unconfined aquifers was studied to identify capture zones, the management of water levels, and develop effective parameters for groundwater flow models.

The majority of lakes on the Swan Coastal Plain act as flow through lakes which capture groundwater on their upgradient side and discharge lakewater on their downgradient side. Two dimensional models were developed to study the shape of the capture and release zones as a function of nearby aquifer flows and net groundwater recharge.

8.3.6 Wetlands of the Swan Coastal Plain - their nature and management *(Volume 1)*

This report by Balla (1994) provides a synthesis of current knowledge on wetlands on the Swan Coastal Plain and management issues associated with these wetlands. It also provides current ideas for addressing wetland management problems.

8.3.7 Wetland mapping, classification and evaluation *(Wetlands of the Swan Coastal Plain, Volume 2)*

This volume by Hill *et al.*, (1996) is a technical volume which details the methods of evaluation and classification of wetlands. It also provides preliminary evaluation and classification information for the wetlands of the Swan Coastal Plain including mapping from Moore River to Mandurah and Pinjarra to Dunsborough.

8.3.8 Value of wetland research

The wetland research discussed above is beneficial to the East Gnangara PER as it provides a significant insight into the requirements of wetlands in terms of water regimes. Research on vegetation water regime requirements is most beneficial for determining EWRs as vegetation cover has a great influence on the health of the wetland. This is discussed further below. Information on the requirements of aquatic fauna and avian fauna also aids in the setting of EWRs.

8.4 Some issues taken into consideration when setting EWRs

8.4.1 State of wetlands: should we be maintaining or improving current values (past vs present)

Due to past activities many wetlands have become degraded through direct impacts or indirectly through activities in the catchment. For example, wetlands in the pine forest within the East Gnangara study area have become degraded through the clearing of buffer vegetation for pines. The pines have contributed to a drawdown in water levels in these wetlands. The wetlands are also suffering from weed invasion including the invasion of pine 'wildings'.

There are however, wetlands within the study boundary which are in relatively pristine condition compared to other wetlands on the Swan Coastal Plain. For example, the Lexia wetlands are not affected by typical impacts such as nutrient enrichment, weed invasion, clearing of buffer vegetation, infill or drainage.

Land-use impacts interact with climate to determine water levels in wetlands. For wetlands not impacted by land-use activities, the below average rainfall since 1975 has led to changes in wetland vegetation.

EWRs are established with the aim of maintaining current values. In other words a 'snapshot' approach is adopted. This approach has been taken rather than trying to identify conditions that prevailed before land-use developments in the area. It would be economically and socially unacceptable to return hydrological regimes to pre-development patterns because of extensive changes in land-use that has occurred. It is also difficult to determine what water regimes did prevail in the past due to the absence of monitoring data and lack of research on the extent of individual impacts on wetlands. Climate has also had an impact on hydrological regimes. Climatic fluctuations are natural and wetlands are adapted to respond accordingly.

The approach to setting water levels has been to identify existing values and develop criteria to protect these values. This approach was taken by the EPA in the assessment of the *Gnangara Mound Environmental Review and Management Programme* (Dames and Moore, 1986) and the *Gnangara Mound Groundwater Resources-Review of Proposed Changes to Environmental Conditions, Section 46* (WAWA, 1995a) in setting minimum water level requirements for wetlands on the Gnangara Mound (EPA, 1987; EPA, 1996).

8.4.2 Need to maintain natural variation in water levels

Wetland water levels fluctuate seasonally in response to rainfall. Therefore wetland water levels will reflect the climatic conditions of the time. For example, after a year with an above average rainfall, water levels in a wetland will be high at the end of winter and the wetland may take longer to dry over summer or not reach as low a minimum water level at the end of summer as in previous years. Alternatively, after a dry year water levels will not reach as high a maximum as past years and the wetland may dry out earlier and reach a lower minimum water level. Therefore environmental water level requirements must have some degree of flexibility to allow for these fluctuations in climate.

In an ideal situation wetland water levels should fluctuate to represent the previous year's rainfall, however it is not practical to adjust water levels to reflect the climatic situation. Variability needs to be balanced with practical management approaches. In other words an Environmental Water Requirement should be set which is satisfactory for the majority of years. However there should be a degree of deviation permitted in some years to allow for climatic impacts on the wetlands.

Long term review of EWRs is also needed to account for any long term changes in climate. For example, when there has been a long period of below average rainfall it may be necessary to have a greater permissible frequency of deviations from the minimum water level requirements. Alternatively it may be necessary to change the minimum water level requirements to reflect the current situation.

8.4.3 Frequency of permitted deviations

The *Gnangara Section 46 Report* (WAWA, 1995a) established that wetland vegetation can tolerate high or low water levels at a deviation of 2 in 6 years. Therefore EWRs have been established with an allowance for deviation from minimum water level requirements at this frequency.

The result of this is that an absolute minimum water level has been determined for each wetland in addition to a minimum water level. The minimum water level can be breached at a frequency of 2 in 6 years. The absolute minimum water level is not to be breached. Allowing a deviation from minimum water levels provides a degree of natural variation as would be expected in response to low rainfall years.

8.4.4 Need for formal review of water level requirements

One of the specific objectives of the wetland research projects discussed above was to provide information about the interactions between wetland components and water levels which could be used in refining water level criteria. The projects have been very successful in this respect, and much more is now known about the water requirements of wetlands. However, it must be recognised that compared to the complexity of wetland processes, current knowledge is still limited. Using the research results to develop criteria which will protect a set of identified values is still somewhat 'experimental'. An appropriate degree of caution is applied.

A straightforward mechanism where water level criteria are reviewed on a regular basis is required. Therefore it is important that the environmental criteria are subject to variation, as and when necessary. It is also proposed that mandatory review of the criteria should take place at a minimum of every six years, as a part of triennial reporting to EPA. This would report on the monitoring programme, and recommend any changes in criteria to the EPA. However, reviews should be able to take place at any time that additional information becomes available.

Given the level of community interest in the wetlands the review of water levels should be a public process, with opportunity for public input.

A proposed six-year-time frame for review is based partly on the existing reporting timetables for other areas of the Gnangara Mound and the Jandakot Mound, but also on the response time of wetlands to water regimes. Three years is considered too short a period to reliably quantify the response of the wetland to water level management practises. A six-year time frame should provide a better indication of the impact of any changes in water regime.

8.4.5 Lowest peak water levels

As discussed in Section 8.3.2, Balla and Davis (1993) conducted a detailed study of six wetlands on the Swan Coastal Plain and found that it is better to maintain water in a wetland in spring to allow the time and conditions (eg, flooding of vegetation) required for aquatic invertebrates to complete their life cycles rather than maintain a pool of water at the end of summer. Therefore for some wetlands it is better to set minimum peak water levels to be reached in spring rather than absolute minimum water levels to prevail towards autumn.

The study by Balla and Davis (1993) also suggests that seasonal wetlands should not be dry before December in order for invertebrates dependent on the seasonal occurrence of water to complete their lifecycles.

In the East Gnangara study area the majority of wetlands which have been selected for EWRs are not likely to have contained water for the period of time water was found to occur in the six wetlands studied by Balla and Davis (1993). They are drier than the seasonal wetlands studied by Balla and Davis (1993). It is recognised that there is a lack of information on these types of wetlands and the sumpland work by Balla and Davis (1993) is not directly relevant to the wetlands in East Gnangara which include the drier type sumplands and dampland areas. However, funds for a research project have recently been obtained through the Land and Water Resources Research and Development Corporation, Water and Rivers Commission and Water Corporation to further investigate water requirements of groundwater dependent vegetation. Dr R. Froend will be the principal investigator for the project. The research will include investigations into water requirements of dampland vegetation and is discussed further in Section 16.5.

8.4.6 Maximum water levels

As discussed, wetlands can be impacted by activities in their catchment. This includes increasing water levels above natural regimes. This is a common problem in urban areas, and on the Swan Coastal Plain in general, and is one of the main impacts on wetlands. For example, in some areas where there was once seasonal wetlands they have become permanent, due to clearing of the catchment and/or drainage into the wetland.

As a water resource manager the Water and Rivers Commission has the responsibility to advise other agencies of the impacts of land-use on water resources. Therefore indications of acceptable maximum water levels to maintain wetland values are provided (see Sections 9.1 and 9.2).

8.5 Application of wetland research in setting EWRs

The setting of EWRs has been based on the principle that wetland vegetation water requirements reflect the water needs of the whole wetland. Impacts on wetland vegetation are likely to be expressed in other components of the wetland system. Vegetation has a significant impact on the health of a wetland as it performs several functions including the provision of:

- food and shelter for aquatic invertebrate fauna;
- organic input (which colours wetlands) in the form of leaf litter and other debris;
- shading of the littoral zone;
- a buffer to nutrients and other pollutants; and
- breeding habitat, shelter and food for waterbirds.

Vegetation is an important component of a wetland ecosystem. Therefore protection of vegetation will play an important role in maintaining the functioning of a wetland. Identifying water requirements for a major component of an ecosystem should ensure other components are protected due to their interdependent nature.

Particular wetland plant species are adapted to particular water regimes. To maintain these species at their current distribution, these water regimes must be maintained in the long term. Therefore findings from the study *The Effects of Altered Water Regimes on Wetland Plants* (Froend *et al.*, 1993) are important in setting EWRs. Dr R. Froend has had a direct involvement in the establishment of the EWRs.

Figure 15 is a diagrammatic example which illustrates how EWRs are determined. Lexia wetland 86 is dominated by *Baumea articulata* in the base of the wetland and *Melaleuca preissiana* at the fringe of the wetland. The maximum water level requirement is 0.5m above ground, the minimum water level requirement 1 m below ground and the absolute minimum 1.3 m below ground.

The findings of Froend *et al.* (1993) indicate that *Baumea articulata* occurs where water regimes are between 1m below ground and 1m above ground. These levels are the extremes within which the species has been found to tolerate. In the case of Lexia wetland 86, *B. articulata* occurs within an average water regime range of 0.2 m above ground to 1m below ground.

Lexia wetland 86 contains only shallow open water and water levels do not reach 1 m above ground. *B. articulata* occurs from the point where maximum water levels occur in the centre of the wetland (point A - at 0.2 m above ground) out to a point where water levels occur 1 m below ground on average at the end of summer (point B). Therefore due to the requirements of *B. articulata*, minimum water levels have been set at 1 m below ground.

The minimum water level criteria can be breached at a rate of 2 in 6 years. Therefore absolute minimum water levels have also been determined. The absolute minimum water level which the vegetation is likely to tolerate is 1.3m below ground. In other words the minimum water level (1m below ground) is able to be breached 2 in 6 years to an absolute minimum of 1.3m below ground. The reason for this (as discussed above in Section 8.4.6) is that wetland vegetation is thought to be able to tolerate high or low water levels at this frequency and it allows for natural variation in water levels due to dry years.

Maximum water level requirements have also been determined using knowledge of water regime impacts on *B. articulata* and observations of water levels in the wetland. *B. articulata* in the centre of the wetland was observed to be healthy and vigorous in growth. Therefore it is not occurring at the outer levels of tolerance in its regime and maximum water levels are expected to be less than 1m above ground. It was estimated that average maximum levels are likely to be 0.2 m above ground and 0.5 m at a maximum after a wet year.

The other vegetation in and fringing the wetland is also adapted to the regime outlined. At the drier end of the water regime (upgradient of *B. articulata*) the growth of *Melaleuca preissiana* is favoured.

Section 9.1 discusses evidence that the Lexia wetlands are perched (i.e. underlain by a layer such as heavy peat or clay resulting in the water in the wetland and the groundwater to not be in direct contact). Therefore the wetlands may be fed mainly by rainfall rather than directly by groundwater. If this is the case, wetland water levels will be largely independent of groundwater levels. Therefore, the wetland water level requirements listed above will be relevant for the wetland area above the perched layer only, and meeting the wetland water level requirement will mostly depend on climate.

As the degree of perching is not known, the component of the water level requirement met by groundwater underlying the perched layer and surrounding the wetland cannot be determined at this stage. EWRs with regards to groundwater levels under the wetlands, have not been set for any of the wetlands in the study area which show evidence of perching. Further investigation is needed to determine the significance of groundwater to these wetlands and therefore the groundwater level requirements.

However, wetland water level requirements expressed as wetland basin water requirements have been determined based on the current vegetation assemblages. These basin wetland requirements are provided as interim EWRs of the wetland vegetation (whether made up of rainfall or some combination of rainfall and groundwater).

These interim EWRs will be reviewed and updated if necessary once further investigations have been carried out. Where survey information is available the basin water requirements provided have been converted to Australian Height Datum (AHD) However at this stage, there is not enough information to convert the criteria at EPP wetland 173 in Melaleuca Park. The future review and update of the EWRs will include development of a water requirement for groundwater underneath and surrounding the wetland basin, in addition to the basin criteria. These criteria will be in the form of minimum water level requirements in monitoring wells outside of the wetland basin. It is the groundwater component which is important because this is impacted by abstraction activity. If investigations show that the wetlands are totally perched with no dependence on groundwater then the regional groundwater level monitoring well requirements will become the EWRs.

In addition to an investigation into the stratigraphy and water regimes of the perched wetland areas by the Water and Rivers Commission, the interaction of perching with wetland vegetation water requirements will be considered within the research project by Dr R. Froend on water requirements of dampland and phreatophytic vegetation (see Section 16.5). The Lexia wetlands will be included as one of the study sites.

The requirements of aquatic invertebrate species is also taken into consideration in setting EWRs. In seasonal wetlands supporting invertebrates minimum water levels will be set to provide water for the period necessary to enable invertebrates to complete their lifecycles and so that the wetland receives enough water for sedge vegetation to become inundated in Spring.

The Water and Rivers Commission does not know what invertebrate species are present in half the selected wetlands. Baseline sampling of invertebrate populations was conducted in the Lexia wetlands in spring 1996 for the Water and Rivers Commission but results are not yet available. Wetland water requirements will be cross-checked with the requirements of any invertebrate fauna.

EWRs will be finalised in the first triennial report to the EPA.

9. Environmental Water Requirements for selected wetlands

The group of wetlands selected for determination of EWRs and the methodology used in their selection is presented in Section 8.1. The methodology, research and approaches taken in determining the EWRs are presented in Sections 8.2 - 8.5.

9.1 The Lexia (Ellenbrook) wetlands

Figure 14 illustrates the location of the Lexia wetlands and the numbering that has been assigned on the WAWA wetland management and conservation estate map series (WAWA, 1993).

The Lexia wetlands are seasonal. Some are seasonally inundated 'sumplands' which contain some free water at the end of winter/spring. The majority of the wetlands, however, are 'damplands' which become seasonally waterlogged (Bowman, Bishaw, Gorham, 1993).

Stratigraphy

There is evidence to indicate the Lexia wetlands are perched to some degree. The V & C Semeniuk Research Group (1993) conducted an investigation into the stratigraphy and groundwater in the north-east corridor. This investigation explored the relationship between groundwater levels and the land surface. It included stratigraphic sampling along a transect through the eastern Lexia wetlands. The sample locations along the transect are illustrated in Figure 16 (Sites D1 to D10).

Stratigraphic samples were obtained by hand auguring shallow piezometers and installing deeper piezometers using a reverse air circulation rig. Samples were collected at intervals as the drilling took place. The 'deep' piezometers are those that sample below the perched layer, the 'shallow' above the perched layer. Water levels were monitored in the piezometers over a nine month period. Water levels in each piezometer along the transect are provided in Appendix 4. Well locations are provided in Figure 16.

Wells D8 and D9 are located within Lexia wetland 94 (the eastern most wetland selected for EWRs). The investigation found that at D8 there is some perching due to the presence of a wetland peat bed. There were different water levels between the deep and shallow wells in this position. Water levels measured are found in Figure 17A and B.

The investigation also found that the region between D1 and D5 was perched due to the presence of a buried ferricrete layer. Wells D1 and D2 are located in a smaller wetland to the east of Lexia wetland 94. There was a difference in water levels between the deep and shallow wells in this area. The shallow wells at D1, D2, D3, D4 and D5 had water levels above that of the deep well at D1 (V & C Semeniuk, 1993).

Water levels respond seasonally to rainfall. They rise with winter rainfall recharge and fall with summer evaporation. The shallow wells at D8 and D1-D5 responded faster to these trends than the deeper wells at D8 and D1 over the period of monitoring conducted by the Semeniuks (1993). This is a strong indication that perching exists.

Bowman, Bishaw, Gorham (1993c) also found some evidence of perching in Lexia wetland 94. The water level in the wetland was found to be 1 - 1.5 m higher than in nearby groundwater monitoring wells upgradient and downgradient of the wetland. This suggests that the water levels in the wetlands may be independent of fluctuations in groundwater in the surrounding aquifer. Therefore Bowman, Bishaw, Gorham (1993c) concluded that the Lexia wetlands are thought to be largely dependent on rainfall.

As mentioned above, the Water and Rivers Commission will conduct further investigations into the degree of perching for the Lexia wetlands in order to refine EWRs.

Water levels

There has been very little monitoring of water levels in the other Lexia wetlands. Water levels in Lexia wetland

94 measured by the V & C Semeniuk Group (1993) and Bowman, Bishaw, Gorham are shown in Figures 17A and 17B and discussed in following sections.

Water Quality

Water quality in the Lexia wetlands was examined in August 1990 (after winter rainfall) by Dames and Moore (1992). The wetlands were found to have a low pH, a low total dissolved solids (TDS) concentration and high concentrations of total phosphorus, orthophosphate, total kjeldahl nitrogen and ammonium-nitrogen in comparison to other wetlands on the Swan Coastal Plain. The Lexia wetlands would be classified as eutrophic to hypereutrophic using Wetzel's (1975) classification based on these nutrient concentrations (Dames and Moore, 1992). The data for each wetland and a comparison to other wetlands on the Swan Coastal Plain can be found in Dames and Moore (1992)

These results indicate that the wetlands are naturally high in nutrients due to high levels of bioproductivity rather than elevated nutrients due to land-use impacts as is the case in many other wetlands on the Swan Coastal Plain. The low TDS readings reflect a lack of mixing from waters containing sodium chloride and other minerals (Dames and Moore, 1992).

Wetland Vegetation

Dames and Moore (1992) describe the vegetation that occurs along various transects surveyed throughout the Lexia wetlands. The vegetation associations were found to be heterogeneous throughout the area. The vegetation in the western sector of the wetlands group was found to be different in floristics and structure from the vegetation in the eastern Lexia wetlands. The vegetation typically forms overlapping concentric bands around the wetlands. In the western sector, where the wetlands are of a seasonal nature, there are higher numbers of bands than in the eastern sector where the wetlands are of a dampland nature. However in the eastern sector the vegetation bands are more varied in their structure and species composition. A typical structure of vegetation bands in the Lexia wetlands (taken from Dames and Moore, 1990) is as follows:

i) jointed Twig Rush (*Baumea articulata*) in the deepest, usually winter inundated area, often with *Villarsia albiflora*;

ii) *Astartea fascicularis* or tereteleaved sedges (*Baumea acuta* and *Lepidosperma tenue*) or both, sometimes *Melaleuca teretetifolia* or *M. lateritia;*

iii) Moonah Paperbark (*Melaleuca preissiana*), often with *Lepidosperma;*

iv) Dense *Pericalymma ellipticum* Swamp Teatree Shrubland;

v) *Hypocalymma angustifolium,* often with *Euchilopsis linearis, Platytheca galioides* and *Pultenea* sp.; and

vi) Tereteleaved sedges (*Baumea acuta* and *Lepidosperma tenue*) with one or more species of orchids.

The sequence of vegetation bands described here are often lower in number or mixed depending on the wetland (Dames and Moore, 1990). There are also some priority flora found to occur in the woodlands surrounding the Lexia wetlands (Dames and Moore, 1990).

The value of the Lexia wetlands

The Lexia wetlands can be considered unique when compared to other wetlands on the Swan Coastal Plain. The wetlands are undisturbed by typical impacts such as nutrient enrichment, weed invasion, changes in water levels due to changes in surrounding land-uses (with the exception of establishment of pine plantation) and in-fill or drainage to provide land for other uses.

The wetlands are diverse in their vegetation. There is a differing floristic structure between the western and eastern sections (Dames and Moore, 1992). The Lexia wetlands are also unique in that they form a large intact system that is linked hydrologically and represents a significant wildlife habitat. The woodlands around the wetlands support fauna including the Southern Brown Bandicoot (*Isoodon obesulus*) which is gazetted as rare (Dames and Moore, 1992). The wetlands also exhibit a naturally high level of nutrients which is indicative of naturally high productivity.

The Lexia wetlands are classified 'conservation' both collectively and individually using the EPA Bulletin 686 (1993a), and the majority of them are protected under *the Environmental Protection (Swan Coastal*

Plain Lakes) Policy, 1992. The wetlands also fall within an area nominated for inclusion on the interim list of the National Estate (Australian Heritage Commission, 1994) and are listed on the National Trust (J. Blake, pers. comm.).

The Approach to Management of the Lexia Wetlands

Due to the high conservation value of the Lexia wetlands an appropriate management objective is to conserve ecological values. An appropriate water regime objective which is likely to achieve this result is one which will maintain current vegetation assemblages in and fringing the wetlands and to protect any fauna dependent on the wetlands.

Determination of the existing water regime which achieves this function was assisted by comparing wetland plant distribution with known relationships between wetland vegetation and water regimes (Froend *et al.*, 1993). Observations of the wetland vegetation were made in April 1995 and water regimes for each wetland were estimated. Vegetation distribution, composition and productivity are good indicators of water regime as each species has particular requirements for water availability (Froend *et al.*, 1993; Froend and McComb, 1994).

As discussed in Section 8.5 vegetation is a major component of a wetland ecosystem and has a strong influence on the conservation value of a wetland. If vegetation is protected then many other values of a wetland are supported. The water regimes presented below are predicted from observations of the vegetation. As discussed EWRs will be updated after investigating the interaction between wetland water regimes and groundwater.

9.1.1 Lexia wetland 1 (Wetland 94)

Water levels

There is no long term data available on water levels in the Lexia wetlands. In August 1990 (after winter rainfall), Dames and Moore (1992) measured water levels in this wetland and found water levels to be within 1 cm of the surface.

The V & C Semeniuk Research Group (1993) has monitored water levels in the east of wetland 94 from May 1993 until December 1993. The results are given in Figure 17A. Water levels above the perched layer varied from 1.2 m below the surface at the end of summer to 0.03 m below the surface at the end of winter. WAWA measurement of water levels in the same monitoring well (D8-shallow) in April 1995 (at the end of summer in a dry year) found water at 1.5 m below the surface.

Bowman Bishaw Gorham also monitored water levels above the perched layer on the eastern side of Lexia wetland 94 from January 1994 to December 1994. This monitoring is provided in Figure 17B. Water levels varied from 1.2m below the surface at the end of summer 1993 to approximately 0.35m below the surface after winter rains.

From aerial photographic interpretation Bowman Bishaw Gorham (1995c) estimated that the historical maximum water levels in the Lexia wetlands was 47.8 mAHD and historical minimum water levels 45.8 mAHD with a normal seasonal fluctuation of approximately 1 m. Under this scenario water depths in the wetlands would have reached up to 1m above the surface at maximum water levels and approximately 1.5 m below the surface at minimum water levels (Bowman Bishaw Gorham, 1993c).

Bowman Bishaw Gorham (1993c) suggest that the Lexia wetlands were once wetter than they are at present. It appears that dampland vegetation has begun to take over in areas which were in the past dominated by sumpland vegetation types. Bowman Bishaw Gorham (1993c) suggest that climatic effects (below average rainfall over the last 20 years) and groundwater drawdown from the planting of pines has been the cause of these effects. The degree of influence of groundwater drawdown does however depend on the degree of perching in the wetland. Dames and Moore (1992) also suggest that the wetlands were once wetter. They found evidence of peat below sand outside the main part of the sumpland areas. This suggests that the wetlands were larger in the past.

Vegetation

An assessment of vegetation in Lexia wetland 94 by Dr Froend found that the dominant vegetation in the wetland was *Leptospermum erubescens*. *Leptocarpus tenax* was also present throughout the wetland.

Using this information it is likely that the wetland is rainfall driven and becomes waterlogged at the surface in winter. In above average rainfall years the wetland will contain some surface water. The water then evaporates over summer falling to approximately 1m (or 1.5 m in a dry year) below the surface. During an average summer and following an average winter the soil will remain moist where peat is found at or near the surface.

Wetland management objective and water level requirements within the basin of Lexia wetland 1 (wetland 94)

Management Objective

- To conserve ecological values

Water regime management objective

- Protect current vegetation assemblages in and fringing the wetlands

Basin Water Requirements (Interim Environmental Water Requirement)

- Maximum: 0.2m above ground (47.5 mAHD)
- Minimum: 1.5m below ground (45.8 mAHD)
- Absolute minimum 1.8m (45.5 mAHD)

Minimum water levels should not be breached more than two years in every six years. Absolute minimum water levels must not be breached.

9.1.2 Lexia wetland 2 (wetland 86)

Wetland 86 was dry at the end of the 1994-95 summer. The bed of the wetland has a peat layer in which *Baumea articulata* dominates. Around the outskirts of the wetland *Melaleuca preissiana* is the dominant species of fringing tree. The wetland also supports some *Banksia littoralis, Leptospermum erubescens, Baumea juncea, Astartea fascicularis* and *Jacksonia furcellata.*

It is estimated from an observation of the vegetation and a knowledge of the requirements of this vegetation that in an average year maximum water levels are likely to be 0.1 - 0.2 m above the ground surface and fall approximately 0.6 m below the surface at the end of summer. The peat in the basin has an excellent water holding capacity and retains moisture throughout summer as water levels fall.

In wet years the wetland is likely to have a maximum water level which is 0.5 m above the ground surface and in a dry year minimum groundwater levels would be approximately 0.8 - 1 m below the ground surface.

Due to the seasonal nature of the wetland there may be aquatic fauna living in the wetland which are adapted to this regime. (Research on invertebrate fauna is discussed above.)

Wetland management objective and water level requirements within the basin of Lexia wetland 2 (wetland 86)

Management Objective

- To conserve ecological values

Water regime management objective

- To protect current vegetation assemblages in and fringing the wetland
- To protect aquatic invertebrate fauna dependent on the wetland

Basin Water Requirement (Interim Environmental Water Requirement)

- Maximum: 0.5m above ground (48.8 mAHD)
- Minimum 1m below ground (47.3 mAHD)
- Absolute Minimum : 1.3m below ground (47 mAHD)

Minimum water levels should not be breached more than two years in every six years. Absolute minimum water levels must not be breached.

9.1.3 Lexia wetland 3 (wetland 186)

This wetland is located to the north of Lexia wetland 86. It is also a seasonal wetland but varies in the composition of vegetation it supports. This wetland is dominated by *Baumea articulata* in the centre and a fringe of *Melaleuca preissiana.* There are also other species occurring as mixed bands between the *Baumea* and *Melaleuca.* Species include *Banksia ilicifolia* and *Banksia attenuata, Leptospermum erubescens, Astartea fascicularis, Leptocarpus tenax* and *Lepidosperma gladiatum.* This wetland also supports a *Eucalyptus calophylla* fringe surrounding the *Melaleuca.*

The presence of these vegetation types indicates that on average maximum water levels are likely to reach

0.2 - 0.3 m above the ground surface and fall to approximately 0.5 - 0.6 m below the surface at the end of summer. There is a substantial layer of peat in the base of the wetland which holds moisture throughout summer.

In a wet year water levels are likely to reach a maximum of 0.5 m above the ground surface and in a dry year minimum groundwater levels may fall to 0.8 m below the surface.

Wetland management objective and water level requirements within the basin of Lexia wetland 3 (wetland 186)

Management Objective

- To conserve ecological values

Water Regime Management Objective

- To protect the vegetation assemblages in and fringing the wetland
- To protect invertebrate communities dependent on the wetland

Basin Water Requirement (Interim Environmental Water Requirement)

- Maximum: 0.5 m above ground (48.8 mAHD)
- Minimum: 0.8 m below ground (47.5 mAHD)
- Absolute minimum: 1.1 m below ground (47.2 mAHD)

Minimum water levels should not be breached more than two years in every six years. Absolute minimum water levels must not be breached.

Note : Minimum water levels recorded since monitoring commenced in April 1996 in the monitoring well GNM15 at the wetland have reached 47.2 mAHD. It is thought that this well is monitoring from the regional watertable rather than above the perched layer. The above levels relate to the basin perched water levels. Basin water levels will be reviewed and regional water level requirements set for the wetlands when investigation on perching investigation has been completed (see Section 8.5).

9.2 Melaleuca Park wetlands

Melaleuca Park has been identified as an area which should be set aside as a nature reserve (CALM, 1987). The management priority of the park is conservation of flora, fauna and landscape. Location 1497 within the boundaries of Melaleuca Park is private freehold land.

Melaleuca Park occurs on the Bassendean dunes and contains the most important remaining example of vegetation in State forest which is characteristic of the Bassendean North Complex (Department of Conservation and Environment, 1983).

The dunes are covered in low-woodland or low-open forest of *Banksia* species. Wetlands in Melaleuca Park are typically dominated by Paperbark and (White Myrtle) *Hypocalymma angustifolium* (Department of Conservation and Environment, 1983).

Melaleuca Park occupies an area of 3000 ha of which 10 per cent is wetlands. Most of the wetlands are damplands or sumplands. There are two permanent wetlands in the park which have been created due to peat mining in the base of the wetlands (Muir, 1983).

Physiography and Geological setting

The Melaleuca Park wetlands exist in the interdunal depressions of the Bassendean dunes (Muir, 1983), lake deposits being peaty clays of lacustrine origin (Arnold, 1990).

The form of each swamp reflects the dune patterns occurring in the area (Muir, 1983). The majority of the wetlands are less than 3 ha in size. However there are six large shallow swamps which are 16-40 ha in size and four small deep swamps 1-6 ha in size (Arnold, 1990). Two of the larger swamps within the park have been converted into permanent wetlands due to peat mining (Muir, 1983). Water depths in the wetlands range from 0.6 - 3.2 m (Muir, 1983).

Vegetation

Muir (1983) described the vegetation in the wetlands in Melaleuca Park. A typical zonation of vegetation was found. In the ecotones of the small deep swamps *Melaleuca preissiana* was found surrounded by *Astartea fascicularis* which zones into *Pultenaea veticulata* then woodland areas further from the wetland. The larger shallower swamps were found to contain a greater variety of vegetation types due to their broader, flatter slopes. These swamps had dominants and co-dominants such as *Eucalyptus rudis* (stratum 1), *Agonis linearifolia, Calothamus lateralis* or *Leptocarpus scariosus* (stratum 2) not found in the deeper wetlands (Muir, 1983).

The typical complete sequence of vegetation in the swamps of Melaleuca Park as described by Muir (1983) is given below. This sequence has small variations or is abbreviated depending on the individual wetland.

i) *Baumea articulata* in the wettest region of the wetland where water persists throughout summer;

ii) *Melaleuca preissiana* either covering the central area or existing as a band surrounding the *Baumea articulata*;

iii) *Leptospermum ellipticum* occurs most commonly where the incline of the swamp edge is shallowest and may become flooded in wet years;

iv) *Pultenaea reticulata* occurs on the upper slopes of the wetland where the soil is peaty and very wet but rarely becomes waterlogged. May be associated with *Regelia* or *Hypocalymma*;

v) *Regelia ciliata / Hypocalymma angustifolium* occurs in the upper slopes of the wetland where the soil is sandy and becomes wet but rarely waterlogged. May be associated with *Eucalyptus rudis;* and

vi) *Banksia* woodland. The transition to *Banksia* woodland may contain complex sub-ecotones of *Eucalyptus marginata, Dasypogon bromeliifolia* and *Xanthorrhoea preissii.*

Water Quality

Muir (1983) investigated pH and total dissolved solids concentrations in wetlands in Melaleuca Park when water levels were at their highest in August. Average values were pH 4.4 and TDS 200 mg.L^{-1} (Arnold,1990).

Davis *et al.* (1993) took water samples in October/ November 1989 from a seasonal swamp north of Neaves road, 13.2 km east of Pinjar Road. This wetland is highly coloured due to the presence of humic acids originating from leaf litter and other debris from the surrounding vegetation. It is surrounded by a 90 per cent covering of vegetation (Storey *et al.*, 1993a). The wetland was found to have a low pH, high turbidity, high concentrations of organic carbon, particulate phosphorus, total nitrogen and nitrite. The N:P ratio was found to be relatively high (Davis *et al.*, 1993). The wetland is classified as dystrophic (high levels of phosphorus but low levels of primary production) which is common for coloured wetlands (Davis *et al.*,1993).

Storey *et al.* (1993a) also found the wetland to be highly coloured and highly turbid. The high turbidity is a result of the lake being shallow and wind mixing disturbing the peaty sediments in the base of the wetland (Storey *et al.*, 1993a). Total filterable solids in this wetland were 226 mg.L^{-1} and the ions dominating the wetland were Na>Mg> Ca> K (Storey *et al.*, 1993a).

Water levels

There is evidence to suggest that wetland water levels in Melaleuca Park were previously higher. Muir (1983) provided evidence that drying has occurred as he found an occurrence of young stands of *Leptospermum ellipticum* inside stands of older trees and also the occurrence of *Melaleuca preissiana* inside a belt of *Melaleuca rhaphiophylla* (*Melaleuca preissiana* prefers drier soils). This supports the conclusion that new vegetation is developing in the inner ecotones of the wetland as the water level recedes. Muir (1983) also found evidence that sand from the adjacent dunes is moving into the swamps.

Monitoring of the groundwater levels in Melaleuca Park since the mid 1970s shows a steady decline in water levels. This is probably due to low rainfall, pine plantation and groundwater abstraction (WAWA, 1995a). Over this period there has also been a decrease in the number of drought vulnerable species and an increase in the number of drought tolerant species (WAWA, 1995a).

Fauna

Davis *et al.* (1993) sampled for aquatic invertebrate fauna in the seasonal swamp north of Neaves road (397200E, 6495900N) in October/November 1989 and 1990. There was a total of 29 species recorded at the wetland. Knott and Jasinska (1996, unpublished data) recently sampled aquatic invertebrate fauna in a seasonal swamp on the south-eastern boundary of Melaleuca Park as a part of investigations for the Water and Rivers Commission and found 42 species.

Gambusia holbrooki was observed in the wetland north of Neaves road when sampled in spring 1989 (Davis *et al.*, 1993). *Galaxiella nigrostriata* (a fish only previously found in the Walpole area) has recently been found in an EPP wetland on the south-eastern boundary of Melaleuca Park by Knott and Jasinska (1996).

Storey *et al.* (1993a) observed the Neaves Road wetland for waterbird species in 8 surveys conducted between April 1990 and January 1992. However no avian fauna were observed on any of the survey occasions.

Wetland values

Melaleuca Park has significant environmental and social values. The vegetation is the most important example of the coastal vegetation type characteristic of the Bassendean North Complex (Department of Conservation and Environment, 1983). The wetlands are significant in that they support swamp vegetation and aquatic invertebrate species.

The social values of the park are mainly related to bushwalking and wildflower observation. However some of the areas of the park are degraded because of four-wheel-driving and illegal rubbish dumping (Arnold 1990, Department of Conservation and Environment, 1983).

Many of the wetlands have undergone change due to reductions in water levels over previous years (Mattiske and Associates, 1989). Mining for peat has adversely effected some of the wetlands by reducing the extent and diversity of wetland plant communities (Arnold, 1990).

Management objectives

As a proposed nature reserve the purpose of Melaleuca Park is wildlife and landscape conservation, scientific study and preservation of features of archaeological, historic or scientific interest (CALM, 1987-1997).

Most of the sumplands and damplands within the Park have been given a preliminary conservation category in the studies undertaken by Murdoch University (1991).

The *Gnangara Section 46 Report* (WAWA, 1995a) reviewed environmental conditions on the Gnangara Mound and established management objectives and specific objectives for water level management for wetlands in Melaleuca Park. These are:

Management Objective

- To conserve wildlife and landscape values of wetlands.

Water Regime Management Objective

- Maintain the existing areas of wetlands and wetland vegetation.

In the *Gnangara Section 46 Report* (WAWA, 1995a) it was proposed to set actual EWRs for individual wetlands in Melaleuca Park in the first triennial report and to apply EWRs established for the protection of phreatophytic vegetation in the interim. Wetlands selected for application of water level requirements for this (East Gnangara) report as discussed in Section 9.2. They will be used for the requirements of *Gnangara Section 46 Report* (WAWA, 1995a).

The management objective for Melaleuca Park wetlands is the same as for the *Gnangara Section 46 Report* (WAWA, 1995a). Water requirements presented below are based on information available at present. EWRs will be updated when the necessary information on groundwater dependence becomes available.

Melaleuca Park wetlands selected for EWRs

9.2.1 Wetland in Melaleuca Park (wetland 173)

There is a group of three EPP *(Environmental Protection (Swan Coastal Plain Lakes) Policy, 1992)* wetlands on the south-eastern boundary of Melaleuca Park. They appear to be remnants of one larger wetland (Knott and Jasinska, 1996, unpublished data). The setting of EWRs is related to the largest most north-east wetland in the group. This wetland is highly coloured with several springs seeping into it from the western side (Knott and Jasinska, 1996, unpublished data). The wetland also has a creek running from its north-eastern end in a north easterly direction.

The vegetation in the wetland includes *Baumea articulata* in the centre and fringing *Melalueca preissiana*. Other species include *Leptocarpus* species, *Astartea fascicuris, Calothamnus lateralis* and *Lepidosperma longitudinalis*. The *Baumea* is more vigorous in growth than in the Lexia wetlands. It is inferred therefore that this wetland has a wetter regime than those at Lexia. There was also evidence of higher water levels in the past. High water marks were evident on the trunks of the trees (approximately one metre high).

Invertebrate sampling of this wetland and creek was carried out for WAWA in November 1995 (Knott and Jasinska, 1996, unpublished data). The swamp was found to have a high diversity with a total of 42 species. Several of the cladoceran crustaceans have only previously been recorded from highly coloured, acidic sumplands between Walpole and Windy Harbour (Knott and Jasinska, 1996, unpublished data). A crayfish, 3 species of frog and a rare fish *Galaxiella nigrostriata* which is only known to occur in a small area around Walpole were also found at this time (Knott and Jasinska, 1996). The water requirements of the invertebrates and fish are inconclusive at this stage. However research on the fish population is currently being carried out by Smith and Knott from the University of Western Australia.

Water quality sampling was conducted at the same time as the invertebrate sampling. Temperature, conductivity and dissolved solids gradients were present at the time of sampling. Anaerobic sediments were noted in the western area of the swamp. The pH ranged from 3.7 - 3.8, dissolved oxygen was 6.2 - 6.7 mg/L at the bottom of the wetland, 6.9 mg/L at the surface and 5.6-6 mg/L in the creek (Jasinska and Knott, 1995).

Wetland 173 is likely to contain open water for half the year. A typical maximum water level for an average year is likely to be 0.4 m - 0.5 m above the surface at the end of the winter rainfall period (based on the vegetation). Measurement of water depth in November 1995 in the north eastern wetland found depths to range between 0.5 m - 0.7 m at deeper parts of the wetland (Jasinska and Knott, 1995). The creek coming from the wetland flows throughout winter with water depths to 0.3 m.

The water in the wetland evaporates over the summer months and water levels fall below the ground surface. Autumn water levels have been found to be greater than or below 1 m below the surface at the edge of the stand of *Baumea* towards the centre of the wetland. However, the western sector of the wetland maintains some surface water due to the presence of the springs. Water levels in this area have been found to be 0.1 - 0.3 m above ground in late summer/autumn (E. Jasinska, pers. comm.).

It is likely that this wetland is perched and relying upon water from the springs and rainfall rather than being a direct groundwater expression during the summer/ autumn period. It is believed that maintenance of the current water regime is the best approach to protecting fish, invertebrates and vegetation. Therefore it is important to maintain the supply of water from the springs as they appear to be the most important contributor apart from rainfall to current regimes.

Interim EWRs have been determined based on information currently available. Further research will be conducted into water regimes, perching of the wetland and the water requirements of the fish and invertebrates. EWRs will be updated as the necessary information becomes available. EWRs will also be set for a monitoring well upstream of the springs.

Management Objectives and Water Requirements for EPP wetland 173

Management Objective

- To conserve wildlife and landscape values of the wetland

Water Regime Management Objective

- To maintain existing areas of wetland and stream and vegetation they support.
- To protect the invertebrate communities dependent on the wetland and stream.
- To protect the fish species, *Galaxiella nigrostriata.*

Water Regime Management Strategy

- Maintain a permanent flow of water from the springs entering the wetland on the western edge.

Interim Environmental Water Requirement

- Maximum: 1m above ground (at the deepest point).
- Minimum: 0.1m above ground (at the western edge).
- Absolute Minimum: 0.1m above ground (fish may require small puddles of water)

9.2.2 Melaleuca Park dampland 78

Wetland 78 is a dampland located in the south western region of Melaleuca Park. Dominant vegetation includes *Melaleuca preissiana* and *Banksia ilicifolia* growing in the bed and on the fringe of the dampland. There are several myrtaceaeous shrubs growing within the wetland. These include *Kunzea, Astartea, Leptocarpus,* and *Regelia.*

This dampland appears to have become drier in recent years as indicated by the growth of young *Banksia ilicifolia* in the bed of the wetland and the dying *Melaleuca preissiana* on the fringe of the wetland. It appears that low rainfall and hot summers has caused vegetation with a preference for drier conditions to establish within at least the last 5 years (R. Froend, pers. comm.). It is unlikely that groundwater abstraction would have significantly depleted water levels in the vicinity of the dampland.

This wetland is likely to contain water within 4.5 m of the surface at the end of the winter rainfall period and fall to approximately 5 m below the surface at the end of summer, based on limited monitoring data and the vegetation present. The vegetation present has been known to occur in areas where water levels are relatively close to the surface and in areas where depth to groundwater is 6 m.

Management Objectives and Water Requirements for Melaleuca Park dampland 78

Management Objective

- To conserve wildlife and landscape values of the wetland.

Water Regime Management Objective

- To maintain existing area of wetland vegetation.

Interim Environmental Water Requirement

- Maximum: 4 m below ground (66.9 mAHD)
- Minimum: 5.5 m below ground (65.4 mAHD)
- Absolute minimum: 5.8 m below ground (65.1 mAHD)

Minimum water levels should not be breached more than two years in every six years. Absolute minimum water levels are not to be breached.

10. Environmental Water Requirements for springs and seepages

10. 1. Selection of springs/seepages

Springs and seepages in the Ellen Brook catchment area were identified and investigated in terms of physicochemical characteristics and aquatic invertebrate fauna, for WAWA in 1994 (Jasinska and Knott, 1994). Some of the springs and seepages identified in this investigation were then selected as representatives of all springs and seepages within the East Gnangara study boundary. As for wetlands it is unnecessary and impractical to set EWRs for all springs and seepages in the area, but more appropriate to set EWRs for a representative sample of springs and seepages or those with the highest conservation values.

The two main considerations in selecting springs/ seepages for EWRs were:

- The conservation significance in terms of the vegetation and invertebrate fauna present at the site; and
- The likelihood of the spring/seepage being impacted by groundwater abstraction from the Lexia groundwater scheme.

10.2 Determining EWRs for the springs/seepages

Once springs and seepages were identified EWRs were determined using the following process:

10.2.1. Identify characteristics of the springs/ seepages

The characteristics of springs and seepages were identified from research and knowledge of people involved in scientific studies in this area. The investigation by Jasinska and Knott (1994) provided information on physicochemical characteristics and invertebrate communities in the area.

10.2.2. Identify the values of the springs/ seepages (environmental and social)

As with the wetlands on the East Gnangara Mound the values of the springs/ seepages which are considered important are the environmental and social values.

Identification of environmental values were determined using the results of the investigation by Jasinska and Knott (1994). Factors considered in identifying environmental values included the degree of disturbance, the abundance and diversity of flora and fauna and the uniqueness of the characteristics.

Identification of social values was undertaken through discussion with the local community, in particular through the East Gnangara Consultative Committee, and with local landowners who have springs on their property.

10.2.3. Determination of management objectives to reflect spring/seepage values, in particular those achievable through management of water levels.

Management objectives are determined with the aim of protecting the identified values of the springs and seepages. The management objectives are reflected in water regimes which define the EWRs.

10.2.4. Development of water level regimes consistent with management objectives

With little knowledge of the natural water regimes of discharge areas on the East Gnangara Mound, further monitoring of water levels is proposed. Interim environmental water regime requirements have been determined using the limited data currently available. If necessary EWRs will be updated in the first triennial report when more information on the water regimes of the springs/ seepages becomes available.

10.3 Knowledge of springs/seepages

At the edge of the East Gnangara Mound there is a change in geomorphology from Bassendean Sands with a high permeability to the Guildford formation consisting of clays with low permeability. Therefore water is forced out of the ground surface to form the springs and seepages found in the area.

Vegetation surrounding these springs and seepages surveyed by Jasinska and Knott (1994) (see Figure 7) included reeds, rushes, eucalyptus, banksia and melaleuca. One of the springs contained liverwort and club moss species rare to the area.

A total of 147 species were collected in the survey and 91 of these had not been found previously in studies of wetlands on the Swan Coastal Plain (Davis *et al.*, 1993), south west wetlands (Storey *et al.*, 1993b; Edward *et al.*, 1994) or on the Darling Scarp (Bunn *et al.*, 1986). Invertebrate assemblages at each site were quite different to other sites and every site had at least 3 species endemic to that site (Jasinska and Knott, 1994).

In addition to the springs sampled by Jasinska and Knott (1994) there is one other in the study area. This spring (The Barnard Spring Trough and Wetland) is north of the Lexia wetlands and has been listed on the National Trust. It contains an historic dam and stock watering trough (K. Tullis, pers. comm.).

10.4 Seepages selected for determination of EWRs

Of the sites sampled by Jasinska and Knott (1994) 5ps, 5pL, 5s, 5d and 7 in Figure 7 are outside the East Gnangara study boundary. Sites 3s, 3b, 3r, 4 and 6 are upstream of the proposed Lexia wellfield and sites 1s/1L (Edgecombe seepage) and Eg (Egerton seepage) downstream of the wellfield.

Groundwater flows down from the peak of the Gnangara Mound at a site 6 km west of Muchea in a south-easterly direction through the East Gnangara study area (see Figure 5 for groundwater contours). Sites 1s/1L (Edgecombe seepage) and Eg (Egerton seepage) are therefore downstream of the proposed Lexia wellfield. Sites 1s/1L and Eg are also closer to the proposed production wells than the other sites sampled. These sites are most likely to be affected from any groundwater abstraction from the Lexia wellfield. These were also two of the three main sites identified to have a high conservation value by Jasinska and Knott (1994) (the third site identified to have a high conservation value is outside the study area and approximately 16.5 km from the nearest proposed production well). Therefore site 1s/1L (Edgecombe seepage) and Eg (Egerton seepage) were selected for establishing EWRs for protection of springs/seepages.

10.4.1 Edgecombe seepage

Edgecombe seepage is permanent. It *flows along an epiphreatic conduit formed in quartz sand under 0.15m of dark, organic soil* (Jasinska and Knott, 1994). Where the water intersects the ground surface it forms a seepage (Jasinska and Knott, 1994). The seepage is surrounded by a 30 m-wide band of vegetation of reeds, rushes, bracken, ferns, figs, eucalyptus and Melaleuca trees. A paddock supporting cattle is located to the west of the seepage and will eventually become urban land.

The seepage discharges into a lake (1L) to its east. This lake is commonly referred to as Lake Yakine which is located on a creek line. Its base consists mainly of peat deposits and it is underlain by clay in the east and peat interlayered with sand in the west. The vegetation in the Lake consists of *Baumea articulata* and *Typha* surrounded by *Melaleuca rhaphiophylla, Banksia littoralis and Eucalyptus rudis.* There are several seepages surrounding the lake (V & C Semeniuk Research Group, 1994).

Water in the seepage and lake was ultra-oligotrophic (using Wetzel, 1983) with concentrations of 0.02 - 0.04 mg/L of PO_4^{3-}, 0.01 mg/L NH_4+ 0.11 mg/L of PO_4^{3-} and 0.02 mg/L NH_4+ respectively (Jasinska and Knott, 1994).

Edgecombe seepage was found to have little seasonal fluctuation in ionic concentration and temperature (temperature only varied 0.7 °C), however measurements were only taken on two occasions, in summer 1992 and winter 1993. The length of time that water spends in the aquifer could account for the small variation (Jasinska and Knott, 1994). Limited fluctuation in water levels could also account for the limited variation.

At Edgecombe seepage a total of 19 invertebrate species were collected between the two sampling occasions and 7 of these were not found at any of the other sites sampled (Jasinska and Knott, 1994). Lake Yakine which is fed by Edgecombe seepage, had a total of 30 species and had the highest number of species endemic to any site (a total of 17 species). The seepage and the lake were not similar in their fauna and contained only five species common to both sites (Jasinska and Knott, 1994).

Edgecombe seepage was also resampled in November 1995 with similar results to the past sampling. One additional crustacean was found at this time (Jasinska and Knott, 1995, unpublished data).

A diverse avifauna has been observed at Lake Yakine on different occasions in the past. The Western Australian Naturalist Club established a list of 30 species. The Southern Brown Bandicoot *(Isoodon obesulus)* (gazetted as rare) has also been observed at the site (V & C Semeniuk Research Group, 1994).

A number of other seepages also surround Lake Yakine (1L) and each is likely to contain diverse aquatic invertebrate species.

Edgecombe seepage was one of three sites identified in the survey of springs on the East Gnangara Mound as having a high conservation value due to the mosaic of habitats present which are likely to support a diverse fauna population (Jasinska and Knott, 1994).

Since April 1994 water levels have been recorded in a well 144m upstream of the Edgecombe seepage by Jim Davies and Associates since April 1994 as part of the water level monitoring for the Egerton development. Results of this monitoring are provided in Figure 18.

10.4.2 Egerton seepage

The Egerton Seepage which is located in Multiplex land is also permanent with water flowing out of a peat mound (Jasinska and Knott, 1994).

This seepage is surrounded by pristine vegetation and supports *Baumea articulata, Cyanthochaete avenacea, Melaleuca rhaphiophylla* and *Eucalyptus rudis* (Alan Tingay and Associates, 1995a) as well as liverworts (*Goebelebyrum unguviculatum & Hyalolepidozia*) and club moss which are rare to the area and growing at the northern limit of their distribution (Jasinska and Knott, 1994). There is also a fern ally (*Lycopodium serepentinium*) present (Alan Tingay and Associates, 1995a). The liverwort and club moss species were recognised as significant at Mound Springs near Muchea (Department of Conservation and Environment, 1983).

The catchment of the seepage includes banksia woodland to the east and pine plantation to the west. The seepage discharges into a stream which discharges into a dam.

The seepage was not sampled for physicochemical characteristics and only sampled on one occasion in Autumn 1994 for aquatic invertebrate fauna. At this site a total of 23 invertebrate species were identified, (14 endemic to the site). This was the second highest number of endemic species recorded at any one site. Of particular significance is the presence of a previously unrecorded amphipod in the Egerton seepage (Jasinska and Knott, 1994).

At this site there were a variety of habitats with water oozing from the surface of small mounds and flowing out into discrete channels. Each of the microhabitats present is likely to support different aquatic invertebrate species (Jasinska and Knott, 1994). This site is considered to have a high conservation value. The area will eventually become public open space within the Egerton urban estate (Alan Tingay and Associates, 1995a). More invertebrate sampling will be conducted once access issues have been resolved.

Water levels have been recorded in a monitoring well 130 m upstream of the seepage as part of the groundwater monitoring by Jim Davies and Associates for the Egerton development. Water level data is available from February 1995. The water height at the seepage is 37.58 mAHD (Jim Davies and Associates, 1994). Results of this monitoring are shown in Figure 18.

10.5 EWRs for seepages

The majority of invertebrate fauna found to be dependent on the Egerton and Edgecombe seepage are unlikely to have resistance to drying. In particular, the amphipod found in the Egerton seepage, requires permanent water (E. Jasinska, pers. comm.). Therefore EWRs aim to maintain the permanent flow of water at the seepages.

In addition to the requirement for a permanent flow of water, interim water level requirements have been determined for monitoring wells upstream of each of the seepages. These have been determined with the aim of maintaining water levels in these wells that will ensure sufficient head upstream of the seepage to maintain a permanent flow of water in the seepage.

10.5.2 Edgecombe seepage

Water table heights were surveyed upslope of Lake Yakine where the Edgecombe seepage first appears and at one of the points where the seepage enters the wetland. At the upslope point which occurs at 14.29 mAHD the soil is moist in summer and the seepage can be seen during winter. One of the points at which the water is constantly seeping into the wetland occurs downslope at 12.04 mAHD. There are several permanent seepage points between the two surveyed. A minimum water level requirement has been determined for the well B10 (installed by Jim Davies and Associates), 144 m upstream, with the aim of maintaining the 2 m of seepage area between 14.29 mAHD and 12.04 mAHD.

The minimum water level recorded to date in the well B10 upstream of the Edgecombe seepage is 14.35 mAHD. There is very little difference between this water height and that at the top of the seepage area at Edgecombe (14.29 mAHD). Therefore the minimum water level requirement in well B10 has been set at 14.35 mAHD. This will ensure that the water table height upstream is sufficient to maintain the 2 m of seepage area at Edgecombe.

In addition to being downstream of the Lexia wellfield, Edgecombe seepage is located directly downstream of the Egerton development and likely to be impacted by the development. Model outputs showing changes in water levels post-development predict a 0.2 m drawdown in the vicinity of well B10 A.J. Peck and Associates for Alan Tingay and Associates (1995b). A drawdown in water levels in this area is predicted as a result of the removal of irrigation on the Egerton property as urbanisation takes place. This irrigation in the past has created an artificially high groundwater level (Alan Tingay and Associates, 1995b).

Alan Tingay and Associates (1995) also states that in this area 'significant groundwater discharge is predicted only for the period June to September. Discharges are predicted to decrease in each month by 10-20 per cent in the period June to August and to nearly cease in September' (p.13, Alan Tingay and Associates, 1995b).

The Egerton development is likely to have a greater impact here than the Lexia wellfield (see Section 13.2.4) and this is likely to limit the Water and Rivers Commission's ability to achieve the desired EWR. The EWR cannot be met by managing groundwater abstraction alone. Therefore, although an EWR is recommended for management purposes, the Water and Rivers Commission makes no commitment to maintain the EWR.

EWRs for Edgecombe Seepage: Recommendation for Management

Management Objective

- Conservation of fauna.

Water Regime Management Objective

- Maintain invertebrate species diversity.

Environmental Water Requirement (for seepage)

- Maintain permanent water flow.

Interim Environmental Water Requirement: (for well B10, 144m upstream of seepage)

- Minimum: 14.35 mAHD.

10.5.1 Egerton seepage

Water requirements upstream of the Egerton seepage were determined using well B25, installed by Jim Davies and Associates as part of the water monitoring required for the Egerton development. This well is 130 m upstream. The minimum water level recorded during monitoring in 1995 was 39.29 mAHD and the watertable height at the seepage is constant at 37.58 mAHD. This equates to a minimum head difference of 1.71 m.

It is believed that some fall in water levels upstream would still provide sufficient head to feed the seepage. However the minimum level of head required and therefore the degree of fall that would be acceptable is not conclusive at this stage due to a lack of monitoring data and a lack of knowledge on the aquifer characteristics in this area.

Therefore the interim water requirement proposed is to maintain a minimum water level of 39.29 mAHD in well B25 until further investigations have been conducted.

Environmental Water Requirement for Egerton Seepage

Management Objective

- Conservation of flora and fauna.

Water Regime Management Objective

- Maintain fringing liverwort, bog club moss and other wetland vegetation.
- Maintain invertebrate species diversity.

Environmental Water Requirement (for seepage)

- Maintain permanent flow of water

Interim Environmental Water Requirement (for monitoring well B25, 130m upstream of seepage)

- Minimum: 39.29 mAHD.

EWRs will be updated in the first triennial report to accommodate additional information, either on the natural water regimes in or feeding the seepages, or water requirements of the invertebrate fauna.

11. Summary of Environmental Water Requirements

11.1 Terrestrial vegetation

A summary of the EWRs determined for phreatophytic vegetation monitoring wells in Melaleuca Park, Whiteman Park and the native vegetation corridor between Melaleuca Park and the Lexia wetlands is given in Tables 11, 12 and 13. Figure 13 provides the location of these monitoring wells. Section 6 describes the methodology used in the determination of the EWRs. Wells with minimum water level requirements in the native vegetation corridor are interim. More appropriate monitoring wells were established in the phreatophytic vegetation areas in the corridor in 1995. Minimum water level requirements will be determined for these wells when more water level monitoring data becomes available.

11.2 Wetlands

Interim EWRs have been set for 5 wetlands within the East Gnangara study area. Further investigations will be conducted and EWRs finalised in the first triennial report.

11.3 Seepages

The EWR for the Egerton seepage is given in Table 15. It is an interim criteria and will be reviewed in the first triennial report to the EPA. The water requirement given for Edgecombe seepage is a suggestion for management. The Water and Rivers Commission does not accept total responsibility for achieving the requirement given that urbanisation will have a greater influence than groundwater allocation on the water level upstream of the seepage (see s10.5.2).

Table 11. EWRs for Melaleuca Park

Well	EWR	Previous Minimum (Year)
WM6	58.8 mAHD	58.8 mAHD (1991,1995)
WM8	65.0 mAHD	65.5 mAHD (1990, 1991)
NR6C	58.5 mAHD	59.8 mAHD (1991, 1995)
WM2	67.0 mAHD	67.6 mAHD (1991, 1995)
NR11C	55.0 mAHD	55.6 mAHD (1993, 1995)

Table 12. EWRs for Whiteman Park

Well	EWR	Previous minimum (Year)
MM49B	24.7 mAHD	24.3 mAHD (1986)
MM53	33.3 mAHD	33.0 mAHD (1991)
MM55B	29.5 mAHD	29.2 mAHD (1986, 1991)
MM18	38.6 mAHD	38.4 mAHD (1991)
MM59B	36.3 mAHD	36.1 mAHD (1991)

Table 13. Interim EWRs in the native vegetation corridor

Well	EWR	Previous minimum (Year)
MM12	43.0 mAHD	43.0 mAHD (1991)
L30C	47.5 mAHD	48.1 mAHD (1986, 1991)
L110C	57.0 mAHD	57.7 mAHD (1986)
L220C	52.5 mAHD	53.0 mAHD (1991,1995)

Table 14. Interim Environmental Water Requirements for wetlands

Wetland	Interim Environmental Water Requirement	
	Minimum	Absolute minimum
Lexia wetland 1 (94)	1.5m below ground (45.8 mAHD - well GNM17A)	1.8m below ground (45.5 mAHD - well GNM17A)
Lexia wetland 2 (86)	1m below ground (47.3 mAHD - well GNM16)	1.3m below ground (47.0 mAHD - well GNM16)
Lexia wetland 3 (186)	0.8m below ground (47.5 mAHD)	1.1m below ground (47.2 mAHD)
EPP wetland 173	0.1m above ground (in the western sector)	
Dampland 78	5.5m below ground (65.4 mAHD - well GNM13)	5.8m below ground (65.1 mAHD - well GNM13)

Table 15. Interim Environmental Water Requirements for seepages

Spring	EWR in seepage	Minimum water level requirement in well B10 (interim)	Minimum water level requirement in well B25 (interim)
Edgecombe seepage	Permanent water flow	14.35 mAHD *	
Egerton seepage	Permanent water flow		39.29 mAHD

* *Recommendation for management*

12. Preferred groundwater abstraction and wellfield layout

12.1. Public groundwater abstraction

12.1.1 The Lexia groundwater scheme

The EPA was first advised of the Lexia groundwater scheme in 1986 in the Gnangara Mound Environmental Review and Management Programme (Dames and Moore, 1986). The Water Corporation now proposes to develop the scheme for operation in 1999. The scheme is proposed to consist of 11 superficial wells to be located in the Gnangara Pine Plantation north of Gnangara road and west of the Ellenbrook development and one semi-confined well to the south-east of the superficial wells and within the proposed development area. See Figure 2 for the scheme layout. The proposed quota for the scheme is 9.8×10^6 kL/yr.

12.1.2 Additional Mirrabooka wells (East Mirrabooka Stage 3)

As well as establishing the Lexia groundwater scheme the Water Corporation proposes to establish two additional East Mirrabooka wells along Gnangara Road with a quota of 1.2×10^6 kL/yr. Proposed locations are illustrated in Figure 2.

Many Lexia and East Mirrabooka scheme layouts, well quotas and operating scenarios were tested using a computer model. The layout and abstraction rates considered to be the most environmentally acceptable were chosen. The modelling aimed to find a scheme which minimised environmental impacts whilst maximising water availability for consumption.

The computer modelling is described in Section 13. The result is a scheme with a reduced production quota. Refer to Appendix 5 for details on the initial scheme and some variations tested.

12.1.3 The need for the Lexia groundwater scheme and East Mirrabooka Stage 3

The Perth Water Future Study (WAWA, 1995c) has identified groundwater schemes as playing a central role in meeting water supply requirements for Perth in the future. The study investigated many broad ranging options including groundwater sources, dams, desalinisation of sea water, rainwater tanks, using icebergs from Antarctica, using drainage water, reuse of wastewater and forest management for meeting the water requirements of the growing population. The study concluded that 86 per cent of additional water supply to 2010 is likely to come from groundwater. Groundwater schemes were found to be the best alternative, minimising environmental, social and economic costs (WAWA, 1995c). The Lexia and East Mirrabooka Stage 3 groundwater schemes are two of the schemes proposed for the Gnangara Mound. They fit within the overall context for Perth's future water supply.

The direct alternative option for supplying water to Ellenbrook and other growing areas of the north-east corridor would be to develop and transport groundwater from the north-west corridor via Wanneroo. This would be an expensive alternative due to the high costs associated with transporting bulk water through trunk mains. The Lexia Groundwater Scheme is the most cost effective method of supply as the water source is located close to the area of demand.

12.2 Private groundwater abstraction

For preferred private groundwater allocations see Section 4.3.2. Quotas are shown in Tables 4 -7.

13. Impact of land-use and groundwater abstraction on water levels - modelling results

This Section presents a discussion of the impacts of proposed future land-use and proposed groundwater abstraction on groundwater levels.

Water levels are predicted through the use of a computer model. The model used in this project is the Urban Water Balance Model which was developed initially for the Perth Urban Water Balance Study (Cargeeg *et al.*, 1987) and has since been refined and used in several other groundwater assessment and management projects.

The model has been used to predict changes in water levels as a result of individual land-use changes alone, and for the influence of all combined proposed future land-uses in the area.

Water level changes predicted by the model are then compared to the EWRs developed for terrestrial vegetation, wetlands and seepages (presented in Sections 7, 9 and 10). Discussion on the changes in water levels in comparison to EWRs can be found in Section 14. The EWPs then established are also discussed in Section 14. An Environmental Water Provision (EWP) is not always equal to the Environmental Water Requirement (EWR). An EWR is the preferred allocation to the environment. The EWP is the actual allocation which is made after considering all social and economic aspects of groundwater allocations in addition to environmental requirements.

The proposed groundwater allocations for public and private users are presented in Section 15.

13.1 The Model

13.1.1 Model components

The Perth Urban Water Balance Model actually consists of two coupled models, the Vertical Flux Recharge Model and the Aquifer Flow Model. Following is a discussion on each of these components of the model.

The Vertical Flux Recharge Model

The Vertical Flux Recharge Model produces an estimate of the recharge to the superficial unconfined aquifer in a monthly time interval. The net vertical flow of water into the watertable incorporates the combined effects of direct recharge to the aquifer, evaporation from the watertable, transpiration by vegetation, groundwater abstraction, and leakage to and from the underlying aquifer. The recharge to the aquifer in turn is the combined effect of a range of factors such as rainfall, interception from tree canopies (native vegetation and pines), evapotranspiration from the unsaturated zone above the water table and irrigation (WAWA, 1995a).

In the Vertical Flux Recharge Model the study area is divided into 500m^2 cells and recharge is calculated for each cell for every month of the model run. Most model runs are for 10-year-periods. Those used for producing hydrographs at particular points are run for the 111-year-period since rainfall records began.

For each cell data sets are entered which specify factors such as rainfall; land-use including agriculture, urbanisation, native vegetation areas (incorporated using canopy cover), pine plantation; extraction from wells and leakage coefficients to the underlying confined aquifer.

The Aquifer Flow Model

The Aquifer Flow Model forms a part of the Perth Urban Water Balance Model to account for the horizontal flow of groundwater below the water table and it simulates the water table response.

The Aquifer Flow Model divides the study area into triangular sub areas. Triangles vary in size, being smaller (approximately 10 ha) in areas of interest and larger (approximately 50 ha) at the edge of the model area. The fluxes from the Vertical Flux Model are distributed to the nodes of the Aquifer Flow Model. The Aquifer flow model then predicts the water table elevation at each node at monthly time intervals and this provides the output for the model.

For more information on the model refer to *The Perth Urban Water Balance Study* (Cargeeg *et al.*, 1987).

13.1.2 Model calibration

Model calibration involves adjusting model parameters to achieve a good fit between observed and simulated data to provide an assurance that the model will provide acceptably accurate predictions of future aquifer behaviour.

The model has been calibrated using data over the period 1983 to 1992. For this period reliable groundwater information, climatic information and information on land-use and abstraction is available. The model is run using the rainfall, land-uses, forest management and groundwater abstraction (both public and private) over the time period concerned to obtain predicted water levels over this period.

Data from 70 groundwater monitoring wells are used in the calibration. These were chosen to represent a variety of prevailing recharge and groundwater flow conditions present within the study area. This enabled calibration to be checked for a range of conditions. In the calibration process the predicted water levels in the form of hydrographs at particular points in the study area are compared to the actual water levels which occurred at these points over this time period.

The points used to check calibration are in the areas of environmental significance where EWRs have been determined. In the process of calibration a variety of model parameters were then adjusted until predicted water levels were reasonably close to actual water levels. Figure 19 shows the calibration results in monitoring wells WM6, WM2, WM8, L30C, MM18, MM53, MM59B, MM12 and L150C. As can be seen from the calibration outputs the model is extremely good in predicting water level trends. However prediction of absolute water levels is less accurate. This has important implications when predicting the number of breaches in water level criteria which may occur. Small errors in water levels may cause large errors in the number of breaches. The reliability of the model is discussed further below.

13.1.3 Model outputs

Model outputs have estimated future changes in groundwater levels as a result of changing conditions in the future to represent proposed abstractions and land-use. The model is run using 1992 as a base year. In other words the land-use scenario prevailing in 1992 was run into the future and compared to some changed scenario. The changed scenario may incorporate one or more changes in land-use conditions from 1992 with other land-use conditions maintained at the 1992 level. E.g. the extent of urbanisation may be increased from 1992 or the quantity of groundwater abstraction and extent of urbanisation may both increase. This enables the model to compare the future impacts of individual land-uses or land-uses in combination. The outcome is the difference in water level of the proposed scenario compared to that of the 1992 condition projected to some point in the future.

1992 has been selected as the base year because it follows two years of average rainfall and data is available for land-use, abstraction, climate and water levels leading up to 1992 (the 10 years used for calibration).

Average rainfall data taken from records back to 1879 has been used in the 111-year model runs

Output from the model has been presented in two forms:

- contour plots which show the predicted change in regional groundwater levels; and
- hydrographs which show the specific water levels and the variation in water level over time in monitoring wells.

For the majority of model runs, outputs have been in the form of contour plots. For the final preferred groundwater abstraction and land-use scenario, outputs also include hydrographs at each of the points where EWRs have been determined. These hydrograph outputs have been compared to the EWR to determine how often the EWRs may not be met under the preferred abstraction and land-use scenario. This information has then been used to aid the setting of EWPs.

If it is predicted that the EWR is likely to be breached regularly, then a trade-off has been proposed. This trade-off involves either: reduced abstraction to set the EWP at the same level as the EWR; or a trade-off to the environment with the EWP being set below the

EWR; or some combination of the two. The setting of the EWPs and the actual EWPs are discussed in Section 14.

13.1.4 Effectiveness of the model

It is difficult to apply classical error analysis to the Urban Water Balance model due to its complexity. Therefore the validation procedure used is to check agreement between the model solutions and real data from an historical calibration period as discussed.

A problem with this approach is the phenomenon of 'non-uniqueness', that is different combinations of model parameters and/or algorithms will give similar model solutions. For example it is often possible to generate physically reasonable model output using unrealistic input data. The severity of this problem generally increases with increasing model complexity and number of input parameters.

The problem of non-uniqueness is minimised in the model for East Gnangara in two important ways:

1. A large number of data sets, from different locations within the East Gnangara study area were used for the calibration process. A variety of different groundwater and recharge processes are dominant at these locations. Achieving a good fit between these data sets and model output depends on the models ability to simulate the variety of processes affecting groundwater levels in the study area.
2. Algorithms in the vertical flux (recharge) model tend to be close representations of physical processes, rather than empirical relationships. Similarly, input data are mainly physically-based quantities which are readily estimated or measured. These data are less likely to assume unrealistic values than empirically-derived parameters.

Examination of the calibration outputs in Figure 19 demonstrates some important features about the capabilities of the model in predicting water level responses. The model is reliable in predicting water level trends in response to changes in climate, land-use and groundwater abstraction. However it is less accurate in predicting absolute groundwater levels, and this is particularly important for examining water level responses. Therefore modelling results are better suited to comparing potential impacts under different scenarios than making specific predictions.

Because of this limitation, difference plots to compare the magnitude of water level changes for various management scenarios have been used extensively in this project. The difference plots illustrate regional trends and avoid the limitations of predicting absolute levels. To identify where abstraction may need to be modified to make EWPs equal to EWRs, or where an EWP may need to be less that the EWR, hydrographs from 111-year-runs have been used to provide an indication of how often the EWRs may be breached. Then hydrographs have also been used to predict the number of interventions required to meet the EWPs. These results need to be interpreted recognising model limitations, and also recognising that climatic conditions will not be exactly the same. Climatic conditions used in the model are predictions of possible future climatic trends based on past climatic data.

13.2 Modelling results—land-use influences on water levels

There are many possible future land-use scenarios which may occur in the East Gnangara area. There are potentially different climatic influences, and combinations of urbanisation, groundwater abstraction and forest management. The discussion below presents an indication of the potential magnitude and relative impacts of each of these land-uses. A preferred land-use scenario is also presented which provides an indication of water level changes resulting from the combination of proposed future forest management, urbanisation and groundwater abstraction.

Details of the components included in each run are given in Table 16.

13.2.1 Urbanisation

Figure 20 illustrates the predicted potential impact of urbanisation alone on water levels. It compares the result of maintaining the current land-use in the area (as in 1992) to having full urbanisation in the north-east corridor as presented in the north-east corridor structure plan (Department of Planning and Urban Development, 1994). It assumes full development of Ellenbrook and Egerton (assuming the housing densities and areas presented in Feilman Planning Consultants, (1992); Environmental Protection Authority, (1993b) and Alan Tingay and Associates, (1994). It also includes development of all Category A

Table 16. Model runs

	Figure 20	Figure 22	Figure 23	Figure 24	Figure 25	Figure 26	Figure 27
Urbanisation	✓			✓			✓
Pine Management		✓					✓
Full private groundwater abstraction			✓				✓
Dry climate					✓		
Wet climate						✓	
Lexia and East Mirrabooka schemes *				✓			✓

** Lexia and East Mirrabooka Stage 3 schemes = 11 Lexia superficial wells (5 at 0.7 x 10^6 kL/yr each; 4 at 1 x 10^6 kL/yr each; 1 at 0.9 x10^6 kL/yr and 1 at 0.95 x 10^6 kL/yr) and 1 Lexia semi-confined (Mirrabooka Sands) well (0.45 x 10^6 kL/yr) and 2 East Mirrabooka wells (0.6 x 10^6 kL/yr each) (see Figure 2).*

land (areas having constraints to immediate development but which should become available in the next 10-15 years) and Category B land (having major constraints to development in the short to medium term but may become available before 2021) (Department of Planning and Urban Development, 1994). This is compared with 2 - 20 per cent pre-urban canopy cover of native vegetation in these areas.

The results show a small rise in groundwater levels in the range of 0.5 - 1 m in the vicinity of the Ellenbrook and Egerton areas. There is a rise of approximately 0.25 - 0.5 m at the Lexia wetlands and 0.5 m at the Egerton seepage.

As the model results and past experience indicate, urbanisation is typically associated with rising groundwater levels. This is the result of reduced evapotranspiration when vegetation is cleared, and increased recharge due to a concentration of runoff from impervious surfaces such as roads and roofs. Water is also imported into urban areas through public water supply and seeps into the groundwater when people water lawns and gardens. Some of the initial groundwater rise is offset when the urban population plant trees and gardens (WAWA, 1995a).Water rises can also be offset by use of private wells for domestic watering. However, the overall result of an area being urbanised is a local rise in groundwater levels which stabilise at a higher level.

13.2.2 Pine management

Planting, thinning and clearfelling of pine trees is represented in the model by a formula which calculates canopy cover as a function of the age of the plantation and the type of management regime imposed. The canopy cover and management for each plot of trees is included within individual cells of the model. Therefore pines are represented to be varying both in time and space.

The model run compares a situation where the pine management regime is kept as it was in 1992 compared to managing pines to achieve an average basal area of $11m^2$ / ha into the future. This future management regime was developed in collaboration with CALM in 1994 to best represent the proposed pine management regime. The future variation in canopy cover over time, resulting from this management regime, is illustrated in Figure 21. It represents the information incorporated into the model and demonstrates the pine management cycle from planting to clearfelling.

Impacts on groundwater levels from future pine management to $11m^2/ha$ (as in Figure 21) are shown in Figure 22. From these results it is evident that the future management of pines has the potential to have a significant influence on groundwater levels in the East Gnangara study area. Figure 22 indicates that water levels may rise up to 5 m. Rises indicated are:

- up to 0.75 m at the Lexia wetlands;
- 0.5 m at Egerton seepage;
- 0.75 - 2 m in the native vegetation corridor;
- 0.25 - 1 m over Melaleuca Park; and
- up to 1.5 m at the top of Whiteman Park.

Since the development of the above management regime CALM has announced that it will be converting the Gnangara pine plantation into a conservation and recreation park. This means that 23,000 ha of pine plantation will be gradually cleared over the next 20 years. Over time, this is likely to have a substantial impact on groundwater levels, resulting in much greater rises than indicated in Figure 22.

As specific plans are not available at this stage the proposal has not been incorporated into the model. However CALM and the Water and Rivers Commission are currently developing a Memorandum of Understanding on pine management. When this is complete and as the clearing of pines in the East Gnangara area takes place the East Gnangara EWPs Plan will be reviewed. The result may be to allow an expansion of the Lexia groundwater scheme and/or private use of groundwater while providing additional water to some areas of conservation value in or adjacent to the Park. At this stage however, as it is likely to be some years before significant areas of the pine plantation are cleared, the water available only takes into consideration the regime proposed above. The results are illustrated in Figures 22 and 27.

13.2.3. Private abstraction

The model has been used to predict changes in groundwater levels resulting from the full private groundwater quotas being utilised in the Swan Groundwater Area and the Mirrabooka Groundwater Area. (Locations of the sub-areas concerned are shown in Figure 10.) This means that the model has predicted the potential change in water level when comparing abstraction of total quotas presented in Tables 4 - 7 in Section 4.3.2 to allocations made in August 1995. Quotas were compared to August 1995 allocations because the model base run (1992 or starting condition) was done at that time (note:Tables 4 - 7 provide allocations at November 1996). The Water and Rivers Commission considers that the increase in allocations between 1995 and 1996/97 has had no significant impact on the surrounding environment.

Modelling of private groundwater abstraction included the Vines allocation of $1.4x10^6$ kL/yr. This makes up a part of the North Swan allocation. It is proposed to relocate the Vines' wells. Instead of having several wells over the property, two large wells will be located on the north-west boundary of the property. This was incorporated into the model run.

Figure 23 shows the impact of private abstraction over the study area. There is a 0.25 m drawdown in the region of the North Swan, South Swan and State Forest sub-areas as a result of reaching full allocation. The rises directly east of these drawdowns are a result of shifting the Vines wells. Water rises in this position due to reduced abstraction and the new wells contribute to the 0.25 m drawdown directly west. The other area where a decrease in water levels is evident is in the Improvement Plan 8 sub-area. This 0.25 m drawdown is also a result of reaching the full allocation.

In terms of the impact of private abstraction on significant environmental areas, Figure 23 shows a 0.25 m drawdown at Egerton seepage.

It should be noted that future installation of private domestic wells at houses in the urban development areas has not been included in the run presented in Figure 23. Figure 23 presents the impacts of licensed private use of water only. The model run was done this way because domestic wells are associated with the urban development. The use of water by domestic wells in the urban development area was therefore included only where urbanisation was included. It was assumed that 25 per cent of households would abstract 500 kL/yr.

13.2.4 Public abstraction

As outlined in Section 12 the model has been used to test many Lexia and East Mirrabooka Scheme layouts and abstraction rates with the aim of identifying a scenario where the scheme will be viable and production maximised but where the environmental impacts are minimised. A selection of runs undertaken is presented in Appendix 5. The layout which is proposed is shown in Figure 2 and proposed abstraction rates in Table 17.

Impacts from the Lexia and East Mirrabooka groundwater schemes are illustrated in Figure 24. Drawdowns include:

- 0.25 m drawdown in Melaleuca Park dampland 78;
- less than 0.25 m in the western Lexia wetlands;
- 0.5 m drawdown in the top north-east corner of Whiteman Park; and
- 0.5 - 2 m drawdown in the vegetation corridor.

There is no significant drawdown on the seepages or other areas of Melaleuca Park including the EPP wetland 173. The impacts (in combination with the impacts of other land-use changes) are discussed in relation to the EWRs and their acceptability in Section 14.

13.2.5 Potential climatic influences

The model was run to look at the potential influence of climate on groundwater levels. Climatic variation, particularly timing and quantity of rainfall, can have a significant effect on groundwater levels on the Gnangara Mound. Future climatic variation is also the largest source of uncertainty in predicting future groundwater levels. This uncertainty is further increased by the possibility of changed climatic patterns in response to global warming.

Figures 25 and 26 illustrate potential variations in groundwater level as a result of potential climatic patterns. Figure 25 looks at the effects of a dry climate by comparing an average 10-year rainfall period to ten years of below average rainfall. The model indicates that under this scenario groundwater levels may fall up to 2 m in the north-west of the study area and up to 1 m in the eastern and southern regions. Data used in the model run is shown in Appendix 6.

In comparison, Figure 26 looks at the effect of a wet period on water levels in the study area. Ten years of average rainfall is compared to ten years of above average rainfall. The result is a potential rise of up to 2.5 m in the north-west of the study area and rises of around 0.5 m in the east and south of the study area. See Appendix 6 for data used in this model run.

13.2.6 Impact of preferred abstraction and land-use scenario

13.2.6.1 Impact on criteria (EWR) areas

The proposed Lexia and East Mirrabooka abstraction scenario (Section 13.2.4) was combined with all the

Table 17. Quotas for the Lexia and East Mirrabooka wells

Well Type	Abstraction	Number of wells	Total
Lexia - superficial	0.7 x 10^6kL/yr 1 x 10^6kL/yr 0.95 x 10^6kL/yr 0.9 x 10^6kL/yr	5 (L420, L620, L510, L430, L710) 4 (L700, L600, L500, L400) 1 (L490) 1 (L410)	3.5 x 10^6kL/yr 4 x 10^6kL/yr 0.95 x 10^6kL/yr 0.9 x 10^6 kL/yr
Lexia—semi-confined*	0.45 x 10^6kL/yr	1 (L12)	0.45 x 10^6kL/yr
East Mirrabooka	0.6 x 10^6kL/yr	2 (M380, M390)	1.2 x 10^6kL/yr
Total		14	11 x 10^6kL/yr

* *It is assumed that the semi-confined well acts like a superficial well. This assumption is necessary because the degree of connection between the Mirrabooka sands and superficial aquifers is unknown. Assuming the well is in an unconfined aquifer therefore provides a worst case scenario.*

other land-uses in the study area to produce the preferred abstraction and land-use scenario. This scenario includes; full urbanisation, full private groundwater allocations being utilised, and pine forest management to achieve a density of $11m^2/ha$ in the future, with an average climate.

The contour plot in Figure 27 shows the change in groundwater levels in comparison to retaining 1992 conditions and indicates the following impacts of the preferred future abstraction and land-use scenario:

- drawdown of 0.25 m at the western Lexia wetlands;
- 0.25 m drawdown in dampland 78 in Melaleuca Park;
- 0.5 drawdown at the top of Whiteman Park;
- 0.5 - 2 m drawdown in the vegetation corridor; and
- minimal impact on Edgecombe and Egerton seepages, the EPP wetland 173 in Melaleuca Park; and the remainder of Melaleuca Park.

The preferred abstraction and land-use scenario has also been run to produce hydrographs at each of the points where EWRs have been determined. They provide an indication of the fluctuation over time in absolute water levels at these points. They have been compared to the EWR to provide an indication of the percentage of years the EWR would be breached under this scenario. This is discussed in Section 14.

The rate of drawdown and the timing for reaching a new stable water level at some lower point will depend on the interplay of each land-use and the rate of commissioning of the wellfield. Production wells in close vicinity to native vegetation and significant wetlands will be commissioned in stages to minimise the rate of drawdown therefore allowing these areas to adapt.

13.2.6.2 Impact on remnant vegetation in the pine plantation

There are a number of small areas of remnant native vegetation and wetlands within the pine forest area north of Gnangara Road. Many have been degraded by establishment of the plantation. Due to the presence of pines water levels have been drawn down through use of water and reduced recharge. Buffer vegetation has been cleared and the areas suffer from weed invasion including invasion by pine 'wildings'. The pine plantation has historically been seen as the area to maximise groundwater production. For these reasons and the objective of protecting high conservation areas outside the pine plantation, large drawdowns are considered acceptable in this area to provide a water supply scheme to the north-east corridor of Perth. Drawdown in groundwater in these areas ranges from 0.25-5 m. The larger drawdowns are likely to result in the death of some vegetation which is reliant on groundwater. In other areas where drawdown is less change in community structure will be experienced.

One wetland (wetland 104 in Figure 27) contains a small area of remnant *Melaleuca rhaphiophylla* closed forest. The areas consists of three areas of *Melaleuca rhaphiophylla* totalling approximately 1 ha, which is remnant of a wetland of approximately 13.5 ha. Although this species is common, the vegetation association has been recognised as limited in its distribution within a comparable geomorphological setting (B. Keighery, pers. comm., 1997). A 3 m drawdown at this wetland is predicted. Current depth to water is 1.8 m. Water levels have been drawn down in this area since the establishment of the pine plantation and over time the vegetation has adapted. However, the *Melaleuca rhaphiophylla* is unlikely to tolerate a further drawdown of 3 m. There is a possibility that water levels in the wetland could be artificially maintained, however an artificial maintenance scheme is not guaranteed to be successful in this type of situation. The Water and Rivers Commission and the Water Corporation propose to investigate some form of wetland mitigation to compensate for the drawdown and impact predicted at this wetland. The Water and Rivers Commission will liaise with the EPA and CALM on this issue.

13.2.6.3 Impact on other EPP wetlands

There are two other wetlands within the study area which are protected by *the Environmental Protection (Swan Coastal Plain Lakes) Policy 1992* likely to be impacted by abstraction from the Lexia wellfield. These are numbered 144 and 169 on the WAWA wetland management and conservation estate map series (see Figure 27). The drawdown predicted at wetland 144 is approximately 0.25 m and approximately 0.5 m at wetland 169.

Both of the wetlands have little remnant fringing vegetation and are on private property. They also have a preliminary evaluation category as 'multiple use' wetlands (Hill *et al.*, 1996). Based on this information, the impacts are considered to be acceptable when compared to the value of water for water supply purposes.

13.2.6.4 Impacts on wetlands in other areas of native vegetation

An additional eight wetlands which fall within the native vegetation corridor will experience some drawdown in water levels (see Figure 27). All of the wetlands are damplands, except 132, which is a sumpland. Wetlands numbered 125, 159, 164, 156, 158 and 132 have a preliminary evaluation category of 'conservation' (Hill *et al.*, 1996). However, from recent observations of wetlands 159, 164 and 156 they are found to only contain remnant tree species which would have been part of a more complete vegetation structure in the past. These wetlands are significantly disturbed and should be assigned a lower evaluation category. Wetland 125 appears to have once been a damp area along a seepage line but now has some disturbance. Wetland 158 appears to have become drier over time, probably due to the establishment of the pine plantation but is less disturbed than 159, 164 and 156. Wetland 132 is considered to still retain its conservation category evaluation. The vegetation types found at the wetlands are *Melaleuca preissiana, Banksia littoralis* and *Banksia ilicifolia* with some shrub species in the central areas of wetlands 158, 132 and 123.

The model predicts that wetlands 125, 159 and 164 will experience a drawdown of approximately 0.5 m. Wetlands 156, 158 and 123 will experience drawdowns of approximately 1m; wetland 132 of 1.5 m and wetland 68 of 2 m. Drawdowns of approximately 0.5m will be tolerated by the species present. A drawdown of 1 m is probably the maximum that wetland 158 will tolerate and it is possible that a few mature trees may be lost, however over time recruitment of seedlings will replace them. The tree species in wetland 132 would be effected in a similar way and some shrub species may be effected by removal of surface water if it currently occurs in Spring. Wetland 68 will be the most severely effected wetland with likely deaths of some trees but given its already disturbed status this is not significant.

Impacts on the wetlands in the vegetation corridor are considered by the Water and Rivers Commission to be an acceptable trade-off to the provision of a public water supply scheme given their current conservation status. The impacts on wetland 132 will be most significant given that it is in better condition than the other wetlands.

13.2.6.5. Social impacts

a) Impacts on wetlands on private land

The wetlands 144 and 169 discussed above are also wetlands identified as private property wetlands which will be impacted. As discussed wetland 144 may experience a minimal drawdown of 0.25 m. This will not significantly affect the aesthetics of the property or any use of the water because of the depth of water in the wetland. Wetland 169 may experience a drawdown of 0.5 m. This is likely to reduce the wetland area and cause it to dry considerably earlier. This could affect aesthetic benefits and availability of water for animals, and summer pasture.

b) Impacts on land-use

There is a group of properties in the north-east of the study area identified as experiencing groundwater drawdowns of up to 0.25 - 0.5 m. These properties are those in the vicinity of Warbrook Road as far east as Lot 1808 (CALM map sheet -Wanneroo). A major part of this area consists of dampland or palusplain with the water table occurring close to the surface. The land in the area is used to support horses including a pony club, native vegetation, a sand pit; emu farm, cattle, sheep and goats.

The main impact therefore will be on the properties with animals that rely on summer pastures. A drawdown in groundwater levels may lead to the loss of some areas of summer pasture which is supported by the high water table. Water levels in small dams in the area may also be affected.

c) Impact on private wells

The Lexia Groundwater Scheme will not impact on the water available to private well owners on rural properties. Drawdown contours are largely outside areas where private wells are located. The drawdown from the scheme is mainly concentrated within the pine plantation. Private groundwater abstraction occurs further south in the Mirrabooka Groundwater Area and further east in the Swan Groundwater Area (see Figure 10). Water allocations to private wells are equal to or greater than previous interim limits. The allocations are summarised in Section 15. There is only one sub-area where allocation limits have decreased and that is in the North Swan sub area. Allocation limits were reduced due to the impacts of abstraction near the Lexia wetlands. This is considered acceptable because in the future urbanisation will be the dominant land-use.

Although water availability to private well owners will not be effected by the Lexia Groundwater Scheme there may be minor reductions in well outputs on a few properties due to reductions in water table levels. The maximum reduction in the water table on existing rural property is between 0.25 - 0.5 m. Properly constructed wells with sufficient clearance between the water table and the top of the screen will not be significantly affected.

14. Environmental Water Provisions

This Section compares the EWRs discussed in Sections 7 and 10 to the predicted impacts of the preferred abstraction and land-use scenario discussed in Section 13.2. The outcome is a set of EWPs for phreatophytic vegetation and seepage areas.

An EWP is the allocation of water that will actually be made to the environment. Wherever possible the EWP has been set to equal the EWR. However in some instances there are conflicts between the predicted impacts of groundwater abstraction and the EWR. Where this occurs there has been a combination of reducing abstraction and setting the EWP below the EWR. Where an EWP is less than the EWR there will be some change to current ecological values.

Interim EWRs have been determined for five wetlands on the East Gnangara Mound (Section 9). However, for various reasons including a lack of information on perching and inaccuracies in the model's predictions of absolute water levels in perched areas, EWPs have not been determined at this stage. EWPs for these wetlands will be proposed in the first triennial report to the EPA.

Although EWPs have not been proposed for the wetlands in East Gnangara at this stage, an indication of the impacts of the preferred abstraction and land-use scenario on the wetlands has been provided. The model has been used to produce groundwater contours showing future changes in water levels in the study area. The results are presented in Section 13 and discussed further in Section 14.2.

To compare EWRs to future water levels under phreatophytic vegetation, 111-year model runs have been used to produce hydrographs at each of the criteria points. This has provided data on water levels for the next 100 years. Climate has been incorporated with the preferred abstraction and land-use scenario using the 111-year rainfall record from 1879- 1990. The results must be interpreted with caution as rainfall patterns in the future will not replicate those in the 111-year climate record. However data from the hydrographs produced does provide an indication of the likely percentage of breaches of the EWR and therefore the need for management intervention should rainfall patterns remain similar to those observed.

The same modelling process was undertaken in the *Gnangara Section 46 Report* (WAWA, 1995a) which also analysed impacts of future land-use, climate and abstraction activity on Whiteman Park and Melaleuca Park. Therefore the results of the Gnangara modelling and the East Gnangara modelling have been compared.

14.1 Terrestrial vegetation EWPs

14.1.1 Previously proposed EWPs

Melaleuca Park

Excluding monitoring well NR6C (where the EWR = EWP) the EWPs proposed in Melaleuca Park in the *Gnangara Section 46 Report* (WAWA, 1995a) actually varied slightly from the EWRs. In wells WM6, WM8 and WM2 the EWPs were set less than the EWRs (see Figure 13 for well locations). This is because the model predicted that the EWRs can not be achieved even with no increase in groundwater abstraction, due to climatic impacts (i.e. EWRs can not be met due to climate alone). The results are repeated in Table 18. The EWPs proposed in the Gnangara Section 46 Report (WAWA, 1995a) do not allow any increase in groundwater abstraction to impact Melaleuca Park because it is considered to be unacceptable given the status of the land as a proposed nature reserve (WAWA, 1995a). This has remained the objective of East Gnangara.

Whiteman Park

Modelling in the *Gnangara Section 46 Report* (WAWA, 1995a) found that in Whiteman Park there would be a low level of breaching of the EWRs in monitoring wells (see Table 18). To provide protection for the conservation areas of Whiteman Park EWPs proposed are set at the same levels as the EWRs. This is important as there should be no further impact on Whiteman Park from groundwater abstraction given the tree deaths which occurred in Whiteman Park in 1991. This is likely to mean that wells in Whiteman Park will not operate at their design capacity and will need to be switched off when water levels in the Park are low.

14.1.2 Role of East Gnangara in setting EWPs for terrestrial vegetation

The EWPs in Melaleuca Park and Whiteman Park will remain the same as those developed in the *Gnangara Section 46 Report* (WAWA, 1995a). However additional EWPs are proposed for the vegetation corridor and for another well in Melaleuca Park (NR11C).

Results from the *Gnangara Section 46 Report* (WAWA, 1995a) modelling and the East Gnangara modelling which both predict breaches of EWRs in Whiteman Park and Melaleuca Park have been compared to ensure that results are consistent.

Comparison of modelling results in East Gnangara and the *Gnangara Section 46 Report* (WAWA, 1995a)

One of the model runs presented in the *Gnangara Section 46 Report* (WAWA, 1995a) has predicted the percentage non-compliance with EWRs in Melaleuca Park and Whiteman Park under a scenario of current abstraction only (i.e. without Lexia or new East Mirrabooka wells). This is similar to the results obtained in the same areas in the East Gnangara modelling which does incorporate the Lexia and East Mirrabooka schemes. Results of each model are provided in Table 18.

Melaleuca Park

The differences in modelling results for the *Gnangara Section 46 Report* (WAWA, 1995a) and East Gnangara in wells WM6 and WM8 in Melaleuca Park are not significant. The Lexia wells will not have significant impacts in Melaleuca Park. However the EWPs are set lower than the EWRs in these wells due to the Gnangara s46 model predictions that climatic impacts will cause water levels to be below the EWRs in approximately 15 per cent of years.

The differences observed in the two models in monitoring well WM2 are significant, with breaches higher in the *Gnangara Section 46 Report* (WAWA, 1995a) modelling (without the Lexia scheme). It is best to accept the worst case scenario and maintain the EWP less than the EWR as in the Report. The *Gnangara Section 46 Report* (WAWA, 1995a) concludes that in this well climate will result in water levels being less than the EWR in 17 per cent of years.

Both the Gnangara and East Gnangara models predict no impacts on the EWR at well NR6C. Therefore the EWP is equal to the EWR in NR6C.

Tables 18. Predicted breaches of EWRs in Whiteman Park and Melaleuca Park and the corresponding EWPs

Well	EWR (mAHD)	% breaches EWR - East Gnangara model with abstraction from Lexia #)	% breaches EWR - Gnangara model (with existing abstraction only - No Lexia abstraction)	EWP (mAHD)
Melaleuca Park				
WM6 *	58.8	14	14	58.3
WM8 *	65	12	15	64.8
WM2 *	67	3	17	66.5
NR6C	58.5	0	0	58.5
Whiteman Park				
MM18	38.6	0	0	38.6
MM59B ¨	36.3	13	0	36.3
MM53	33.3	0	0	33.3
MM49B	24.7	0	0	24.7
MM55B ¨	29.5	12	2	29.5

 # Lexia includes the Lexia groundwater scheme of eleven superficial wells, one semi-confined well and two East Mirrabooka superficial wells.

** The EWP < EWR as the model predicts that climate will cause a fall in groundwater levels.*

¨ Production wells will be turned off approximately 1 in 8 years in order to meet the EWP.

Whiteman Park

In Whiteman Park results are consistent between the Gnangara s46 modelling and the East Gnangara modelling, apart from well MM55B and MM59B. With the Lexia and East Mirrabooka groundwater schemes in place (East Gnangara model) breaches of the EWR in 12 - 13 per cent of years in MM55B and MM59B are predicted. However the EWP should still be equal to the EWR [as in the *Gnangara Section 46 Report* (WAWA, 1995a)] because it is considered important to set the EWP above the minimum water levels associated with the 1991 tree deaths.

The implications of setting the EWP equal to the EWR in well MM55B and MM59B will be the need for close management of abstraction from nearby production wells. Production wells close to these monitoring wells will need to be turned off approximately 1 in 8 years.

14.1.3 Additional wells with EWPs for terrestrial vegetation

The East Gnangara model has been run in the form of 111-year hydrographs to predict future water levels resulting from the preferred abstraction and land-use scenario in an additional well NR11C in Melaleuca Park and in wells MM12, L30C, L110C and L220C in the native vegetation corridor. The predicted water level data obtained have been compared to the EWRs to obtain an indication of the percentage breaches of the EWR as discussed. The results are presented in Table 19.

Melaleuca Park

Monitoring well NR11C is a new addition to wells in Melaleuca Park with EWRs. There are no predicted breaches of the EWR in this well and the EWP is equal to the EWR.

Native vegetation corridor

The model predicts that the EWR in monitoring wells MM12, L30C and L220C cannot be met in approximately 15 - 30 per cent of years. Observations of the predicted hydrographs show that the breaches occur because predicted water levels fall below the Environmental Water Requirement by approximately 0.3 - 1 m in certain periods.

The remaining well in the vegetation corridor is L110C. At this location the Water and Rivers Commission considers the 111-year hydrograph inaccurate. Water levels appeared to be much lower in the calibrated part of the hydrograph than the actual levels which have been recorded in this well since 1984 and it has been concluded that the model is inaccurate in its predictions of absolute water levels at well L110C. Therefore the percentage breaches of the Environmental Water Requirement cannot be predicted from the hydrograph. Instead impacts have been assessed using the water table contour plot produced for the preferred abstraction and land-use scenario and presented in Section 13.2 and illustrated in Figure 27. This provides information on the degree of change to water levels likely to occur in this area. This information, and past water level monitoring data, has then been used to determine impacts at L110C.

Table 19. Predicted breaches of EWRs in NR11C and the vegetation corridor and the corresponding EWPs proposed

Well	EWR (mAHD)	% breaches of EWR	Proposed EWP (mAHD)
Melaleuca Park			
NR11C	55	0	55
Native vegetation corridor			
MM12	43	25	42
L30C	47.5	31	47.2
L110C	57	model cannot predict absolute levels in this area	55.7
L220C	52.5	13	52.2

The drawdown predicted at L110C using the contour plot presented in Figure 27 is 2 m. However, what this equates to in terms of how low water levels are likely to go below the EWR is unknown due to the inability of the model to provide absolute levels in this area. Therefore, the following approach has been taken to determine the potential impacts:

i) the previous lowest recorded minimum in L110C was obtained from monitoring records;

ii) 2 m was subtracted from the previous minimum to obtain a worst case potential minimum water level which could be reached; and

iii) the impacts associated with this minimum were considered.

The previous minimum ever recorded in L110C is 57.7 mAHD. A 2 m drawdown from this level would result in a minimum water level of 55.7 mAHD. A water level of 55.7 mAHD is 1.3 m below the EWR (57 mAHD).

The result of allowing the EWP in wells in the vegetation corridor to be less that the EWR by the amounts predicted would be a gradual change to a drier community structure. The existing community of the native vegetation corridor consists of *Banksia attenuata, Banksia menziesii* open woodland with scattered *Banksia ilicifolia* open woodlands in low-lying areas (Gibson *et al.*, 1994; R Froend, pers. comm.). A change to a drier community structure means that there would be a gradual change in abundance of some species. Banksia species most dependent on higher groundwater levels and soil moisture (e.g. *Banksia ilicifolia)* would reduce in number and those more tolerant of lower water levels would become more dominant (e.g. *Banksia menziesii)* (R Froend, pers. comm; WAWA, 1992; Mattiske and Associates, 1981-1997). In general, species diversity over the vegetation corridor is not expected to change and will not change in higher points in the landscape and western areas furtherest from abstraction. There is a possibility that in localised areas where drawdown is highest there may be a loss of particular species. However, the species present in the corridor are common on the Gnangara Mound and any trees lost will be replaced by more drought tolerant species.

As groundwater levels change, individuals of the same species can respond differently, depending on what they become adapted to over time. For example, individuals of the same species can have different tolerances to changes, depending on what water source (water table, soil moisture or some combination) they have become adapted to using. Also, individuals can change from being phreatophytic (accessing the water table) to xerophytic (accessing soil moisture) if the rate of drawdown is slow enough for them to adapt. This switching to different sources of water can fluctuate seasonally and will also vary between individuals of species depending on their position in the landscape (previous depth to groundwater) (R Froend, pers. comm., 1997).

If water levels were allowed to drop in the vegetation corridor some of the more groundwater-dependent mature individuals may die. These trees would be replaced by seedlings. This has been documented to occur at a transect monitored by Mattiske Consulting (1991-1997) where a number of trees died in the Summer of 1991 due to a combination of low water levels (poor recharge) caused by low rainfall and groundwater abstraction and from stress due to the occurrence of record high temperatures. Mature species of *Banksia ilicifolia, Banksia attenuata* and *Banksia menziesii* became stressed and/or died. However the condition of the trees has improved and juvenile *B. ilicifolia* and *B. menziesii* have since become established (Mattiske and Associates 1995, 1997). If changes were to occur in the vegetation corridor they would be much slower and much less severe than this. There would be a gradual change, similar to the slow changes discussed below. As new seedlings become established they would adapt to being less reliant on high groundwater levels than the trees they replace. They would become adapted to the new lower groundwater level created by groundwater abstraction.

Natural changes to a drier community structure have been observed on the Gnangara Mound over many years of monitoring vegetation transects. Havel and Edminson (1966), Havel (1975), Alpin (1976), Heddle (1980) and Mattiske and Associates (1981- 1997) have been monitoring vegetation transects over the Gnangara Mound over 30 years. This monitoring includes transects which are located both in close proximity to groundwater abstraction and remote from groundwater abstraction. They illustrate a regional trend of moves towards the more xeric (drier) end of the community continuum. For example, one transect which has been monitored since 1966 is located at least 20 km from the nearest public groundwater abstraction scheme and is also remote from areas of private abstraction (although it is not far from the northern end of the Yanchep pine plantation). The results of monitoring show a gradual trend of decreasing soil moisture with resultant stress on tree species which rely on moister soil conditions such as *Melaleuca priessiana* and *Eucalyptus rudis* and increased numbers of species which prefer drier soils (e.g. *Banksia prionotes*). These effects can be attributed mostly to climatic impacts with some influence from reduced recharge due to pines upstream (Mattiske and Associates, 1995, 1997). Another transect distant from public abstraction activity and pine plantation has also shown natural declines in soil moisture. The results of monitoring here has shown a gradual decline in the condition of tree species on the transect in general and a maintained number of species that tolerate drier conditions (Mattiske and Associates, 1992). Results from these transects are consistent with regional trends demonstrated at other transects closer to groundwater abstraction and/or pine plantations. It can be concluded that all transects are showing changes to the drier end of the continuum mainly due to climate but with some local changes exacerbated by groundwater abstraction and pine plantation effects (Mattiske and Associates, 1981 - 1997).

It is proposed to allow a change to a drier community structure in the vegetation corridor by setting the EWP below the EWR. A gradual change to a drier community structure in this location is considered an acceptable trade-off to public water supply in the North-East Corridor for the following reasons:

- The current status of the land. Although the land is being considered for inclusion in Bushplan the area is currently set aside for basic raw materials in the North-East Corridor Structure Plan (DPUD, 1994) and a mining lease currently exists over the majority of the corridor. Therefore significant areas of vegetation are likely to be cleared over the next few years.
- As a result of the modelling process the scheme layout has been optimised to minimise drawdowns on the vegetation corridor and other important areas. To meet the EWRs in the vegetation corridor, abstraction would have to be reduced much further. This may make the scheme unviable.

Given this justification the Water and Rivers Commission proposes that the EWP be set below the EWR by: 0.3 m in wells L30C and L220C; 1 m in well MM12; and 1.3 m in L110C. The rate of change in community structure will vary depending on the amount of drawdown (i.e. it will be greatest in the vicinity of L110C). The rate of change will also depend on the rate of drawdown in the water table and could be exacerbated by unusual climatic events such as the low rainfall/high temperature event which occurred in 1991. This contributed to tree stress in areas on the Gnangara Mound, in the wheatbelt and other areas of the south west (Mattiske and Associates, 1995; WAWA, 1992). Under normal climatic conditions the rate of loss and change in structure should be gradual. Production wells nearby to the vegetation corridor will be phased in to ensure drawdown under vegetation is slow, therefore enabling the community to adapt to some extent.

14.1.4 Summary of EWPs for terrestrial vegetation and interventions required to ensure compliance

Table 20 provides a summary of the EWRs and EWPs for terrestrial vegetation. The 111-year hydrograph data has also been compared to the EWPs to predict if there are likely to be breaches of the EWP and therefore to provide an indication of the interventions that are required.

Groundwater abstraction in the East Gnangara study area will be managed to meet the EWPs at all times. Therefore if there are years when water level monitoring indicates that water levels may fall below the EWP, abstraction will be reduced close to the susceptible area to avoid the EWPs being breached. The percentage of breaches in some wells of the EWPs predicted in Table 20 indicate that production wells near the top of Whiteman Park and the bottom of the vegetation corridor (i.e. the East Mirrabooka wells) may need to be turned off up to 1 in 8 years.

Table 20. Summary of EWRs and EWPs and interventions required to ensure compliance with EWPs

Monitoring well	EWRs (mAHD) Minimum level	EWPs (mAHD) Minimum level	predicted % of years intervention required to ensure compliance with EWPs
Melaleuca Park			
WM6	58.8	58.3	3
WM8	65	64.8	8
WM2	67	66.5	0
NR6C	58.5	58.5	0
NR11C	55	55	0
Whiteman Park			
MM18	38.6	38.6	0
MM59B	36.3	36.3	13
MM53	33.3	33.3	0
MM49B	24.7	24.7	0
MM55B	29.5	29.5	12
Vegetation corridor			
MM12	43	42	0
L30C	47.5	47.2	11
L110C	57	55.7	*
L220C	52.5	52.2	0

** model unable to predict absolute water levels.*

14.2 Impacts on criteria wetlands

As mentioned previously there is insufficient information at this stage to determine EWPs for the wetlands chosen within the East Gnangara study area. However the model has been used to predict the potential impacts of the future abstraction and land-use scenario on groundwater levels at these wetlands. Several variations of the Lexia and East Mirrabooka wellfield have been investigated using the model for their relative impacts. As discussed in Section 12 the final wellfield layout has a reduced number of wells and total quota from the original proposed scheme. The layout is shown in Figure 2 and corresponding abstraction in Table 17. The predicted impacts on each wetland are discussed below:

EPP wetland 173

As seen in Figure 27 the preferred abstraction and land-use scenario is predicted to have little impact on the EPP wetlands on the south-eastern boundary of Melaleuca Park. The contour plot shows that drawdowns in groundwater will be considerably less than 0.25 m and is likely to be close to zero. This means that there will be minimal influence on current water regimes and therefore no impact on the distribution of wetland vegetation, invertebrate species diversity or fish conservation.

Dampland 78

The preferred abstraction and land-use scenario is predicted to have a 0.25 m drawdown on groundwater where dampland 78 is located. This dampland has been experiencing a drier regime within at least the last 5 years. Evidence of this can be seen in the development of young *Banksia ilicifolia* in the bed of the wetland and dying *Melaleuca priessiana* on the fringe. The vegetation assemblages establishing as a result of the drier climatic regime will adapt to the 25 cm drop in the water table predicted from groundwater abstraction. The vegetation occurring at the dampland has been found to occur elsewhere where the watertable is 6 m below ground. Minimum water levels taken in early 1996 indicate the watertable is currently 5 m below ground.

Lexia wetlands

The model has predicted a 0.25 m drawdown on groundwater levels where wetlands 86 and 186 are located (see Figure 27) and no drawdown at wetland 94. The Lexia wetlands are suspected to contain a certain degree of perching and therefore are not totally dependent on groundwater. Therefore drawdowns on actual wetland water levels may be much less. However if we assume the worst case scenario that they are not perched and that there will be up to a 0.25 m drawdown in wetland water levels, the impacts are still within tolerance levels of wetland vegetation. There will be no change to current vegetation assemblages under this scenario.

14.3 EWPs for seepages

The EWP for the Egerton seepage has been set at the same level as the EWR. It is important that a permanent flow of water is maintained in the seepage and based on current knowledge this EWR is believed to maintain the head upstream required for this to be achieved.

Attempts at producing a 111-year hydrograph at the monitoring well upstream of the seepage proved unsuccessful. The model had difficulty in predicting the limited fluctuation in water levels which occur in this area as a result of the constant seeping of water from higher on the mound. During 1994-95 actual water levels were measured (Jim Davies and Associates) and model calibration at this point does not predict the actual. Part of reason is the lack of calibration points close to the seepage. Here there are variations in hydrology occurring over small areas and therefore the model is unable to predict absolute water levels in this situation. Therefore the contour plot was used to determine the impacts likely to occur.

From observation of Figure 27, drawdowns in the vicinity of Egerton seepage are predicted to be minimal and unlikely to influence the head upstream and the flow in the seepage.

EWPs have not been set at Edgecombe seepage. The EWRs determined in Section 10.5 are a suggestion for management and it is not recommended to form part of the environmental conditions. The justification for this is that modelling by A.J. Peck and Associates for the *Egerton Nutrient and Drainage Management Plan* (Alan Tingay and Associates, 1995b) indicates that urban development upstream of the seepage is likely to have a greater influence on water levels than the Lexia and East Mirrabooka Stage 3 groundwater schemes (see s 10.5). *The Egerton Nutrient and Drainage Management Plan* has been cleared by the Minister for the Environment.

15. Groundwater allocations

A summary of groundwater allocations given to native vegetation (EWPs) is shown in Table 20. EWPs for wetlands are to be determined and EWPs for the seepages are discussed in Section 14.3. A summary of groundwater allocations to public water supply and private groundwater users is given in Tables 21 and 22.

Table 21. Public Water Supply allocation

Scheme	Proposed Commissiong Date	No Superficial/ Semi-confined wells	Quota kL/yr x 10^6
Lexia	1998	12	9.8
East Mirrabooka	1998	2	1.2
Total Proposed schemes			**11**

Table 22. Private groundwater sub-area allocations

Sub Area	Superficial/ Mirrabooka Sands Allocation Quota (kL x 10^6)		Unallocated availability (kL/yr x 10^6) (at November 1996)	
	Superficial	Mirrabooka	Superficial	Mirrabooka
Beechboro	1.0		0.556	0
Whiteman Park	1.3		1.019	0
Henley Brook	0.2		0.049	0
Ballajura	2.086		0	0
IP8	3		2.924	0
Landsdale	1.6		0	0
Plantation	0.7		0.097	0
State Forest	0.964	0	0	0
North Swan	3.3	0.25	0.3	0
South Swan	4.25	1.6	0.33	0.5
Neaves	3.8	0.5	0.588	0.5
Radar	3.4	1.2	2	1.147
Central Swan	1.7	0	0.024	0
East Swan	no limit set	no limit set		
Cockman Bluff	1.9		1.232	
Bandy springs	no limit set	no limit set		

16. Management and monitoring programme for the East Gnangara Mound

To assess the impacts of groundwater abstraction and other land-use activity on water levels in the East Gnangara study area, the Water and Rivers Commission will produce annual and triennial reports which will be submitted to the EPA. These reports will provide information on; water level changes over the year, operations by the Water Corporation and other users, compliance with water level criteria and results of ecological monitoring. Triennial reports will provide more detailed information than annual reports and will also focus on identifying any necessary changes to the monitoring strategy and management of groundwater abstraction. The annual and triennial reporting for East Gnangara will be incorporated with the Gnangara reporting.

16.1 Groundwater monitoring

WAWA has previously monitored water levels in a comprehensive network of wells over the Gnangara Mound. Within the East Gnangara study area there are approximately 215 groundwater monitoring wells. The aquifer monitored and the frequency of monitoring depends on the well location and purpose of monitoring. Monitoring frequency varies between 1 - 3 monthly.

This monitoring programme will be continued by the Water and Rivers Commission. Water level trends will be assessed annually and triennially and addressed in reports to the EPA.

16.2 Terrestrial vegetation monitoring

Monitoring wells

To ensure protection of current vegetation assemblages EWPs have been determined for a number of monitoring wells in the East Gnangara study area (see Section 14). These monitoring wells will be monitored monthly to check compliance with the EWPs. The monitoring will provide an indication of when water levels are approaching the EWPs. If this occurs, monitoring will increase in frequency and water level readings will be taken weekly. If it appears that falling water levels are likely to breach EWPs then pumping from production wells will cease until there is sufficient recharge to the water table.

Terrestrial vegetation transects

In addition to the groundwater monitoring, five terrestrial vegetation transects will be monitored in the East Gnangara area. One of these is in Whiteman Park and was established in 1991, but has not been monitored since. Another in Melaleuca Park was established in 1966 and has been monitored on a three-yearly-basis (Mattiske and Associates, 1995). These transects will be monitored every 3 -6 years.

An additional transect has also be established in Melaleuca Park and was monitored initially in Spring 1996. It will also be monitored at a frequency of every 3 - 6 years. The final two terrestrial vegetation transects have been established in the vicinity of the Lexia wetlands and will be monitored every 3 - 6 years.

Four of the five terrestrial vegetation transects proposed for East Gnangara are in addition to the 11 transects which are monitored every 3 - 6 years as part of the Gnangara Mound environmental monitoring programme.

The East Gnangara transects will be monitored for vegetation health, species composition and abundance, and soil moisture. The objective of monitoring will be to assess the condition of the native vegetation and relate it to soil moisture, climate and pumping operations. In addition to the transects monitored in the East Gnangara study area (which are within areas which may be impacted by groundwater abstraction), the Water and Rivers Commission also has transects that are remote from areas of groundwater abstraction which are monitored as part of the Gnangara Mound monitoring programme. This helps to identify the relative importance of groundwater abstraction in causing drawdown beneath phreatophytic vegetation. Terrestrial vegetation transect monitoring will provide feedback on whether EWPs are sufficient to achieve the aim of protecting the vegetation.

Additional measures of vegetation change

In addition to the general monitoring of vegetation transects two other monitoring tools will be adopted to assess changes in community structure in native vegetation areas. Similarity indices and measurements of health and age structure of indicator species will be taken along each of the terrestrial vegetation transects.

Indicator Species

Indicator species will be determined for key plant community types within each of the terrestrial vegetation transects. It will be necessary to select a range of indicator species because different species tolerate different degrees of change depending on their biology and lifeform. Indicator species selected at each transect will be monitored for age (size), class, distribution, vigour and recruitment

Similarity Indices

A similarity index for each transect at each monitoring period will be calculated. Similarity indices will be used to monitor changes in composition over time and differences in vegetation structure between sites (i.e. differences may be found between sites near areas of groundwater abstraction and remote from groundwater abstraction).

These indicators will be quantified by comparison to a predetermined 'acceptable' rate of change in vegetation composition. An 'acceptable' rate of change will initially need to be determined through analysis of data from existing vegetation transects and further investigation into EWRs of phreatophytic vegetation. The effectiveness of the vegetation criteria will be reviewed on a triennial basis at the time of reporting to the EPA. If necessary the criteria will be modified in consultation with the EPA.

Other vegetation monitoring

The Water and Rivers Commission will conduct dieback surveys over the study area where EWPs have been determined. This will provide an indication of the impact of dieback disease on the native vegetation. This is important as often it is difficult to determine if groundwater abstraction or dieback have been the cause of tree deaths. A survey will provide an indication of the relative impact of dieback disease in the area. A baseline survey was conducted in Spring 1996 which indicated several areas have been effected by dieback disease including the eastern sectors of the Lexia wetlands, the EPP wetland in Melaleuca Park and patches of the vegetation corridor, particularly a large area in the northern part of the corridor (Hart, Simpson and Associates, 1997). A survey will be conducted again three years after the Lexia groundwater scheme has been in operation. The need for any further surveys will then be assessed.

Rare flora water level monitoring

Water levels will be monitored upstream of rare flora locations through the existing network of monitoring wells.

16.3 Wetland monitoring

Water level monitoring

Monitoring wells have been established in each of the wetlands selected for determination of EWRs (see Section 8.1). Staff gauges have been installed in the base of the wetland at wetlands which contain open water for some of the year (i.e. apart from dampland 78 and Lexia wetland 94). Monitoring wells will also be installed outside of the wetlands showing evidence of perching to gain a better understanding of the relative importance of groundwater to the wetland. Before reviewing EWRs water level monitoring will be carried out on a monthly basis to gain more information on water regimes.

Once EWRs have been reviewed and EWPs have been determined for each wetland the monitoring wells and staff gauges will continue to be monitored monthly to ensure compliance with the EWPs.

Ecological monitoring

The EWPs aim to ensure adequate protection of the identified values of the wetlands. To ensure the EWPs are adequate in achieving the task of protecting wetland values the Water and Rivers Commission will conduct monitoring of ecological components of the wetlands. Initially ecological monitoring will be conducted to gain baseline information against which any future changes will be assessed. The ecological monitoring includes vegetation transects and aquatic invertebrate fauna monitoring.

Vegetation monitoring

Vegetation transects will be established at each of the wetlands selected for EWRs/EWPs. For each wetland a minimum of one vegetation transect will be established to monitor the species distribution in response to wetland water levels. More than one transect will be established where it is necessary to ensure that the majority of plant communities present at the wetland is represented. Transects will be monitored for distribution of plant species relative to water level regime and for seedling recruitment on an annual basis for the first three years. The frequency of monitoring will then become every two years. However the wetlands will be visited on an annual basis for a visual assessment of vegetation health. Photographic records of the vegetation will be taken on each occasion. Transects will be monitored in Spring using procedures and specifications as in Froend *et al.*, 1993.

Regional wetland vegetation monitoring

In addition to monitoring individual wetlands, changes in area of wetland plant communities will be assessed on a regional basis. As a part of the *Gnangara Section 46 Report* (WAWA, 1995a) the establishment of two regional transects have been proposed over the Gnangara Mound. One of these incorporates Melaleuca Park. Aerial photography will be used to monitor this transect to obtain an indication of wetland habitat change on a regional basis. Monitoring will be conducted every three years in Spring when water levels are highest.

Aquatic invertebrate monitoring

Initially, aquatic invertebrate monitoring will be conducted to gain baseline information on invertebrate community structure in each of the wetlands selected for EWRs. Monitoring will then be conducted annually to assess any impacts on the invertebrate community. Monitoring will be conducted in Spring when the wetlands contain water and there is peak biological productivity. Monitoring will be carried out using standard procedures and samples will be taken from all microhabitats present at each wetland.

Initial baseline monitoring was carried out in November 1995 for the EPP wetland in Melaleuca Park. See Appendix 7 for a list of species. The remaining wetlands (Lexia) have been sampled in Spring 1996 however results are not yet available.

Water Quality monitoring

In addition to the monitoring of aquatic invertebrate species, water quality monitoring will also be conducted annually. This will be carried out at the same time as invertebrate monitoring. Parameters to be monitored include pH, conductivity, temperature, colour, turbidity, total P, PO_4^{3-}, total N, NO_3 /NO_2 and chlorophyll *a* levels. Analysis of water samples will be carried out using standard methods. These parameters should provide an indication of changes in water quality resulting from land-use developments. This will provide information to assess the relative importance of groundwater abstraction and other land-use impacts on wetland ecology.

16.4 Seepage monitoring

Water levels in wells upstream of and within the Egerton and Edgecombe seepages will be monitored when the Water and Rivers Commission has permission from Multiplex Constructions. Water levels will be monitored on a monthly basis to ensure compliance with EWPs (see Section 14) for the Egerton seepage. If water levels approach EWPs then production wells closest to the areas of concern will be turned off until there is sufficient recharge upstream.

Ecological monitoring of the seepages will also be undertaken. Aquatic invertebrate and water quality monitoring will be conducted annually in Spring. Monitoring will be done using standard procedures. The parameters measured will be the same as listed for wetlands in Section 16.3.

In 1995 monitoring was conducted in Edgecombe seepage (see Appendix 8) Egerton seepage was not monitored at this time because permission to enter the property could not be obtained.

16.5 Further investigations and research

The need for further investigation and research on wetlands, vegetation and seepages of the East Gnangara Mound has been highlighted in various Sections of this report. Further investigations and research proposed includes:

- investigation into the perching of the Lexia wetlands and EPP wetland 173 in Melaleuca Park;
- investigation into the minimum water level requirements upstream of the Egerton and Edgecombe seepages and the seepages feeding EPP wetland 173 (Melaleuca Park) which ensure sufficient head to maintain a permanent flow of water in the seepages;
- research into the fish outlier *Galaxiella nigrostriata* in EPP wetland 173 in Melaleuca Park (Research Project by Kim Smith and supervised by Dr B. Knott);
- investigate artificial maintenance of the *Melaleuca rhaphiophylla* wetland within the pine plantation and other forms of wetland mitigation as discussed in Section 13.2.6.2; and
- research into EWRs and the effectiveness of EWPs in dampland and phreatophytic vegetation.

With respect to the final dot point a grant has recently been obtained from the Land and Water Resources Research and Development Corporation to conduct the research. The Water and Rivers Commission, Water Corporation, Mattiske Consulting, Edith Cowan University and the Commonwealth Scientific and Industrial Research Organisation are also providing support. Dr R. Froend is the principal investigator and the study area is the Gnangara Mound. The project will expand and fill gaps in knowledge identified through the *Wetlands of the Swan Coastal Plain* research discussed in Section 8.3. Further information is required on the EWRs of phreatophytic vegetation and wetland vegetation in drier sumpland areas and damplands. The project will also identify indicators of vegetation response to changes in groundwater levels and establish a protocol for monitoring the effectiveness of EWPs. It will finish in 1999.

Objectives of the Research Proposal

i) identify the groundwater dependent plant communities within Groundwater Management Areas on the Swan Coastal Plain and the variability in groundwater dependency within communities and across different topographical features;

ii) identify indicators (species or community characteristics) to use as a standard assessment of vegetation response to EWPs;

iii) determine the water use characteristics of key indicator species and the response of phreatophytic plant communities to change in groundwater regime; and

iv) develop a generic strategy for standardising the identification of EWRs, indicators of vegetation response and protocols for monitoring phreatophytic vegetation, for resource allocation within water resource management agencies.

Benefits of the research to this Plan will include:

- increased knowledge of the water requirements of groundwater dependent terrestrial vegetation. This will be applicable to Melaleuca Park, the vegetation corridor and Whiteman Park;
- increased knowledge of the water requirements of dampland and drier type sumpland vegetation. This will be applicable to the Lexia wetlands and wetlands in Melaleuca Park selected for criteria; and
- identification of indicator species for monitoring the effectiveness of EWPs in vegetation and wetlands.

The Lexia wetlands have been selected as one of the study sites. Transects will be established in and upgradient of the wetlands. The water use of the key vegetation will be investigated including the source of water used. This should provide information on whether the wetland vegetation relies on perched water, groundwater or alternatively how the two interact.

17. Summary, conclusions and commitments

This document has been produced to determine EWPs and groundwater allocations between the environment, public and private users of groundwater on the East Gnangara Mound. It has proposed environmental criteria for phreatophytic vegetation, wetlands and seepages. This Section summarises the criteria developed to date and makes commitments on behalf of the Water and Rivers Commission for the allocation and management of groundwater within the East Gnangara study area.

17.1 Water and Rivers Commission commitments

1. The Water and Rivers Commission will manage public and private groundwater abstraction to meet the water regime management objectives and EWPs summarised in Table 23.

2. The Water and Rivers Commission will report on the management and monitoring of the East Gnangara Mound to the EPA as part of existing reporting for the Gnangara Mound. Triennial reports will include information on the operation of groundwater schemes by the Water Corporation and private groundwater use, compliance with EWPs and environmental conditions and outline any environmental impacts. Annual reports will provide information on compliance with environmental conditions.

3. The Water and Rivers Commission will investigate stratigraphy and water regimes in the Lexia wetlands, EPP wetland 173 in Melaleuca Park and Melaleuca Park dampland 78. For wetlands displaying characteristics of perching the importance of groundwater to wetland water levels will be established and EWRs updated for the first triennial report to the EPA. EWPs will also be determined at this time.

4. The Water and Rivers Commission will support further research and investigations into the EWRs of wetlands, vegetation and seepage areas as defined in Section 16.5.

5. EWPs will be reviewed every six years in triennial reports or as necessary. Feedback, through the monitoring programme, of any unexpected impacts of groundwater abstraction will be used to update EWPs and water allocations if necessary. Any update will involve consultation with the EPA and incorporate public involvement.

6. The Water and Rivers Commission will, after receiving environmental approvals, implement and undertake the following monitoring programme to the satisfaction of the EPA and report results in annual and triennial reports to the EPA:

    6.1 Continue monitoring the network of wells on the East Gnangara Mound, at the frequency of 1 - 3 monthly depending on the well.

    6.2 Monitor water levels in terrestrial vegetation monitoring wells with EWPs monthly.

    6.3 Develop three new terrestrial vegetation transects on the East Gnangara Mound: one in Melaleuca Park and two in the Ellenbrook bushland near the Lexia wetlands. and monitor every 3 - 6 years.

    6.4 Recommence monitoring of the terrestrial vegetation transect (established by the Water Authority (WAWA) in 1991) in Whiteman Park, on a shared cost basis with the Whiteman Park Board of Management. Monitoring will recommence in Spring 1996.

    6.5 Continue monitoring the terrestrial vegetation transect established in 1966 in Melaleuca Park, at a 3 - 6 year frequency.

    6.6 At each of the terrestrial vegetation transects, select a range of species which provide an indication of vegetation composition. The indicator species will be monitored in Spring every 3 - 6 years to assess any change towards a drier community. Parameters that will be assessed include; age (size), class distribution, vigour and recruitment.

6.7 Calculate a similarity index for each transect at each monitoring period with the aim of summarising spatial and temporal changes in vegetation composition.

6.8 For each terrestrial vegetation transect on the East Gnangara Mound determine an 'acceptable' rate of change in vegetation composition. Rates of change will be measured using indicator species and similarity indices.

6.9 Monitor water levels monthly in wetlands and/or in nearby monitoring wells for the following wetlands (see Figure 14):

- Lexia wetland 94;
- Lexia wetland 186;
- Lexia wetland 86;
- Melaleuca Park Dampland 78; EPP wetland 173; and
- Lake Yakine (located east of Edgecombe seepage).

6.10 Develop vegetation transects in each of the wetlands listed in Section 6.9 (with the exception of Lake Yakine). Monitoring will be undertaken in Spring of the first three years and reviewed in the first triennial report.

6.11 Conduct baseline monitoring on aquatic invertebrates and water quality in the Lexia wetlands. Findings will be published in the first annual report.

6.12 Monitor aquatic invertebrate fauna and water quality in the wetlands listed in Point 6.9 which contain open water, in Spring each year.

6.13 Map wetland habitats along a regional transect in Melaleuca Park in Spring using large scale aerial photography annually for the first three years, then every three years.

6.14 Monitor water levels in the Egerton and Edgecombe seepages and upstream of the seepages on a monthly basis (once access is granted).

6.15 Provided access is granted, conduct baseline monitoring of aquatic invertebrate fauna and water quality in the Egerton seepage. Results will be given in the first triennial report.

6.16 Monitor aquatic invertebrate fauna and water quality in the Egerton and Edgecombe seepages annually in Spring (once access is granted).

6.17 Monitor water levels in wells with EWPs more frequently than once a month where necessary to determine compliance with EWPs.

7. By June 1998 the Water and Rivers Commission and CALM will develop a Memorandum of Understanding (MOU) on pine management regimes in State Forest 65 which recognises the dual use of forests and optimises water and timber production, while minimising environmental impacts. The MOU will include agreements associated with the removal of the pine plantation over the next 20 years and the proposed establishment of Gnangara Park. In the process of developing the MOU, further modelling studies will investigate the impact of the various scenarios of pine removal on water tables. This will include consideration of how the 'extra water' could be 'allocated' between consumptive and ecosystem protection uses.

8. The Water and Rivers Commission will provide advice on the impact of land-uses on groundwater resources of the Gnangara Mound to relevant agencies.

9. The Water and Rivers Commission will determine EWPs for new wells in the native vegetation corridor which have been installed at more appropriate places to replace wells MM12, L30C, L110C and L220C once sufficient monitoring data is available from the new wells.

10. The Water and Rivers Commission will continue to chair and provide support for a Consultative Committee as a forum of information exchange and to provide advice to the Water and Rivers Commission in relation to management of water on the Gnangara Mound. Some representatives from each of the East Gnangara and Gnangara Committees will be combined to form one Consultative Committee for the Gnangara Mound.

11. The Water and Rivers Commission will request that the Water Corporation, through licence conditions, phase in the production wells closest to phreatophytic vegetation to allow the vegetation to adapt slowly to the drawdown and minimise the overall impacts of drawdown.

12. The Water and Rivers Commission will liaise with the Department of Environmental Protection (DEP), CALM and the Water Corporation with regards to an appropriate wetland mitigation strategy for the *Melaleuca rhaphiophylla* wetland in the pine plantation. The Water and Rivers Commission will then require the Water Corporation, through licence conditions, to implement the proposed strategy.

13. The Water and Rivers Commission will within six months of receiving environmental approval, require that the Water Corporation, through licence conditions, to update its operations plan to include the Lexia and East Mirrabooka groundwater schemes. This will include environmental management of the schemes and details of how abstraction will be managed to meet EWPs. As part of the operating strategy the Water Corporation will be required to submit annual production plans.

Table 23. Environmental criteria

WELL	LOCATION	ENVIRONMENTAL WATER PROVISIONS (EWPs)		
		Management Objective	**Minimum water level (mAHD)**	**Absolute minimum water level (mAHD)**
WM6	Melaleuca Park	Protect native vegetation from any further groundwater abstraction impacts	58.3	*
WM8	Melaleuca Park	Protect native vegetation from any further groundwater abstraction impacts	64.8	*
NR6C	Melaleuca Park	Protect native vegetation from any further groundwater abstraction impacts	58.5	*
WM2	Melaleuca Park	Protect native vegetation from any further groundwater abstraction impacts	66.5	*
NR11C	Melaleuca Park	Protect native vegetation from any further groundwater abstraction impacts	55	*
MM49B	Whiteman Park	Protect native vegetation from any further groundwater abstraction impacts	24.7	*
MM53	Whiteman Park	Protect native vegetation from any further groundwater abstraction impacts	33.3	*
MM55B	Whiteman Park	Protect native vegetation from any further groundwater abstraction impacts	29.5	*
MM18	Whiteman Park	Protect native vegetation from any further groundwater abstraction impacts	38.6	*
MM59B	Whiteman Park	Protect native vegetation from any further groundwater abstraction impacts	36.3	*
MM12	Native vegetation	Protect native vegetation but allow a slow change to a drier community structure	42	*
L30C	Native vegetation	Protect native vegetation but allow a slow change to a drier community structure	47.2	*
L110C	Native vegetation	Protect native vegetation but allow a slow change to a drier community structure	55.7	*
L220C	Native vegetation	Protect native vegetation but allow a slow change to a drier community structure	52.2	*
GNM13	Dampland 78 - Melaleuca Park	Maintain existing areas of wetland vegetation	**	**
GNM14	EPP 173 - Melaleuca Park	* Maintain existing areas of wetland and stream * Maintain existing areas of wetland vegetation * Protect invertebrate communities dependent on the wetland and stream * Protect the fish, *Galaxiella nigrostrata*	**	**
GNM15	Lexia wetland 186	* Protect current vegetation assemblages in and fringing the wetland * Protect any aquatic invertebrate fauna dependent on the wetland	**	**
GNM16	Lexia wetland 86	* Protect current vegetation assemblages in and fringing the wetland * Protect any aquatic invertebrate fauna dependent on the wetland	**	**
GNM17A	Lexia wetland 94	Protect current vegetation assemblages in the wetland	**	**
B10	Edgecombe seepage	Maintain a permanent flow of water in the seepage	14.35 ***	*
B25	Egerton seepage	Maintain a permanent flow of water in the seepage	39.29 ****	*

** not applicable, ** to be determined, *** recommendation for management only, **** cannot be monitored until access to the land is granted.*

Glossary

Abundance The relative quantity or number of species present.

Allocation An amount of water identified for use by a user-group, such as private groundwater users, or the Water Corporation for public water supply.

Amphipods An order of crustaceans; they lack a carapace, bear unstalked eyes, and breathe through gills.

Aquatic Of a watery environment or species which lives primarily in water.

Aquifer A geological formation which stores and yields groundwater supplies.

Artificial maintenance, supplementation
The addition of water into a wetland to maintain a water level.

Association (vegetation)
A plant community dominated by two or more dominant species.

Bathymetry A plan showing the shape of the base of a wetland by surface contours.

Beneficial use The current or future uses of a part of the environment which have priority of other uses because of their significance to the community. Beneficial uses include conservation of flora and fauna, active recreation, potable water supplies etc. The beneficial use designation provides guidance in managing and protecting the environment.

Biological diversity
The variety of life - the different plants, animals and microorganisms, the genes they contain, and the ecosystems they form.

Buffer (for a wetland)
Any part of a wetland catchment where human impacts are managed to protect the integrity of that wetland.

Confined aquifer
Groundwater located between an upper and lower layer of relatively impermeable material.

Community (vegetation)
Any natural assemblage of interacting populations of different species in a particular area or habitat.

Dampland A seasonally waterlogged basin.

Diversity A measure of the number of species and their relative abundance. A community is said to have a high degree of diversity if it contains many species of fairly equal abundance. Diversity is lower when species abundance is uneven, and very low when species are few.

Dystrophic Applied to wetlands with coloured water which have high levels of plant nutrients but do not display the symptoms of nutrient enrichment.

Ecologically Sustainable Development (ESD)
Development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends.

Ecosystem A defined community of organisms, their interactions, and their physical surroundings.

Emergent Growing or protruding above the water surface, as opposed to floating or submerged (applied to plants).

Environmental Water Provision (EWP)
That part of the EWR that can be met and is provided after consideration of economic and social issues. Ideally the EWR and EWP will be the same.

Environmental Water Requirement (EWR)
The water regime required by the environment to maintain its current ecological values. Can include elements of quantity and duration, and applies both spatially and temporally.

Geomorphic Concerned with the structure, origin and development of the topographical features of the earth's crust.

Gnangara Mound
The mound of groundwater which occurs in the superficial formations bounded by the Swan River, Ellenbrook, Gingin Brook, Moore River, and the Indian Ocean.

Hydrograph A graph showing water level changes with time.

Hydrological regime See water regime.

Lake A permanently inundated basin.

Leederville (aquifer, formation)
A deeper aquifer/formation which is separated from the superficial aquifer by an non water-bearing layer.

Littoral Pertaining to the shore, and in wetlands to the shore area which wets and dries seasonally.

Lowest peak (water) level
The water level that a wetland should reach at its maximum depth, during spring.

Macroinvertebrate
Any animal without a backbone that is large enough to be seen with the naked eye.

Macrophyte A large aquatic plant which can be submerged, floating or emergent.

Perched (wetland)
A wetland which is perched has an underlying layer such as peat, clay or ferruginous pans which results in the water in the wetland not being in direct contact with the regional water table.

Phreatophyte, phreatophytic
A plant, or pertaining to a plant, that obtains its water supply from roots in or near the water table.

Pristine Undisturbed by the activities of people.

Recharge The process of renewing underground water by infiltration of rainfall.

Salinity The measure of total soluble (or dissolved) salt (ie mineral constituents) in water. Water resources are classified on the basis of salinity in terms of milligrams per litre Total Soluble Salts (mg/l TSS). Fresh = < 500mg/L; Marginal = 500 - 1000 mg/L, Brackish = 1000 - 3000 mg/L; Saline = >3000mg/L

Seasonal wetland
A wetland containing water in a certain season or seasons of the year.

Semi-confined aquifer
An aquifer which has some direct connection with the superficial aquifer.

Spring/seepage A flow of groundwater naturally rising to the surface and flowing over the land. A seepage is a small spring.

Stratigraphy The composition, distribution and succession of rock strata.

Sumpland A seasonally inundated basin.

Superficial aquifer/ formation
An aquifer which is close to the surface and can receive direct recharge from rainfall.

Taxa (taxon) A taxanomic group of any rank (e.g. species, genus, family)

Transect A line or narrow belt used to survey the distribution of organisms across a given area.

Trophic (status) The nutrient status of a water body, categories include; eutrophic (high levels of nutrients) and oligotrophic (low levels of nutrients).

Unconfined aquifer See superficial aquifer.

Vadophyte A plant that obtains its water supply by accessing water from the capillary zone of the soil profile.

Water (level) regime The prevailing pattern of water flow and behaviour over a given time, incuding minimum and maximum water depths, timing of filling and drying.

Water table The top of the saturated soil in an unconfined aquifer.

Wetland Areas of seasonally, intermittently or permanently waterlogged soils or inundated land, which are further delineated by the presence of a naturally occurring ecosystem of plants and animals adapted to living in such areas.

Wetland Suite A group of wetlands occurring in the same geomorphic setting.

Xerophyte A plant that obtains its water supply by accessing soil moisture.

Zonation The distribution of organisms in distinctive areas, layers or zones.

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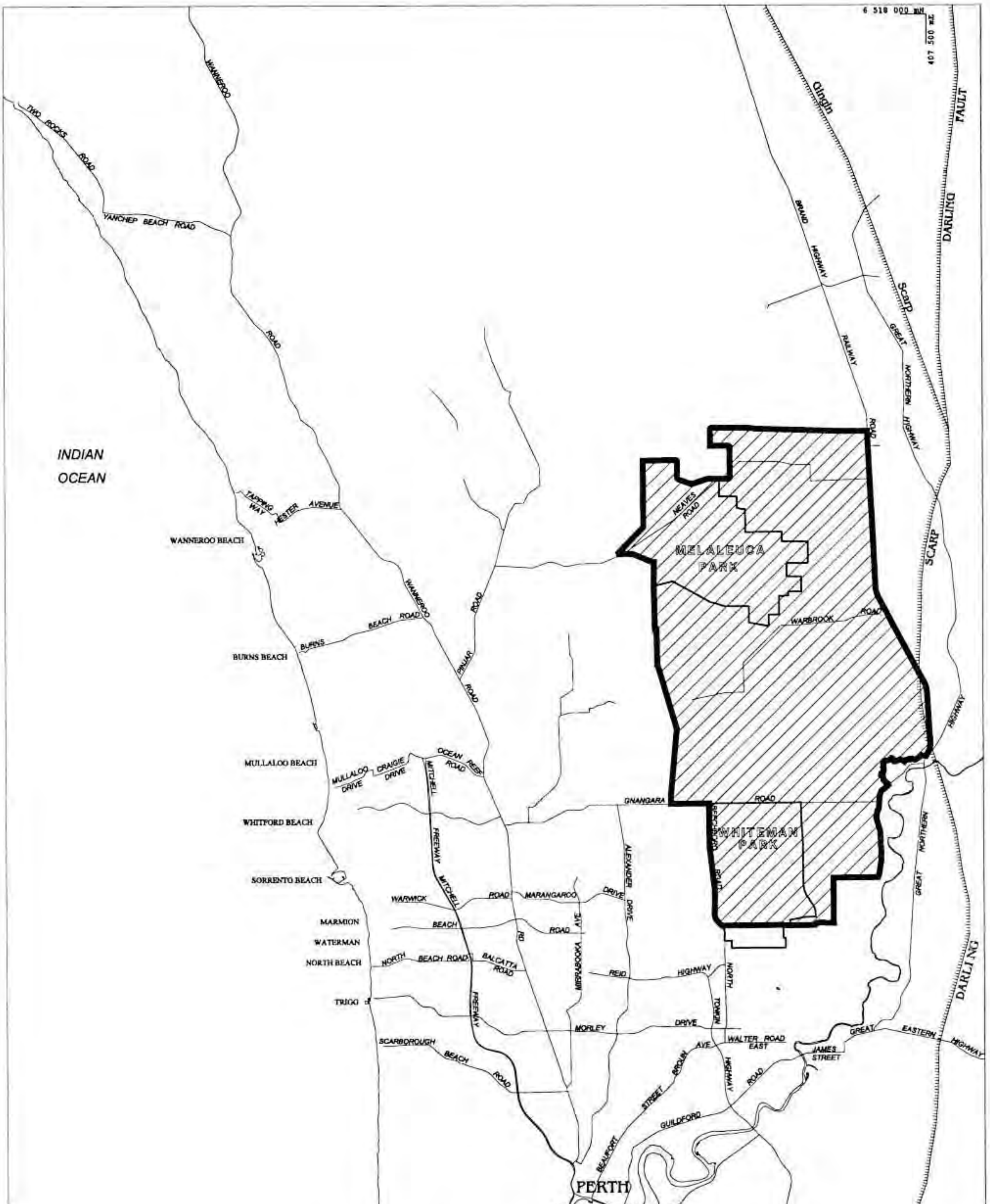


FIGURE 1
EAST GNANGARA MOUND
Study Area

Drawn by D.R.A Date 10/02/96

Catchment and Waterways Management Branch

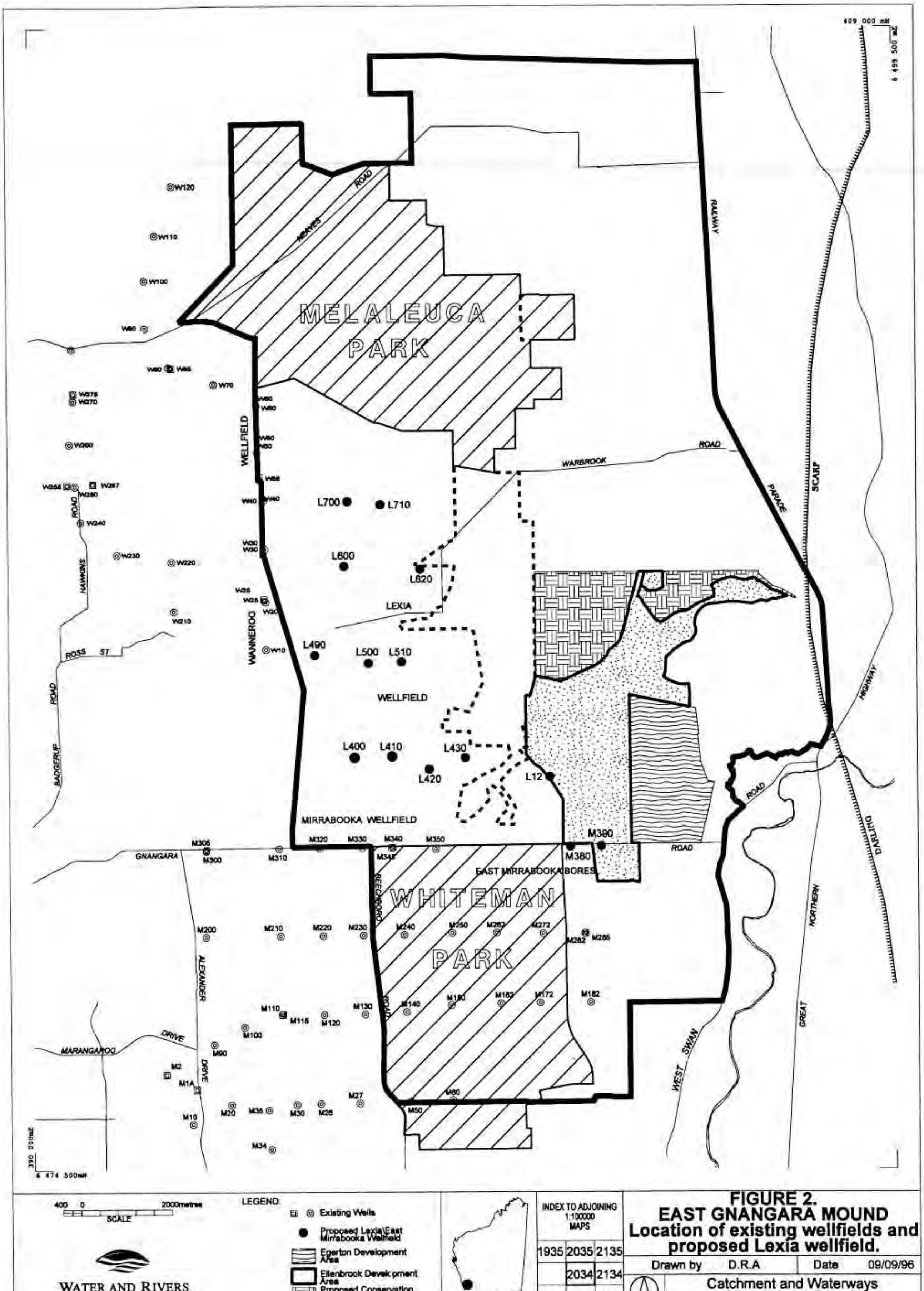


FIGURE 2.
EAST GNANGARA MOUND
Location of existing wellfields and proposed Lexia wellfield.

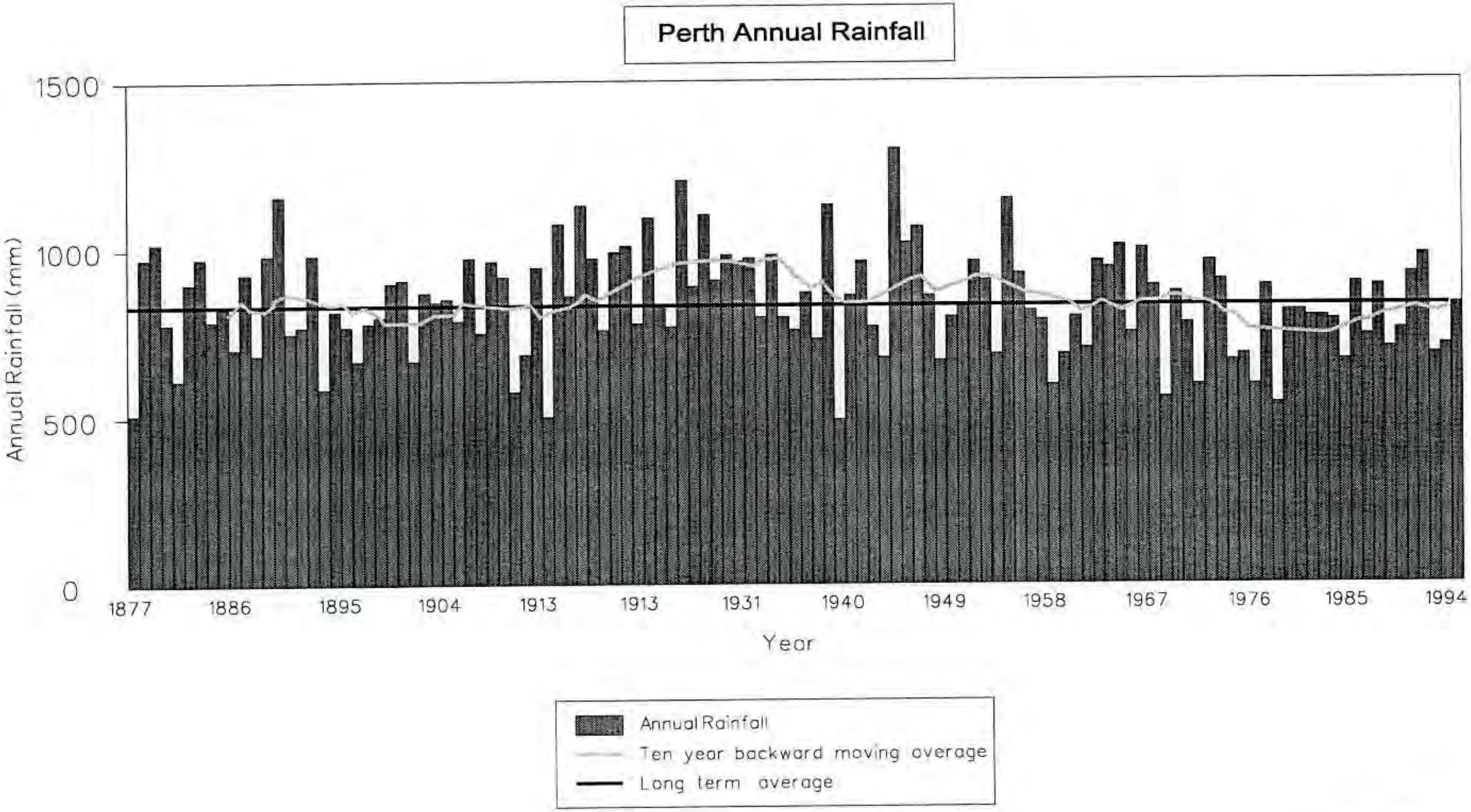

Perth Annual Rainfall
1500
1000
500
0
Annual Rainfall (mm)
1877
1886
1895
1904
1913
1913
1931
1940
1949
1958
1967
1976
1985
1994
Year
Annual Rainfall
Ten year backward moving average
Long term average

FIGURE 3

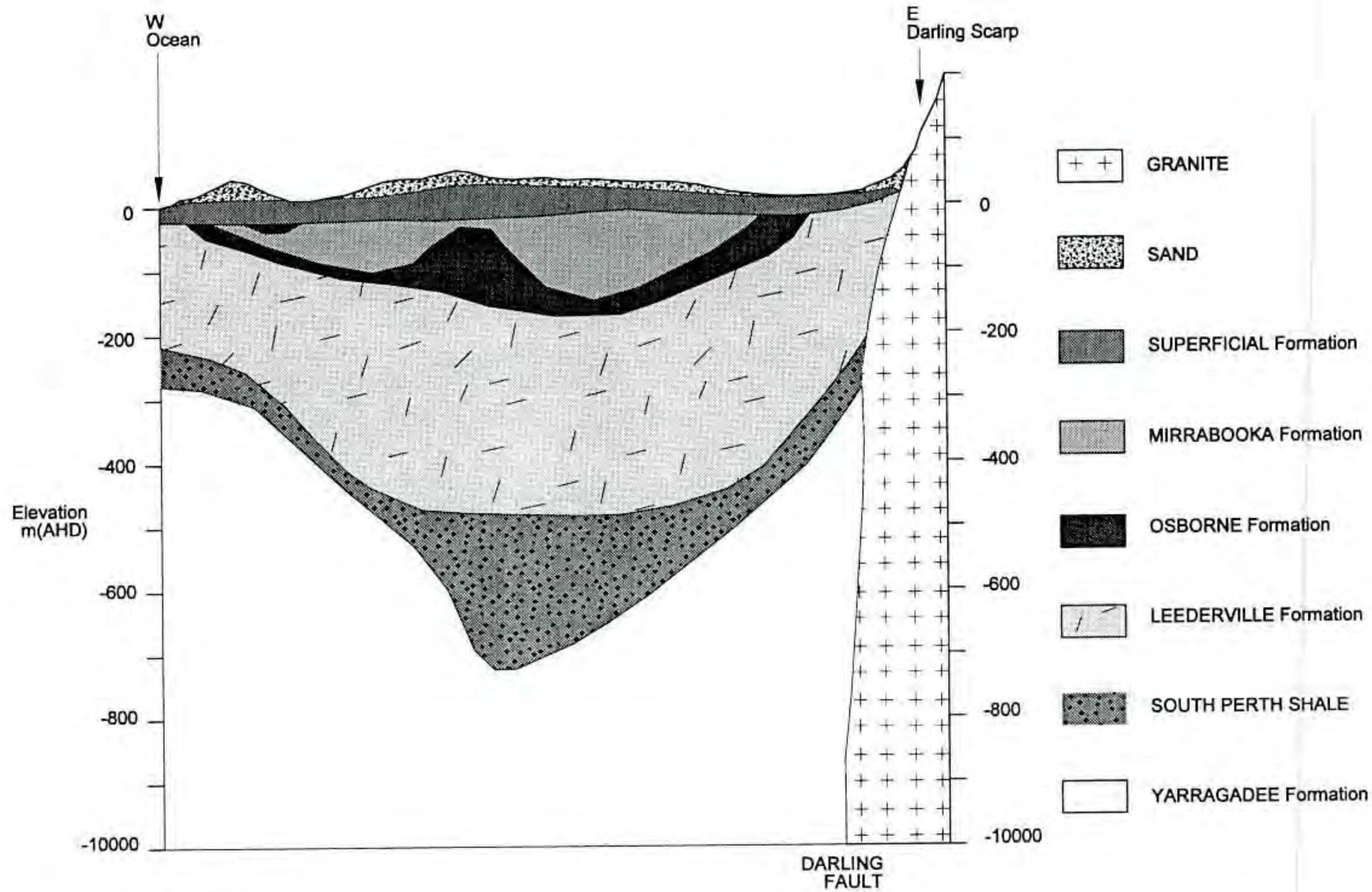


FIGURE 4.
GNANGARA MOUND
Geology of Perth Basin

Drawn by D.R.A Date 21/01/96

Catchment and Waterways Management Branch

WATER AND RIVERS COMMISSION

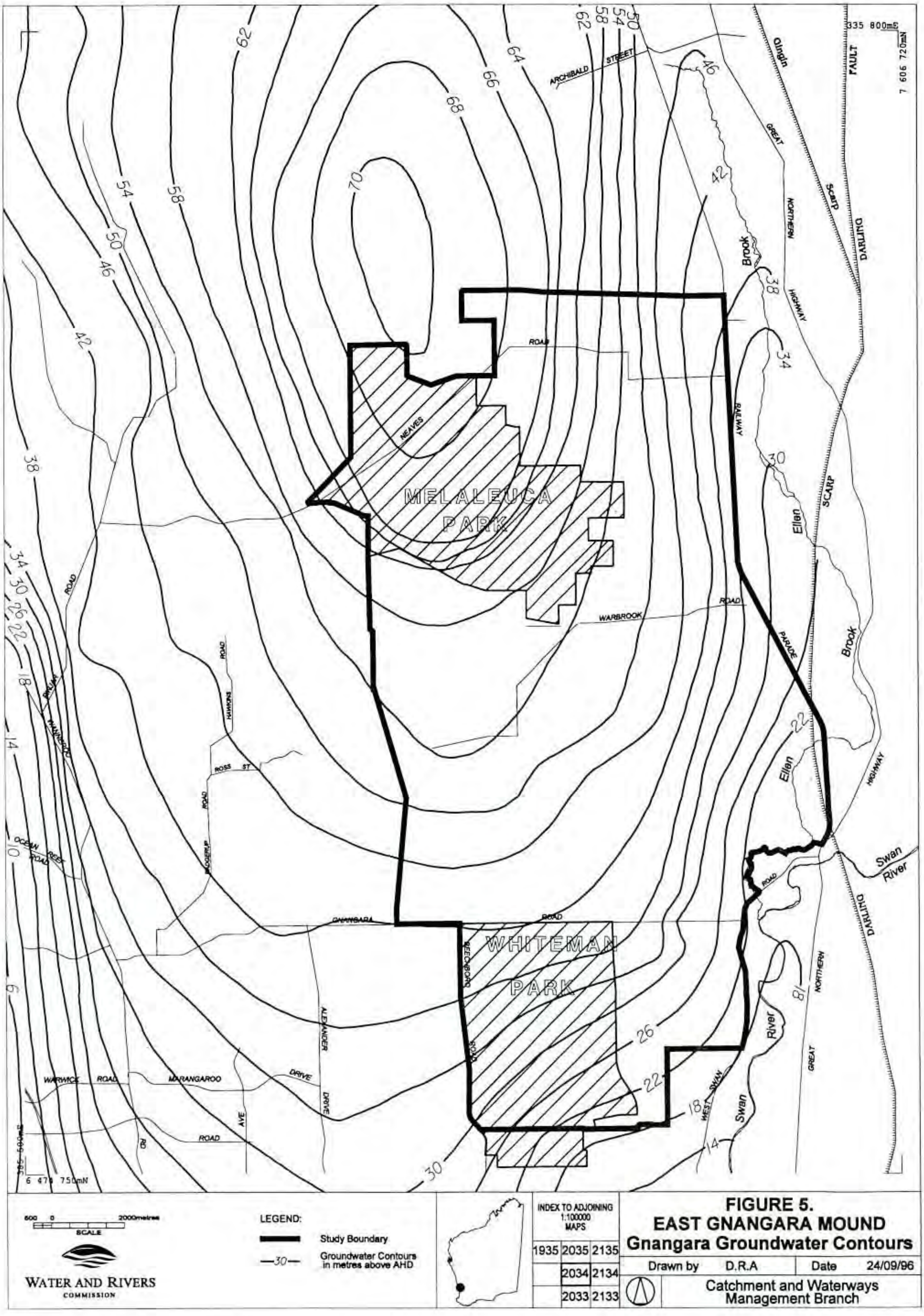
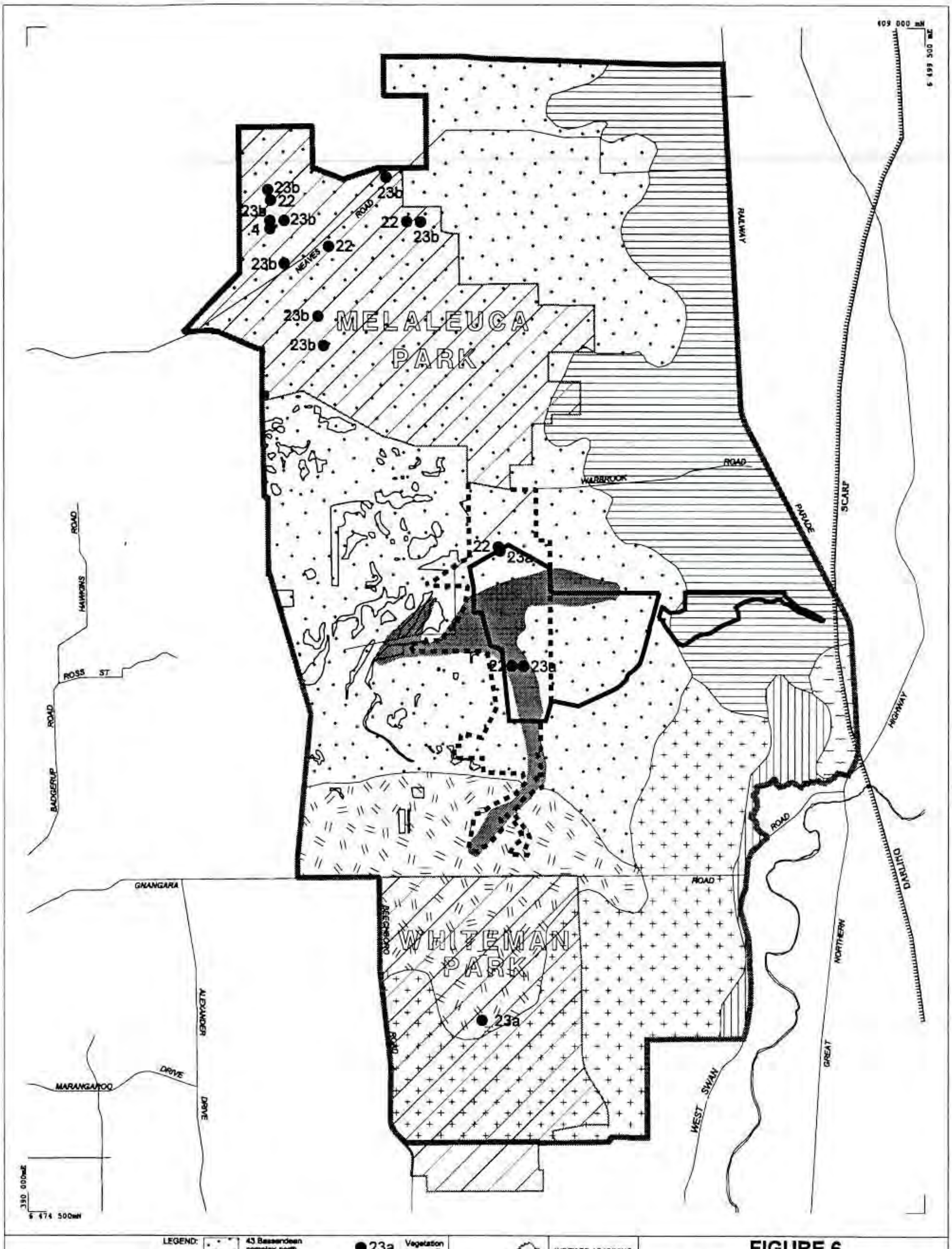


FIGURE 5.
EAST GNANGARA MOUND
Gnangara Groundwater Contours



LEGEND:
- 43 Bassendean complex-north
- 38 Yanga complex
- 45 Bassendean complex-north transition vegetation complex
- 42 Southern River complex
- 32 Guildford complex
- 44 Bassendean complex -central and south
- 23a Vegetation community types
- 33 Swan complex
- Ellenbrook bushland
- Vegetation corridor
- Remnant vegetation in pine plantation

400 0 2000metres SCALE

WATER AND RIVERS COMMISSION

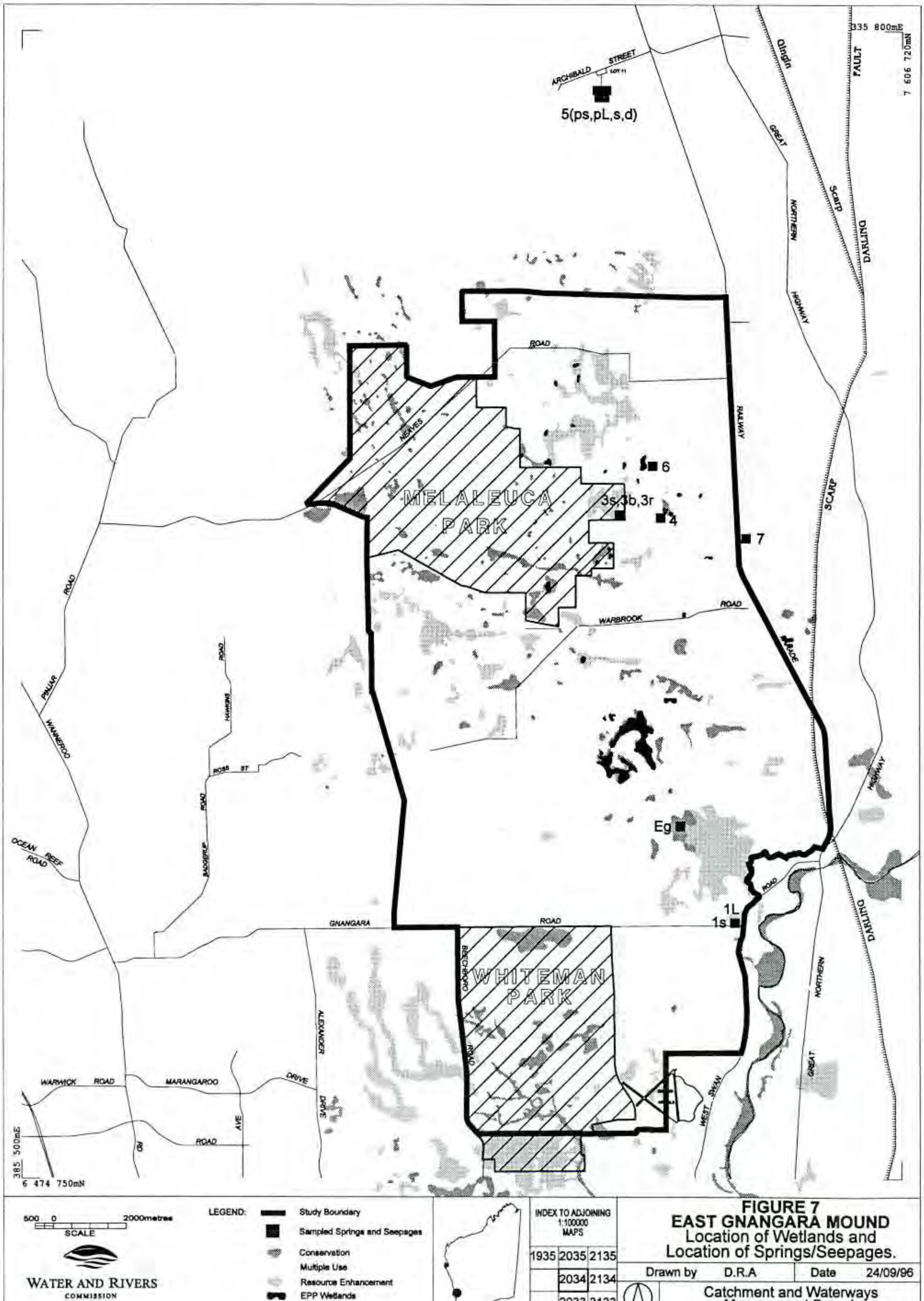
INDEX TO ADJOINING 1:100000 MAPS

1935	2035	2135
	2034	2134
	2033	2133

FIGURE 6
EAST GNANGARA MOUND
Location of Vegetation Complexes

Drawn by D.R.A Date 09/09/96

Catchment and Waterways Management Branch



335 800mE
7 606 720mN
ARCHIBALD STREET
LOT 11
5(ps,pL,s,d)
GREAT NORTHERN HIGHWAY
Gingin
SCARP
DARLING FAULT
ROAD
NEAVES
MELALEUCA PARK
6
3s,3b,3r
4
7
RAILWAY
ROAD
WARBROOK
ROAD
PINJAR
WANNEROO
HAWKINS
ROAD
ROSS ST
BADGERUP
ROAD
OCEAN REEF ROAD
Eg
HIGHWAY
1L
1s
GNANGARA
ROAD
BEECHBORO ROAD
WHITEMAN PARK
ALEXANDER DRIVE
WARWICK ROAD
MARANGAROO DRIVE
AVE
RD
ROAD
WEST SWAN ROAD
GREAT NORTHERN
DARLING
385 500mE
6 474 750mN
500 0 2000metres
SCALE
LEGEND:
Study Boundary
Sampled Springs and Seepages
Conservation
Multiple Use
Resource Enhancement
EPP Wetlands
WATER AND RIVERS COMMISSION
INDEX TO ADJOINING 1:100000 MAPS
1935 2035 2135
2034 2134
2033 2133
FIGURE 7
EAST GNANGARA MOUND
Location of Wetlands and
Location of Springs/Seepages.
Drawn by D.R.A
Date 24/09/96
Catchment and Waterways
Management Branch

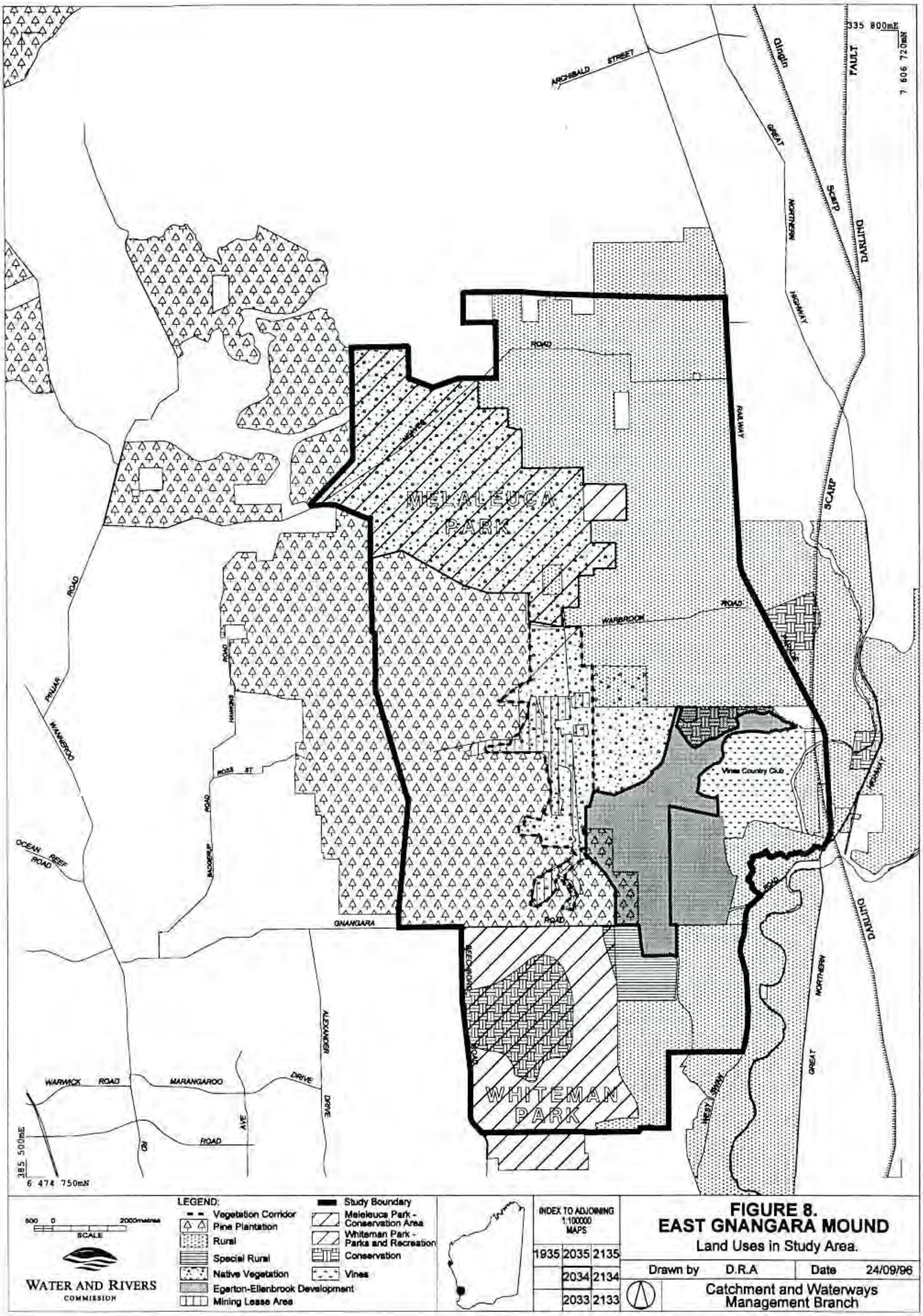
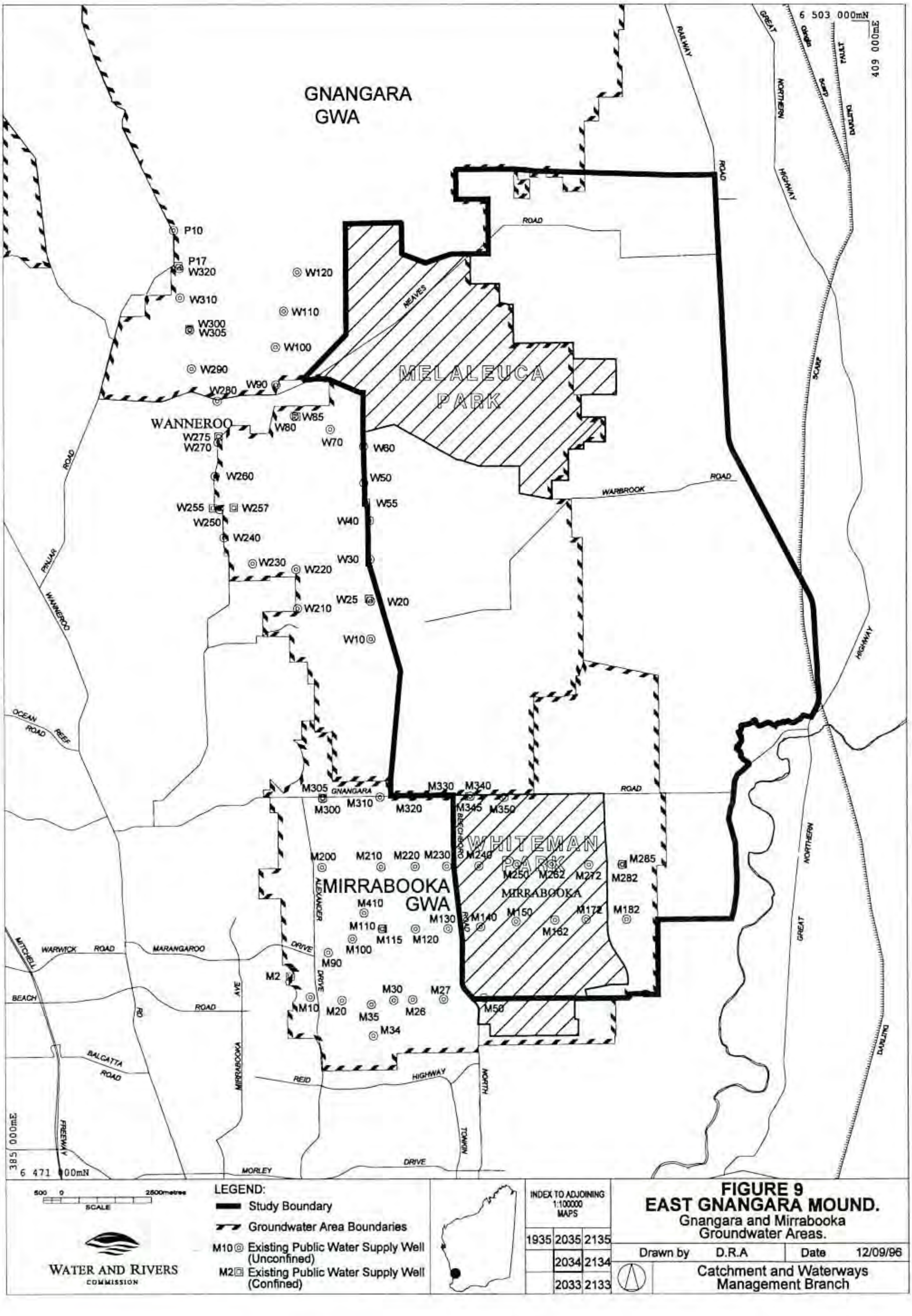


FIGURE 8.
EAST GNANGARA MOUND
Land Uses in Study Area.
Drawn by D.R.A
Date 24/09/96
Catchment and Waterways Management Branch
WATER AND RIVERS COMMISSION
SCALE
500 0 2000metres
LEGEND:
Vegetation Corridor
Pine Plantation
Rural
Special Rural
Native Vegetation
Egerton-Ellenbrook Development
Mining Lease Area
Study Boundary
Melaleuca Park - Conservation Area
Whiteman Park - Parks and Recreation
Conservation
Vines
INDEX TO ADJOINING 1:100000 MAPS
1935 2035 2135
2034 2134
2033 2133
MELALEUCA PARK
WHITEMAN PARK
Vines Country Club
GREAT NORTHERN HIGHWAY
DARLING SCARP
DARLING FAULT
Gingin
RAILWAY
ARCHIBALD STREET
WARBROOK ROAD
GNANGARA ROAD
BEECHBORO ROAD
ALEXANDER DRIVE
MARANGAROO DRIVE
WARWICK ROAD
OCEAN REEF ROAD
WANNEROO ROAD
ROSS ST
BADGERUP ROAD
335 800mE
7 606 720mN
385 500mE
6 474 750mN



GNANGARA GWA
MELALEUCA PARK
WHITEMAN PARK
MIRRABOOKA GWA
WANNEROO
MIRRABOOKA
6 503 000mN
409 000mE
385 000mE
6 471 000mN
LEGEND:
Study Boundary
Groundwater Area Boundaries
M10 Existing Public Water Supply Well (Unconfined)
M2 Existing Public Water Supply Well (Confined)
SCALE
WATER AND RIVERS COMMISSION
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2034 2134
2033 2133
FIGURE 9
EAST GNANGARA MOUND.
Gnangara and Mirrabooka Groundwater Areas.
Drawn by D.R.A Date 12/09/96
Catchment and Waterways Management Branch

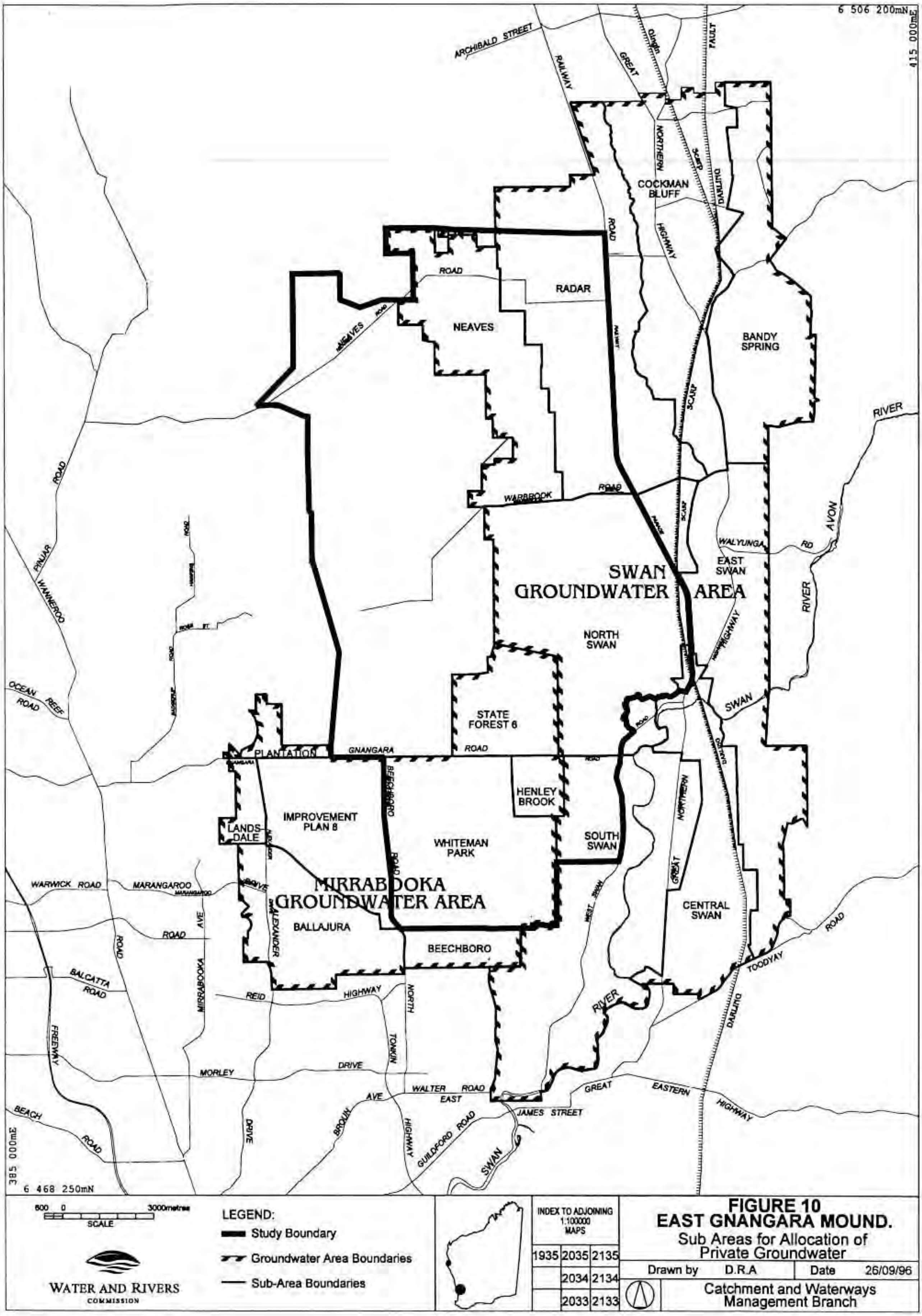
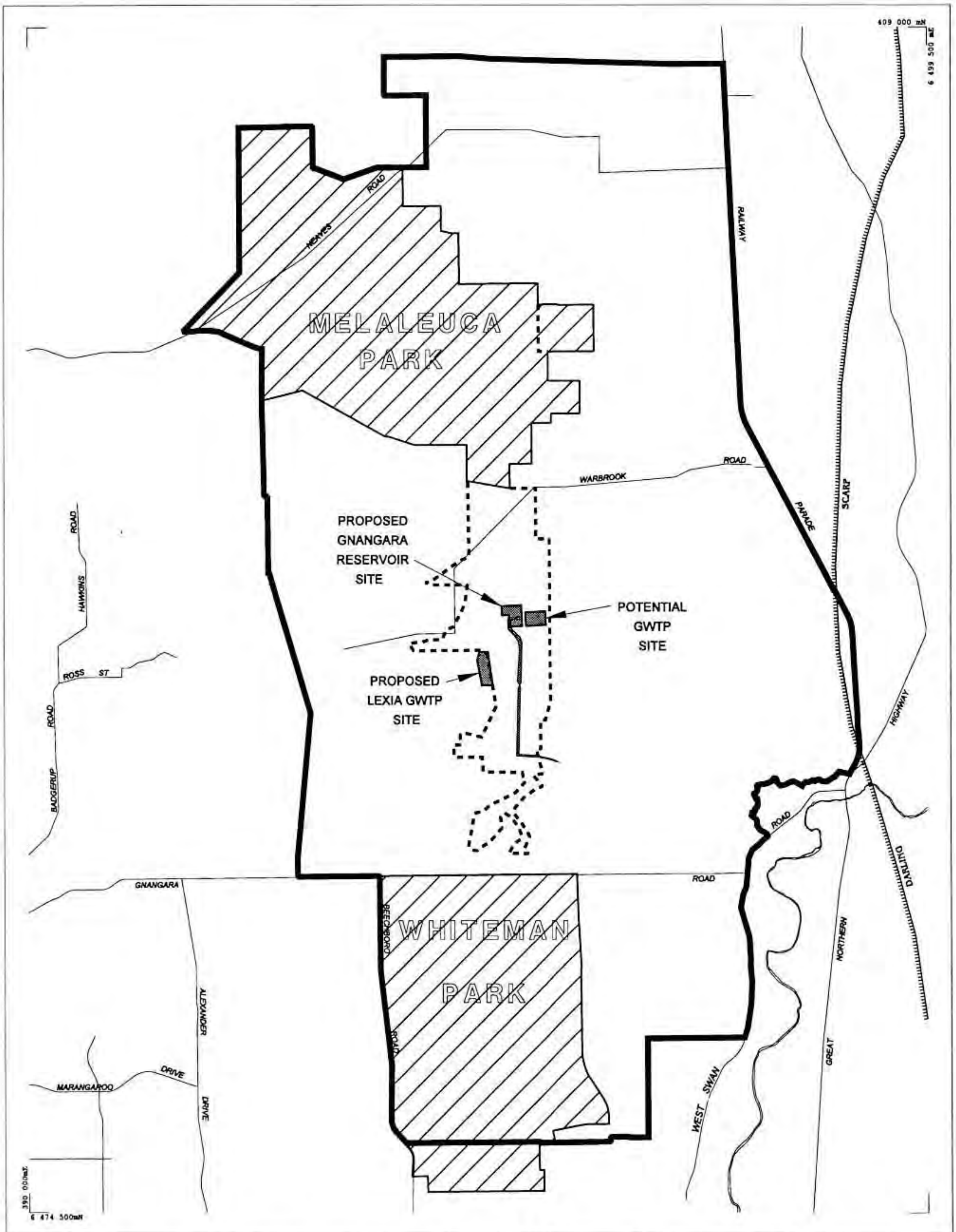


FIGURE 10
EAST GNANGARA MOUND.
Sub Areas for Allocation of Private Groundwater



400 0 2000metres
SCALE

LEGEND:

Study Area

Area Surveyed for Aboriginal Sites

Vegetation Corridor connecting Melaleuca Park & Lexia Wetlands

WATER AND RIVERS COMMISSION

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FIGURE 11
EAST GNANGARA MOUND.
Area Surveyed for Aboriginal Sites

Drawn by D.R.A Date 09/09/96

Catchment and Waterways Management Branch

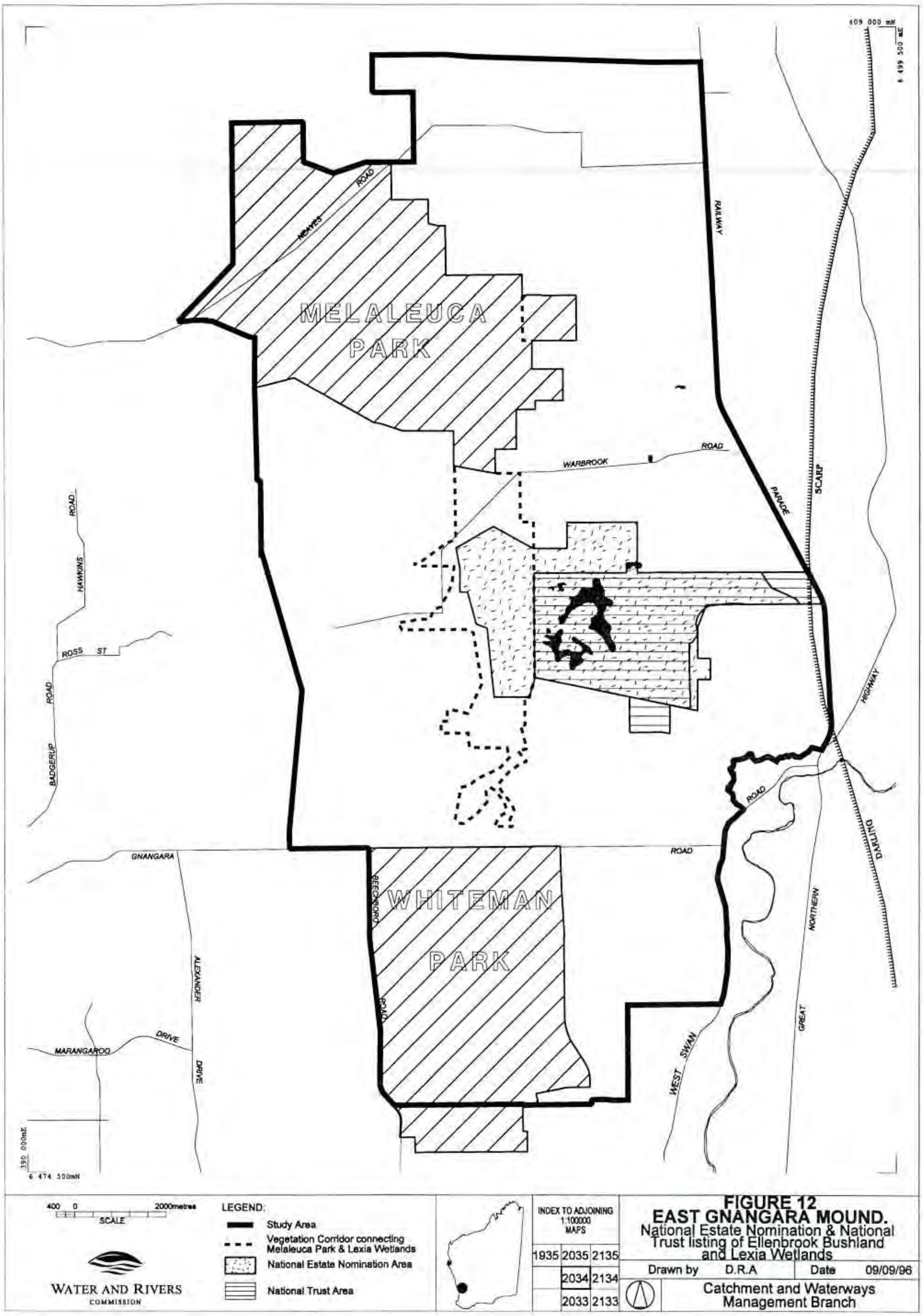
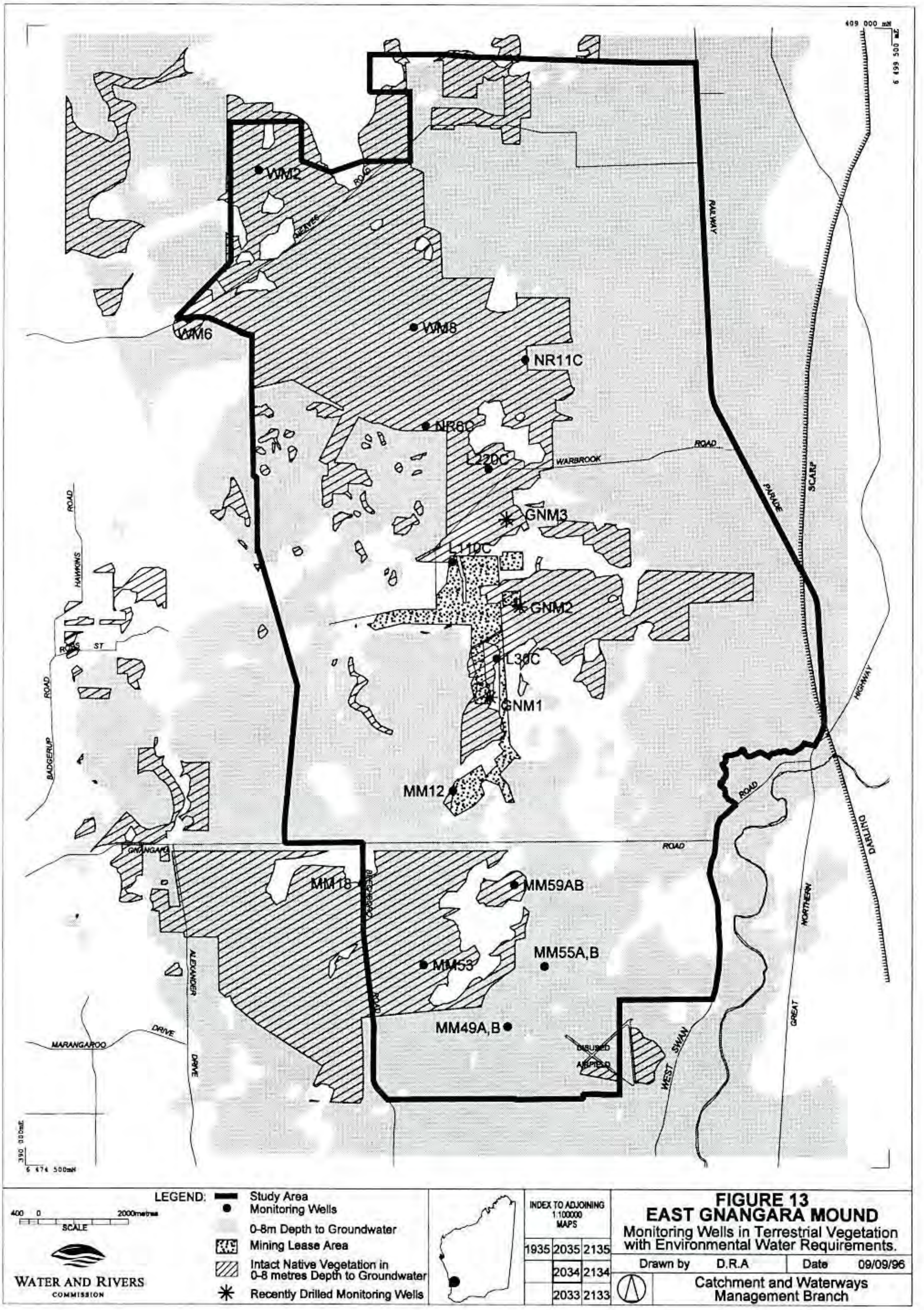


FIGURE 12
EAST GNANGARA MOUND.
National Estate Nomination & National Trust listing of Ellenbrook Bushland and Lexia Wetlands



WM2
WM6
WM8
NR11C
NR6C
L220C
GNM3
L110C
GNM2
L30C
GNM1
MM12
MM18
MM59AB
MM55A,B
MM53
MM49A,B
WARBROOK ROAD
RAILWAY PARADE
SCARP
GREAT NORTHERN HIGHWAY
DARLING
WEST SWAN ROAD
GNANGARA ROAD
ALEXANDER DRIVE
MARANGAROO DRIVE
BADGERUP ROAD
HAWKINS ROAD
ROSS ST
DISUSED AIRFIELD
LEGEND:
Study Area
Monitoring Wells
0-8m Depth to Groundwater
Mining Lease Area
Intact Native Vegetation in 0-8 metres Depth to Groundwater
Recently Drilled Monitoring Wells
400 0 2000metres
SCALE
WATER AND RIVERS COMMISSION
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FIGURE 13
EAST GNANGARA MOUND
Monitoring Wells in Terrestrial Vegetation with Environmental Water Requirements.
Drawn by D.R.A
Date 09/09/96
Catchment and Waterways Management Branch

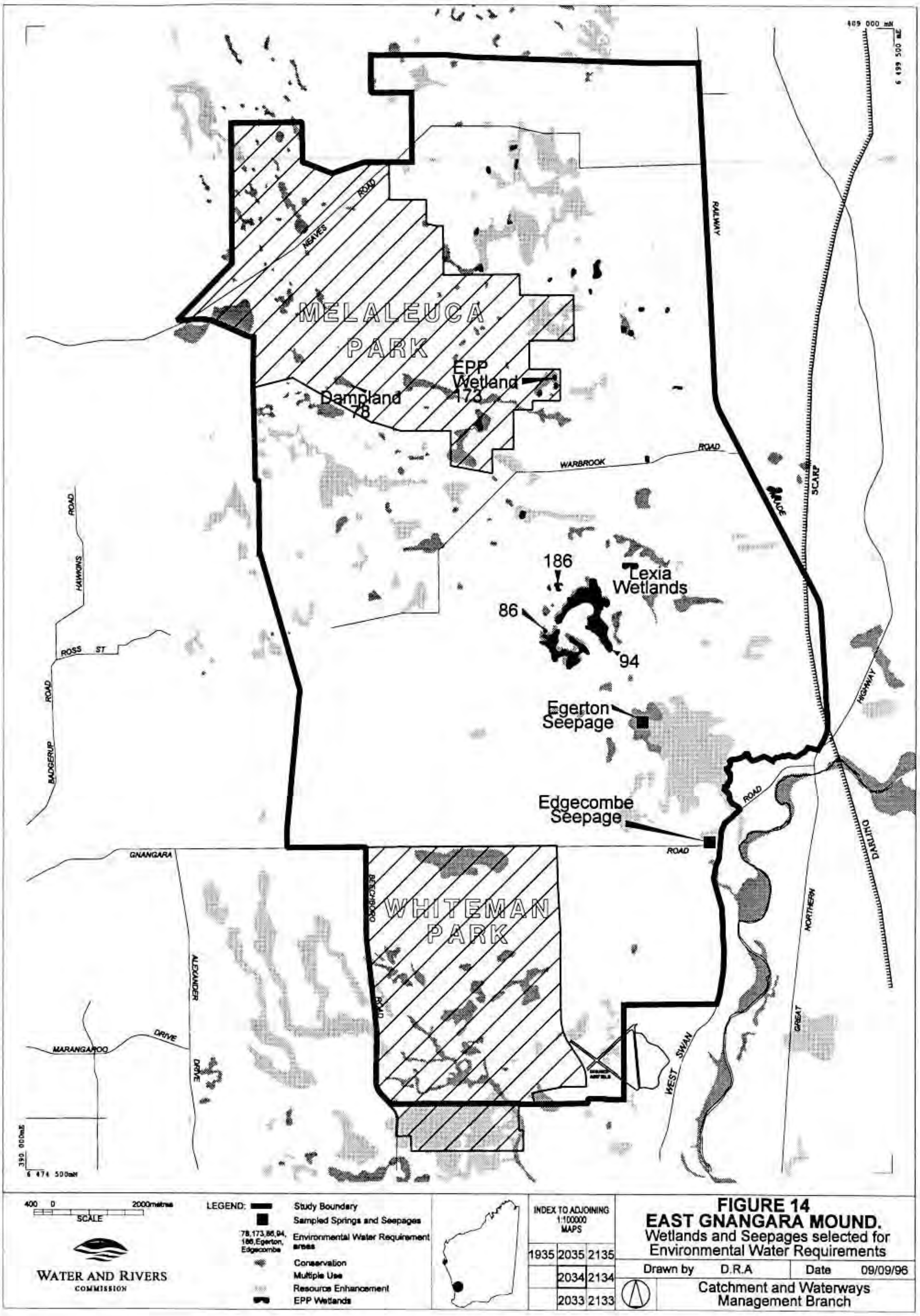
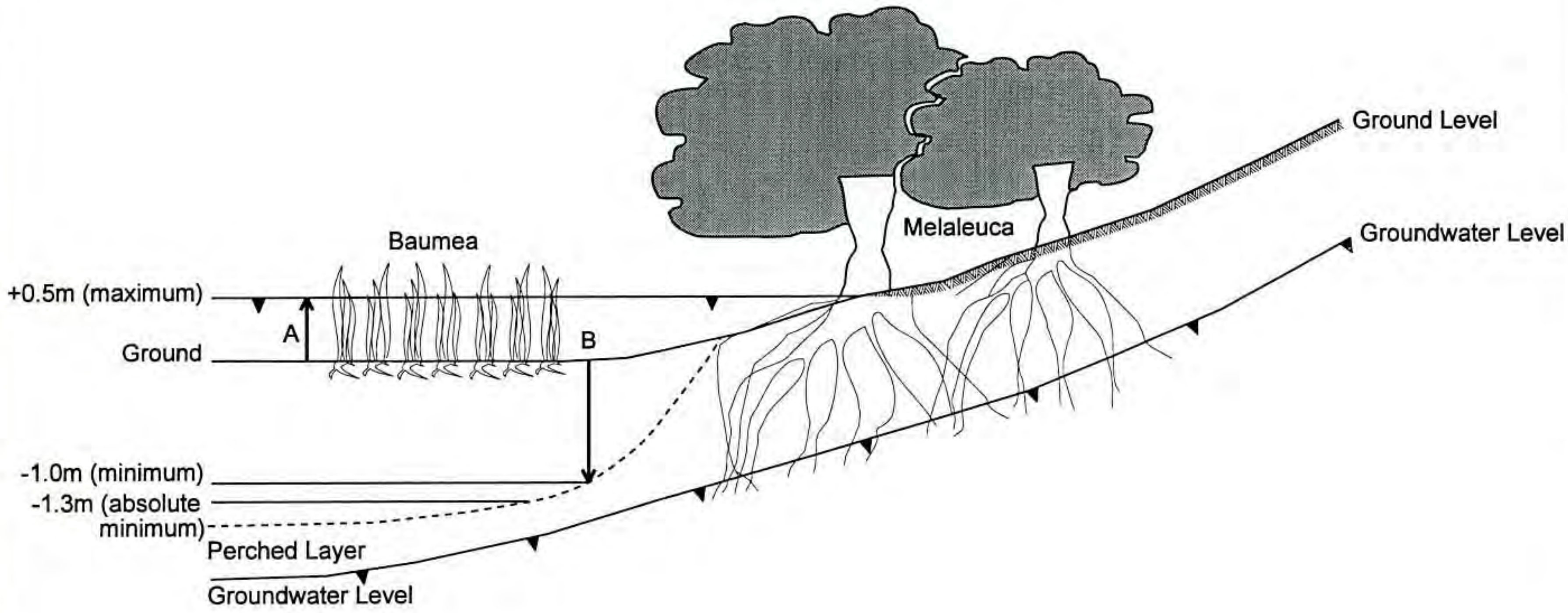


FIGURE 14
EAST GNANGARA MOUND.
Wetlands and Seepages selected for Environmental Water Requirements



WATER AND RIVERS
COMMISSION

FIGURE 15. Schematic Wetland Cross Section Environmental Water Requirements in Lexia Wetland 86.

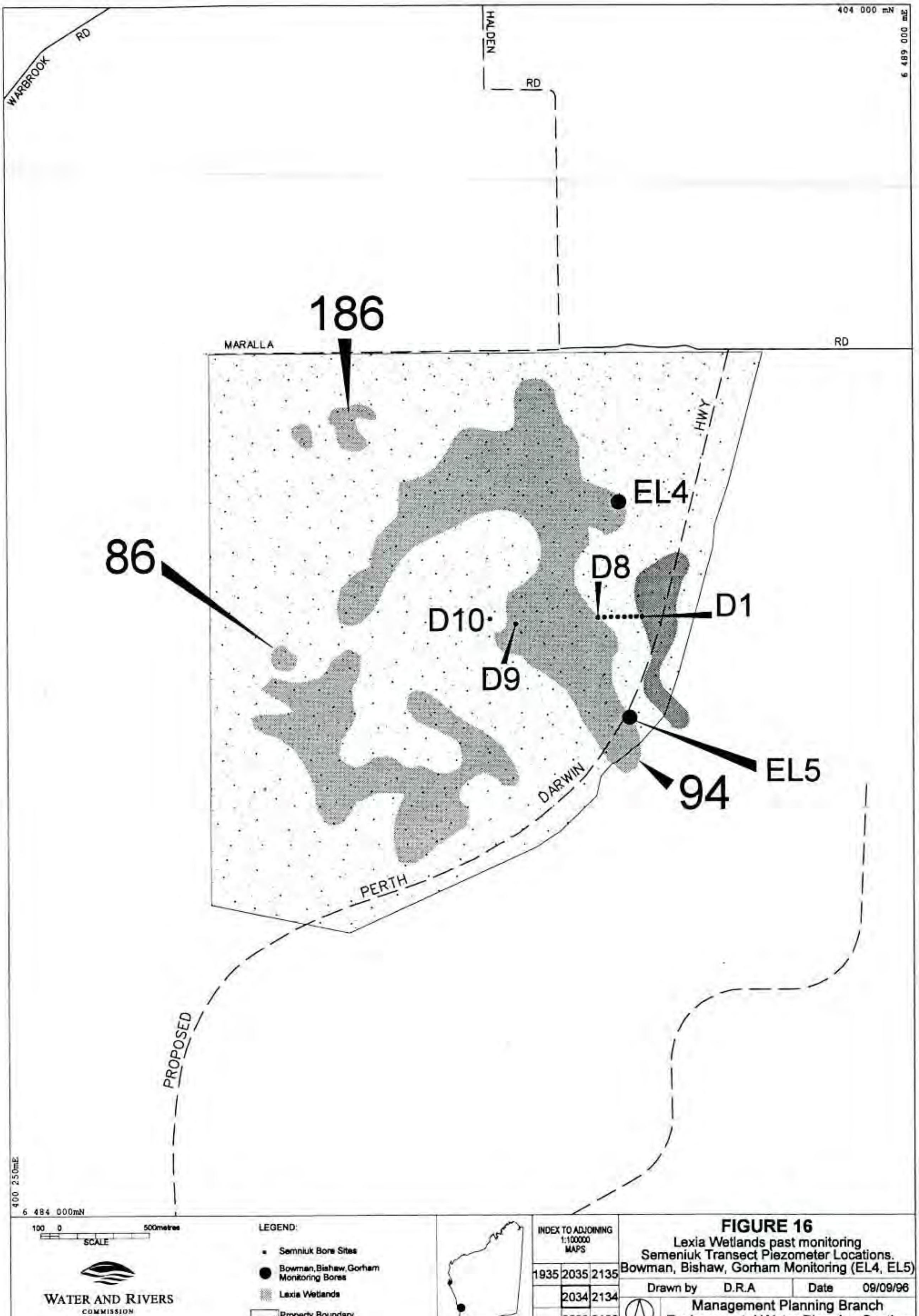
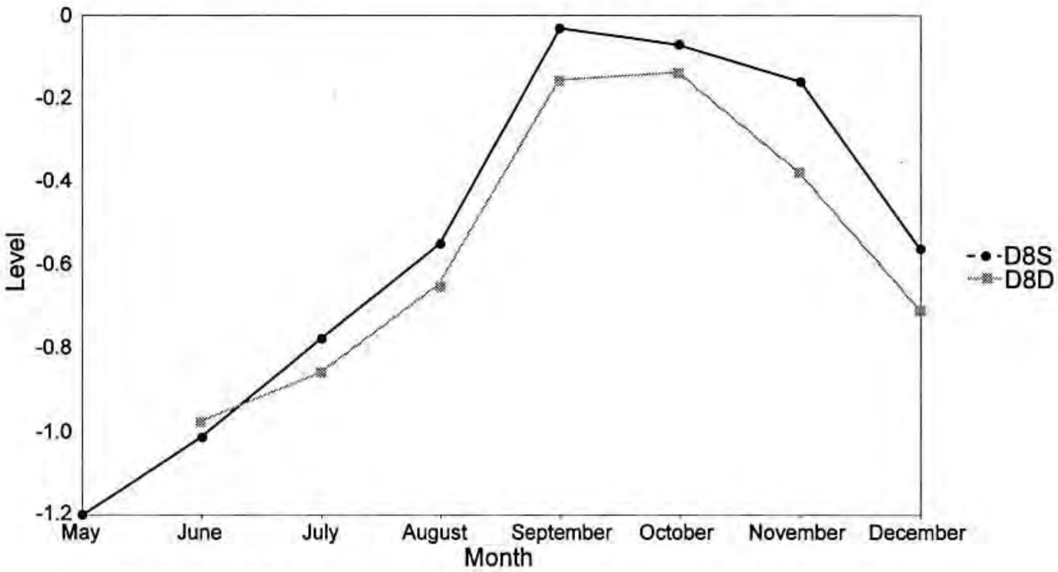


FIGURE 16
Lexia Wetlands past monitoring
Semeniuk Transect Piezometer Locations.
Bowman, Bishaw, Gorham Monitoring (EL4, EL5)

FIGURE 17A

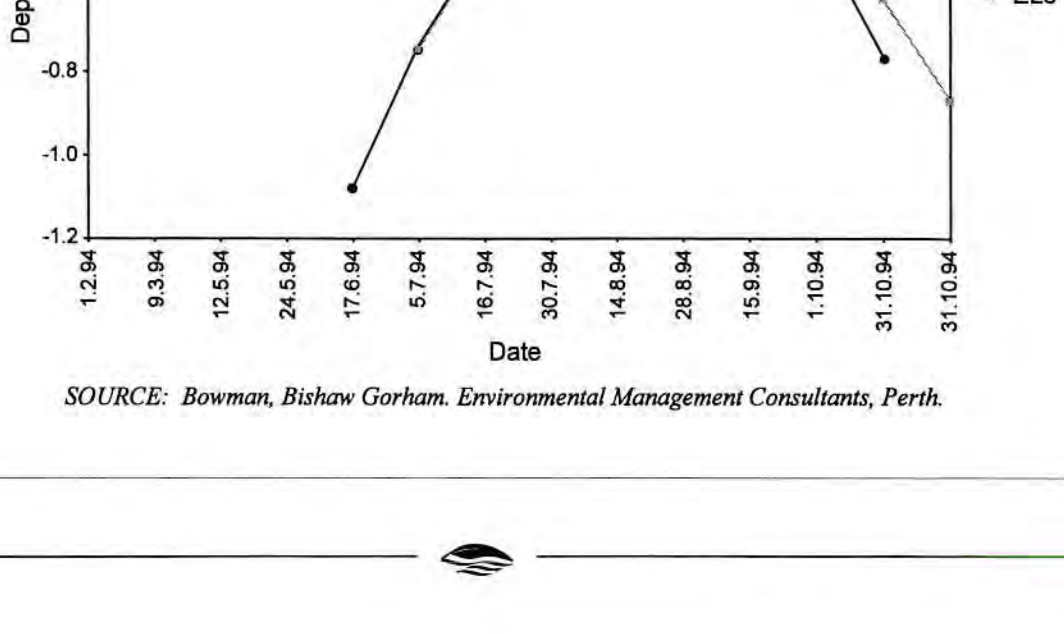
Water levels in Lexia wetland 94, Bore D8S and D8D throughout 1993



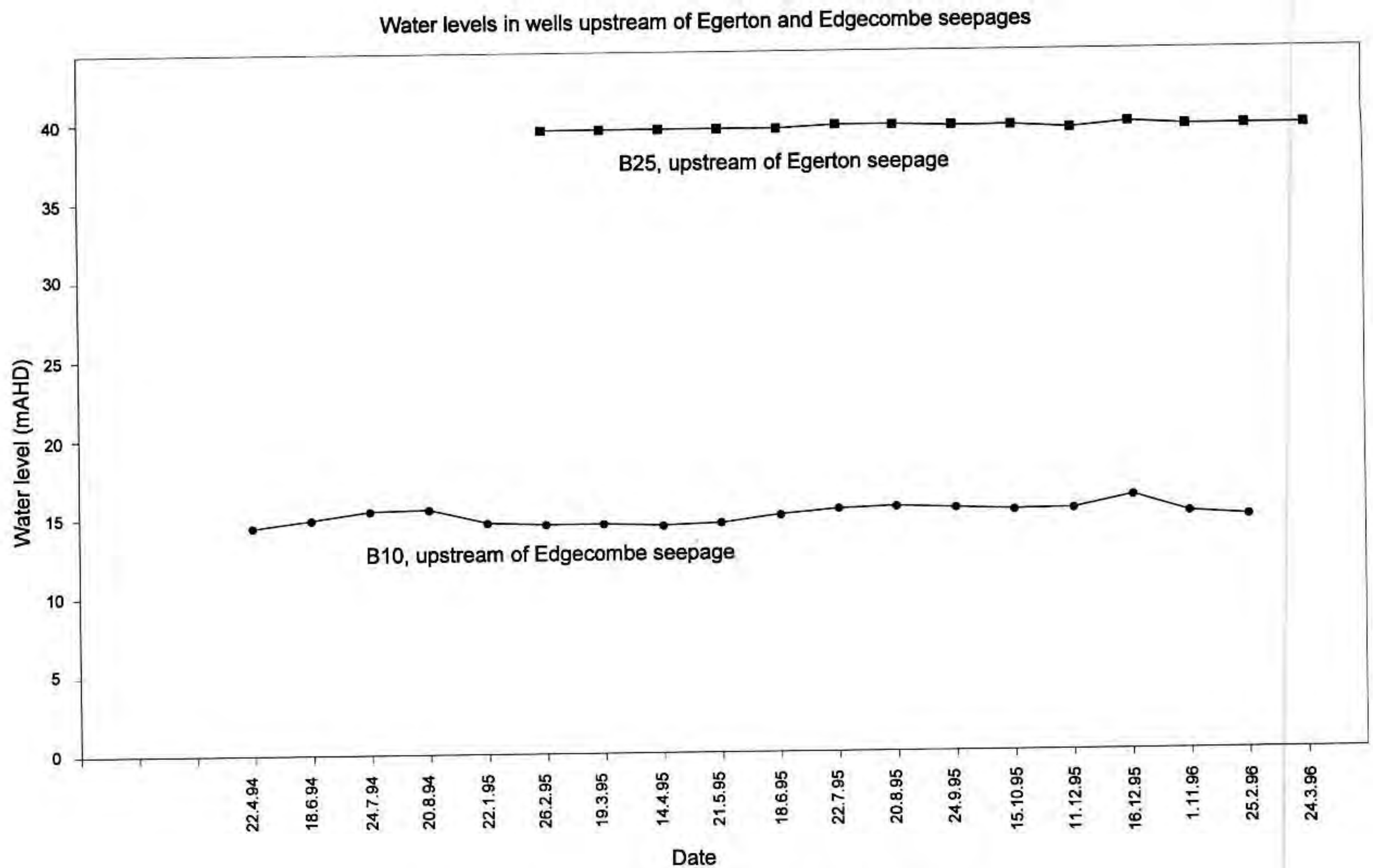
SOURCE: V & C Semeniuk (1993). Investigations of Stratigraphy and Groundwater in four selected areas of the North-East Corridor, Perth Metropolitan Area. V & C Semeniuk Research Group, Perth.

FIGURE 17B

Water levels in Lexia wetland 94, Bores EL4 and EL5 in 1994

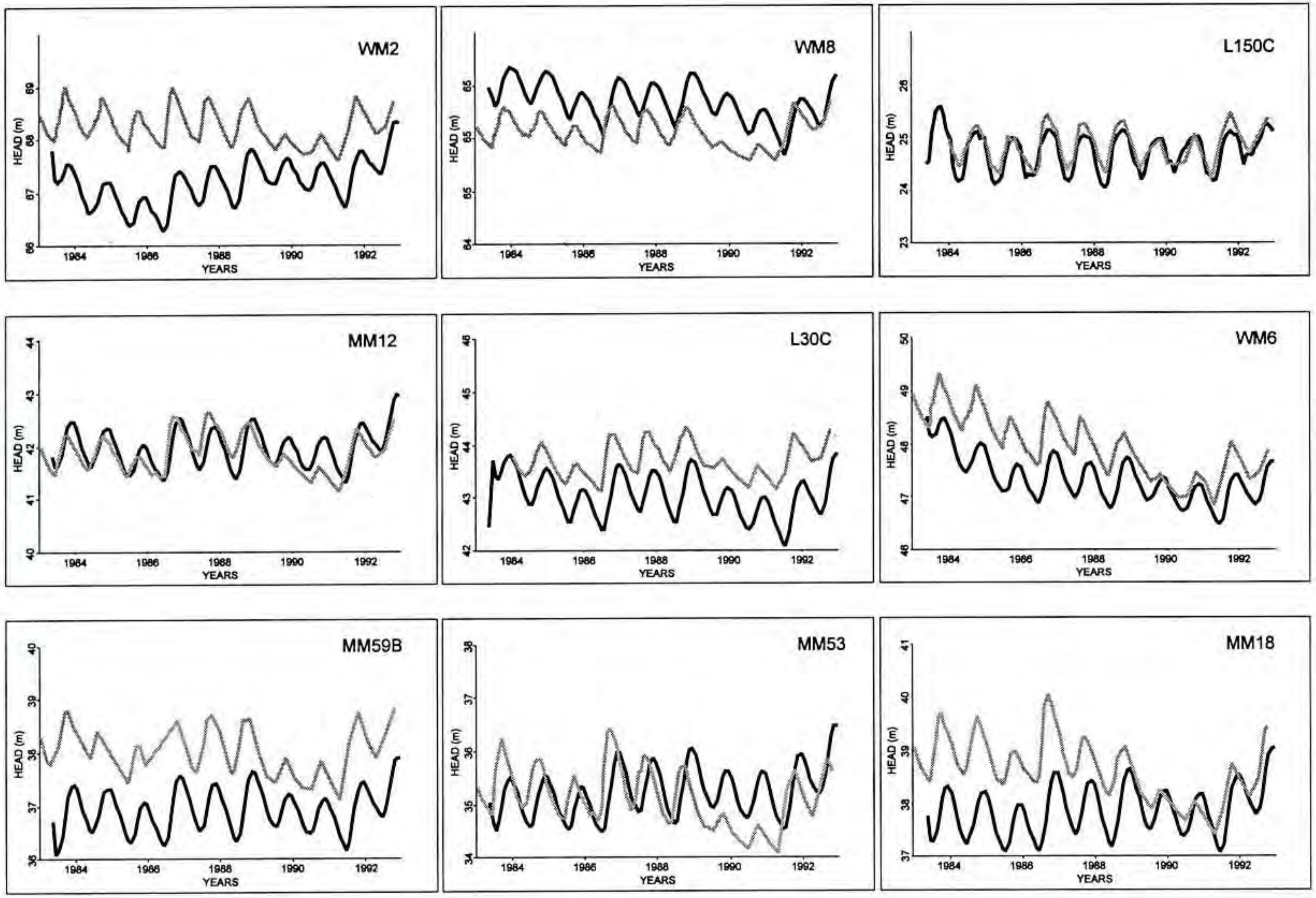


SOURCE: Bowman, Bishaw Gorham. Environmental Management Consultants, Perth.



SOURCE: Jim Davies and Associates, Consultant Hydrologists, Perth

FIGURE 18



LEGEND:
Predicted Groundwater Level
Actual Groundwater Level

FIGURE 19 - EAST GNANGARA
Model Calibrations at Criteria Wells.

WATER AND RIVERS COMMISSION

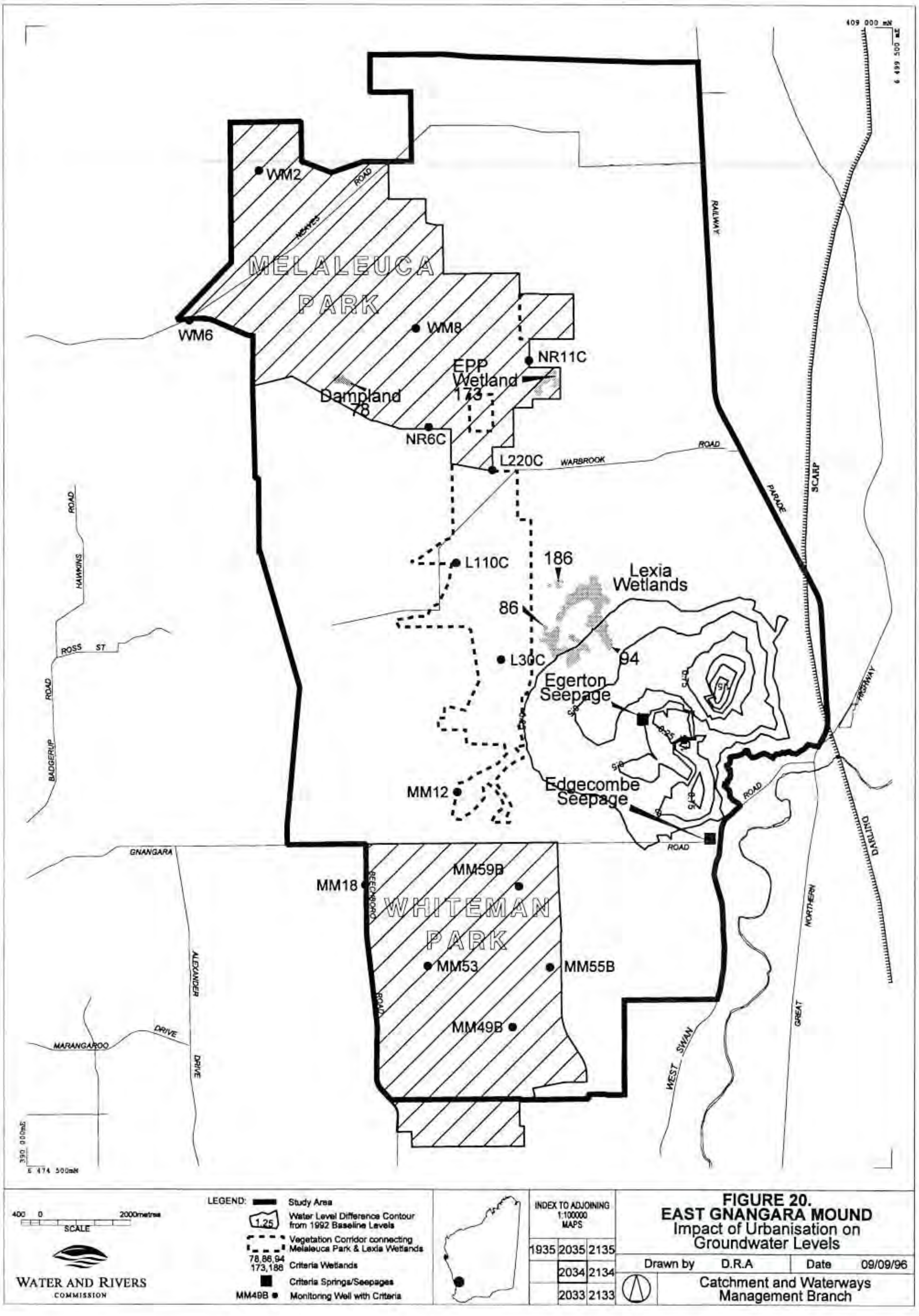


FIGURE 20.
EAST GNANGARA MOUND
Impact of Urbanisation on Groundwater Levels

VARIATION IN PINE CANOPY COVER WITH TIME

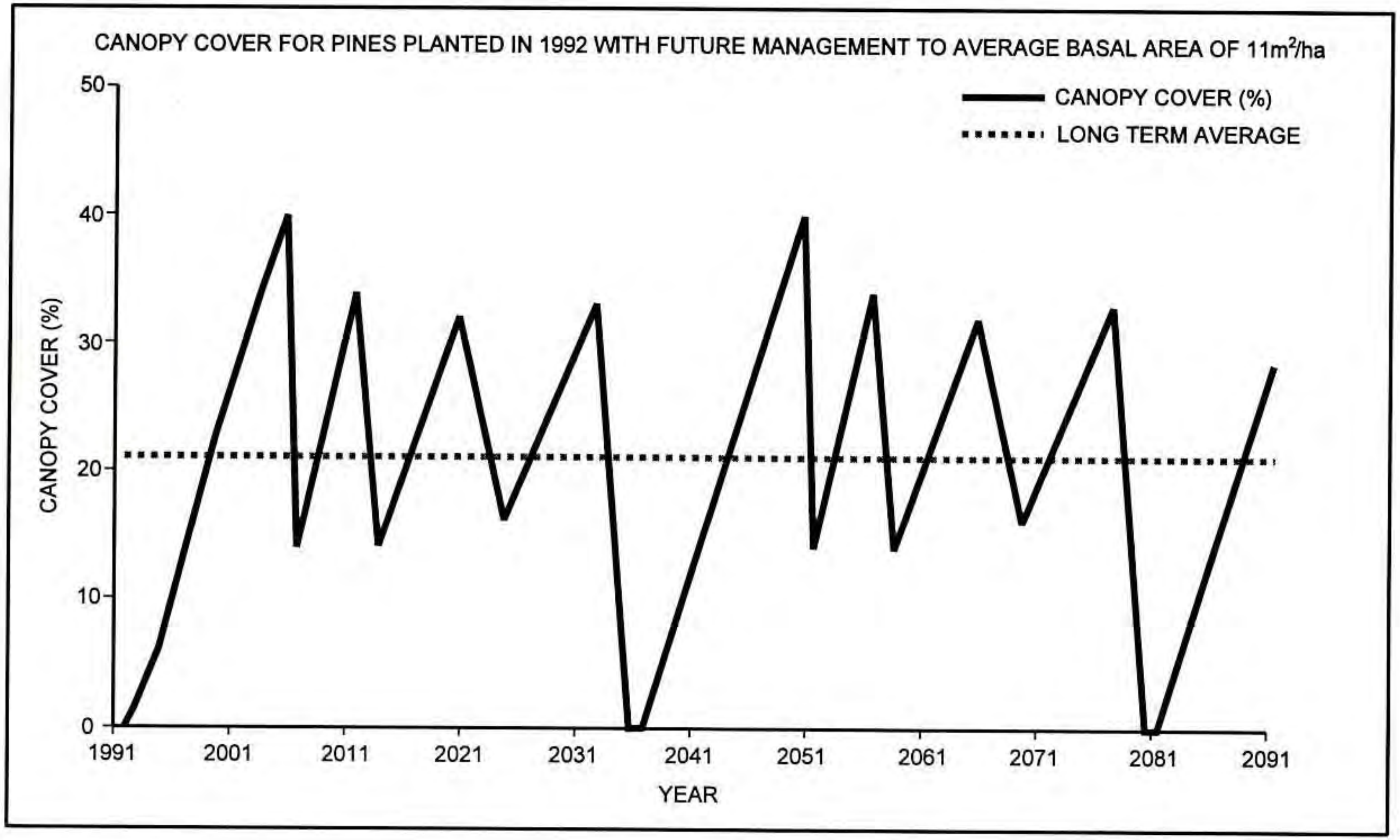


FIGURE 21.

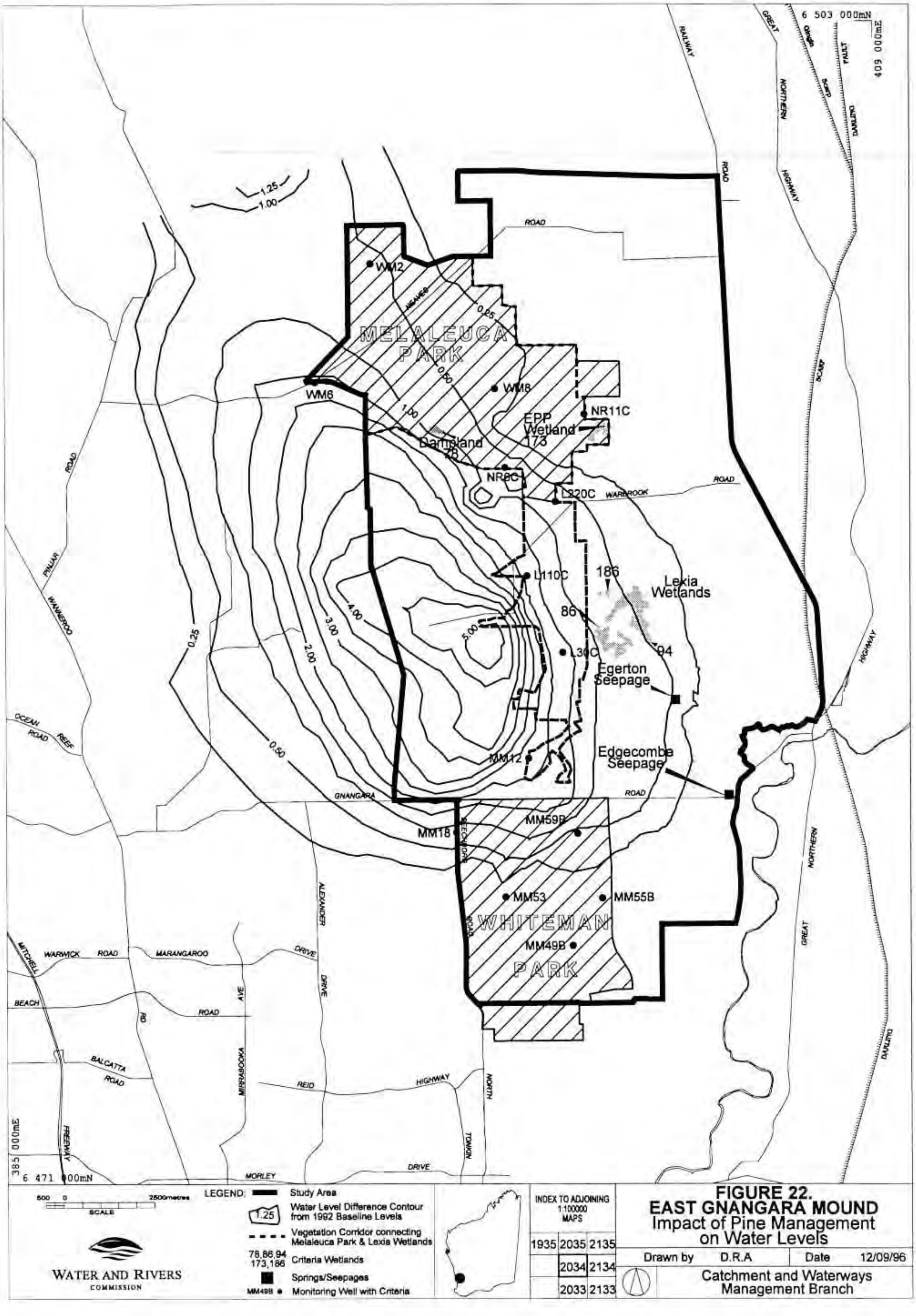
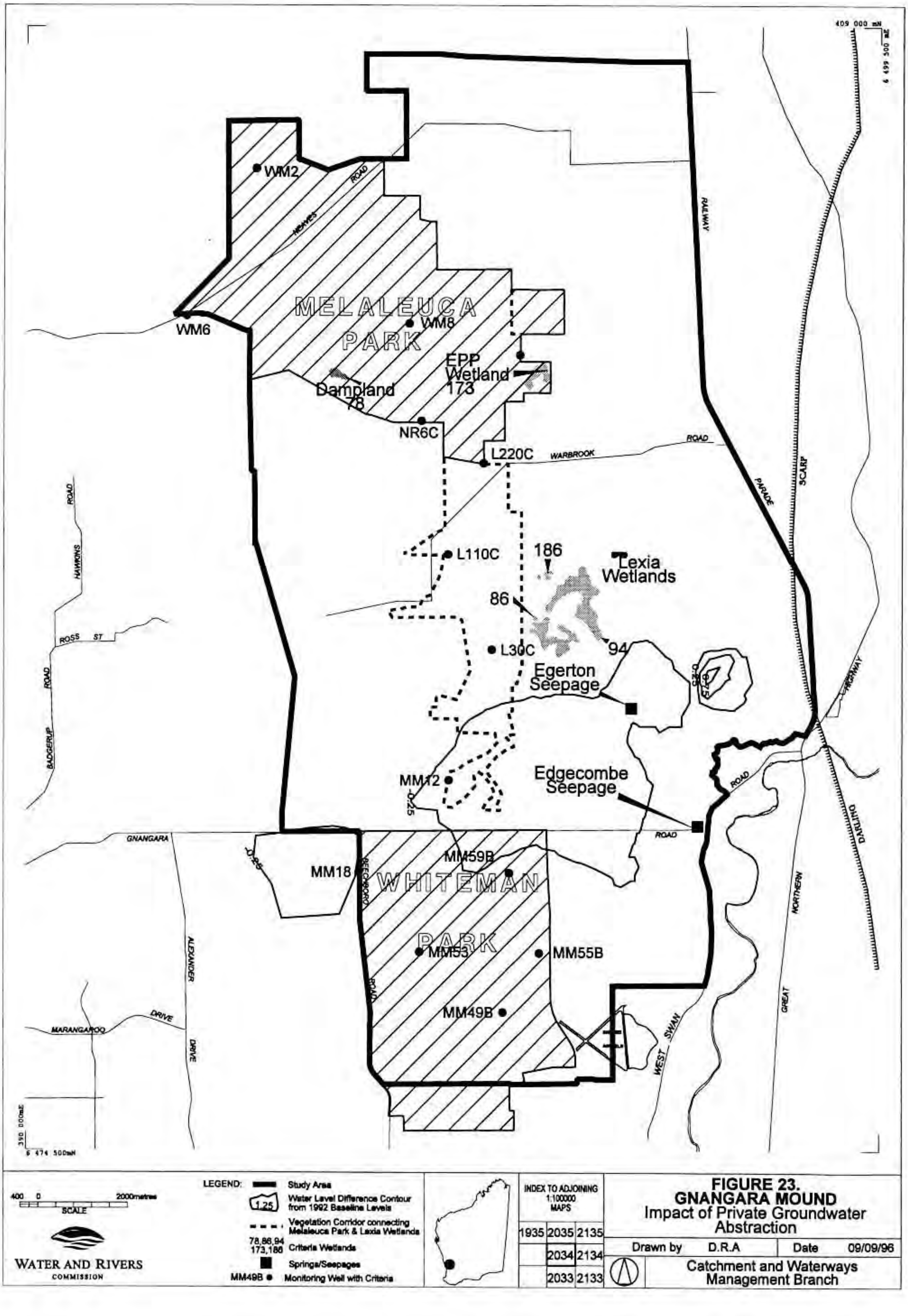


FIGURE 22.
EAST GNANGARA MOUND
Impact of Pine Management on Water Levels



WM2
WM6
MELALEUCA PARK
WM8
EPP Wetland 173
Dampland 78
NR6C
L220C
WARBROOK ROAD
L110C
186
Lexia Wetlands
86
94
L30C
Egerton Seepage
MM12
Edgecombe Seepage
GNANGARA ROAD
MM18
MM59B
WHITEMAN PARK
MM53
MM55B
MM49B
RAILWAY
PARADE
SCARP
HAWKINS ROAD
ROSS ST
BADGERUP ROAD
ALEXANDER DRIVE
MARANGAROO DRIVE
WEST SWAN ROAD
GREAT NORTHERN HIGHWAY
DARLING
LEGEND:
Study Area
Water Level Difference Contour from 1992 Baseline Levels
Vegetation Corridor connecting Melaleuca Park & Lexia Wetlands
78,86,94 173,186 Criteria Wetlands
Springs/Seepages
MM49B Monitoring Well with Criteria
SCALE
2000metres
WATER AND RIVERS COMMISSION
INDEX TO ADJOINING 1:100000 MAPS
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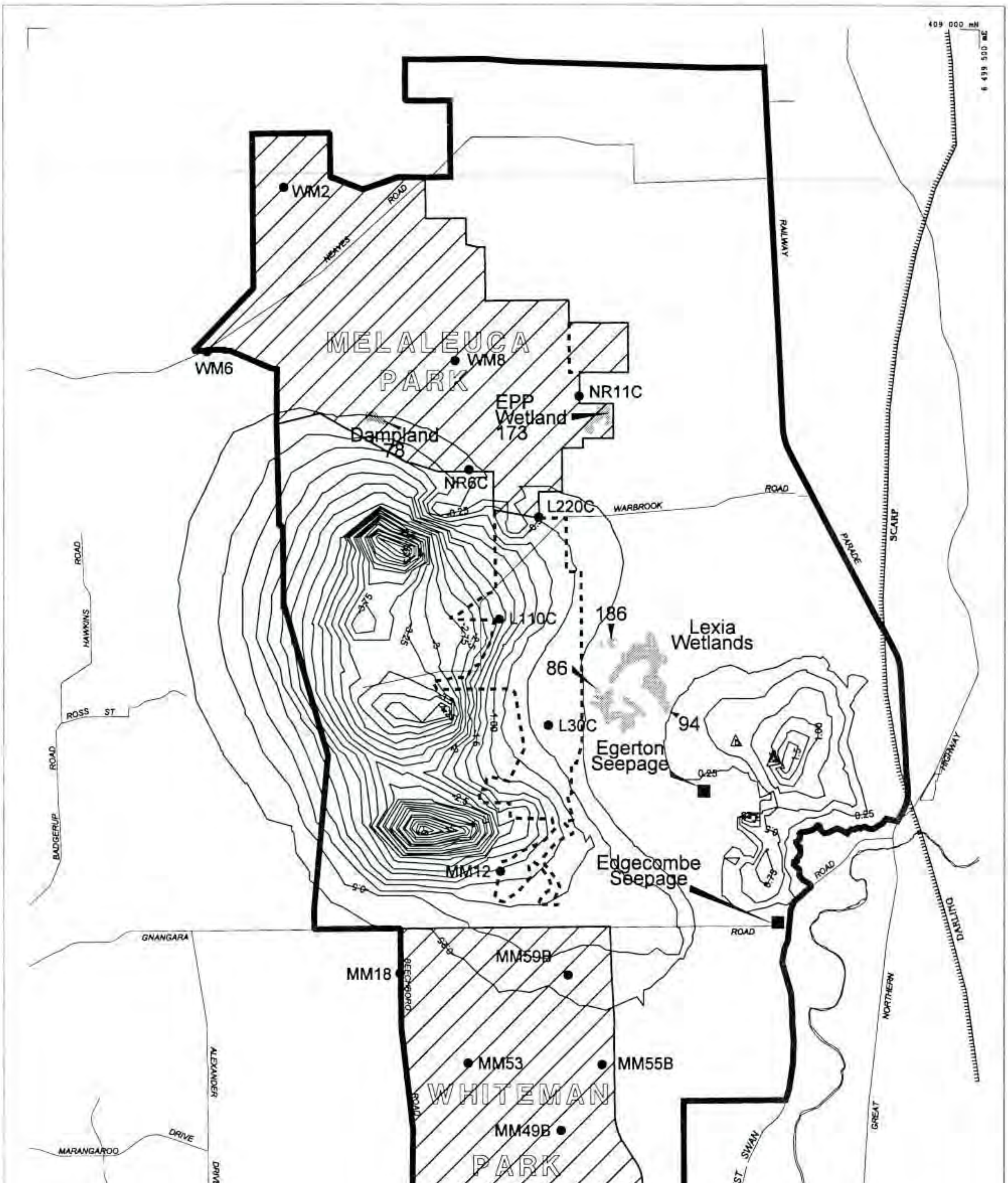
2033 2133
FIGURE 23.
GNANGARA MOUND
Impact of Private Groundwater Abstraction
Drawn by D.R.A
Date 09/09/96
Catchment and Waterways Management Branch


MELALEUCA PARK
WHITEMAN PARK
WM2
WM6
WM8
NR11C
EPP Wetland 173
Dampland 78
NR6C
L220C
L110C
L30C
186
86
94
Lexia Wetlands
Egerton Seepage
Edgecombe Seepage
MM12
MM18
MM59B
MM53
MM55B
MM49B
NEAVES ROAD
WARBROOK ROAD
HAWKINS ROAD
ROSS ST
BADGERUP ROAD
GNANGARA ROAD
BEECHBORO ROAD
ALEXANDER DRIVE
MARANGAROO DRIVE
WEST SWAN ROAD
GREAT NORTHERN HIGHWAY
DARLING SCARP
RAILWAY PARADE
409 000 mE
6 499 500 mN
390 000mE
6 474 500mN
LEGEND:
Study Area
Water Level Difference Contour from 1992 Baseline Levels
Vegetation Corridor connecting Melaleuca Park & Lexia Wetlands
78,86,94 173,186 Criteria Wetlands
Springs/Seepages
MM49B Monitoring Well with Criteria
400 0 2000metres
SCALE
WATER AND RIVERS COMMISSION
INDEX TO ADJOINING 1:100000 MAPS
1935 2035 2135
2034 2134
2033 2133
FIGURE 24
EAST GNANGARA MOUND.
Impact of Proposed Lexia and East Mirrabooka Groundwater Schemes (Urbanisation included)
Drawn by D.R.A
Date 09/09/96
Catchment and Waterways Management Branch

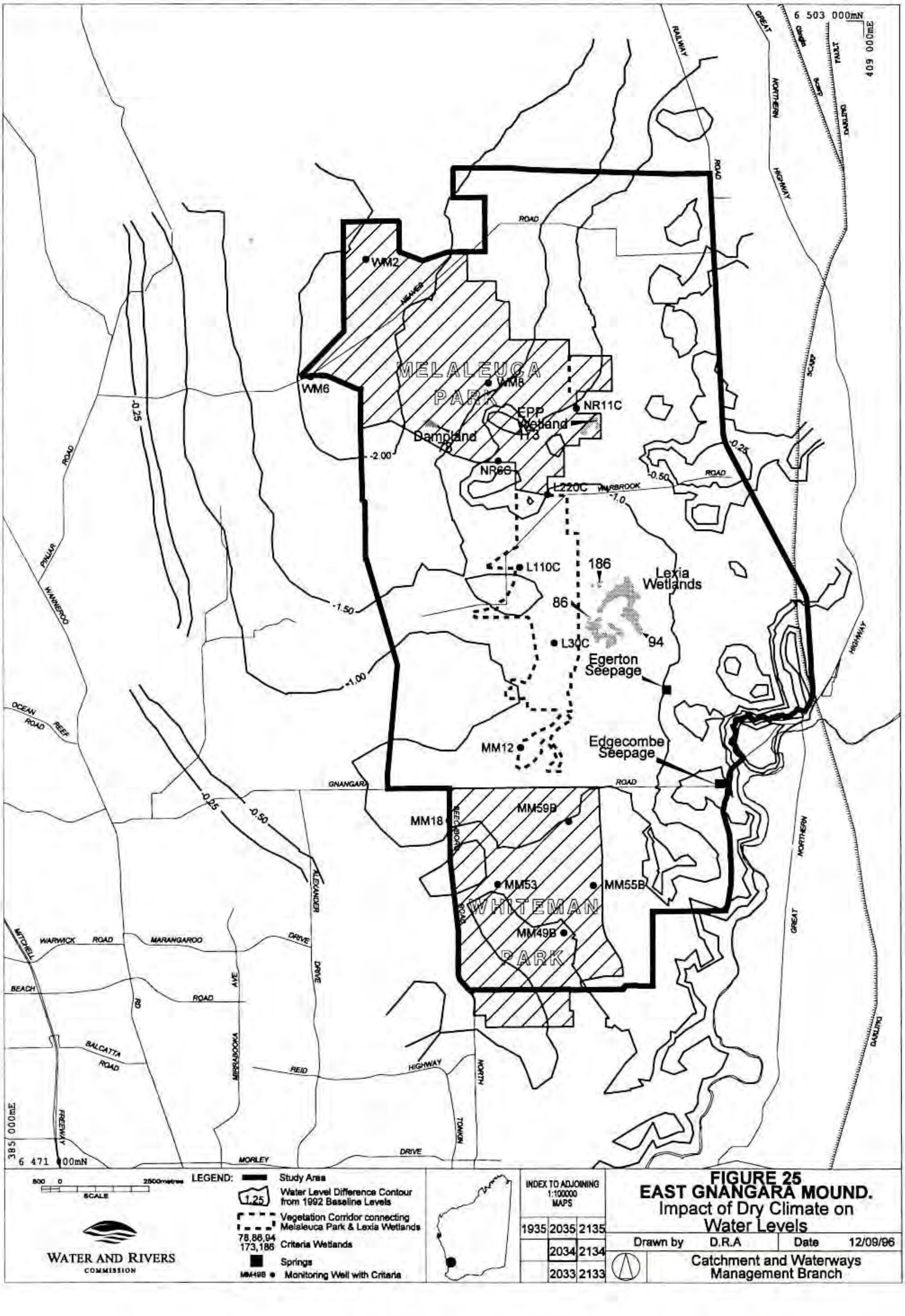


FIGURE 25
EAST GNANGARA MOUND.
Impact of Dry Climate on Water Levels

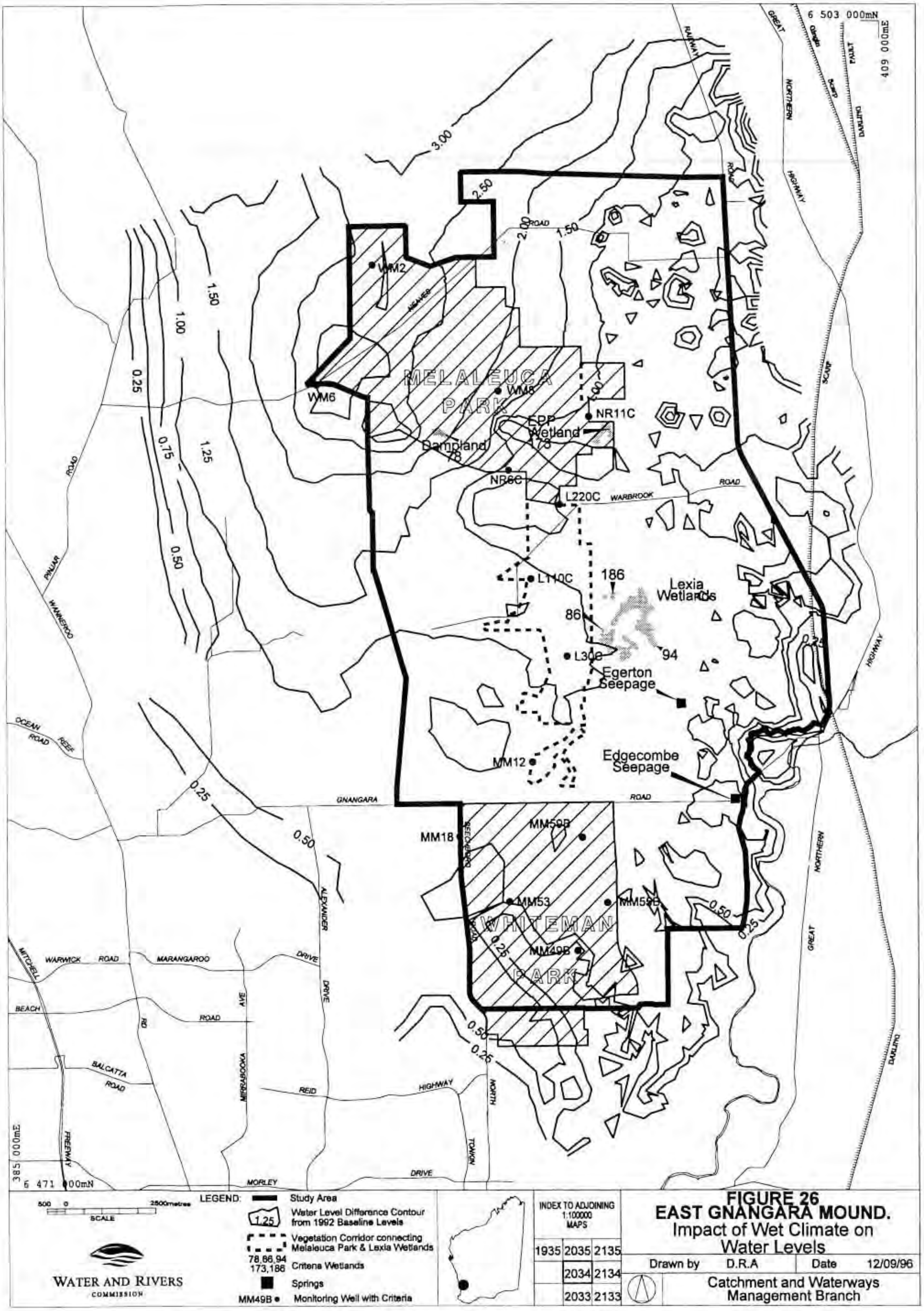
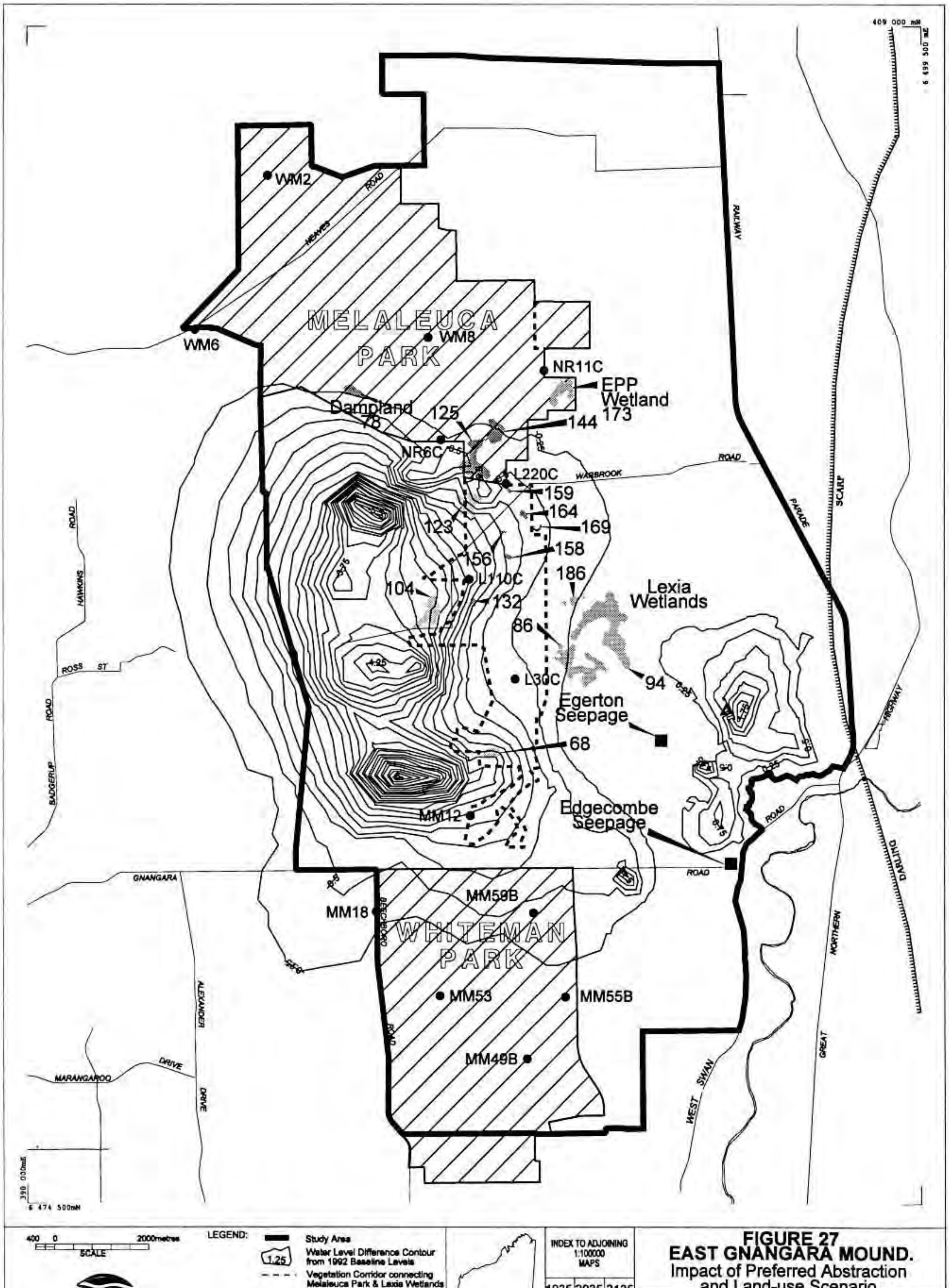


FIGURE 26
EAST GNANGARA MOUND.
Impact of Wet Climate on Water Levels



400 0 2000metres
SCALE

WATER AND RIVERS COMMISSION

LEGEND:
- Study Area
- 1.25 Water Level Difference Contour from 1992 Baseline Levels
- Vegetation Corridor connecting Melaleuca Park & Lexia Wetlands
- 78,86,94,173,186 Criteria Wetlands
- Springs/Seepages
- MM49B Monitoring Well with Criteria

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FIGURE 27
EAST GNANGARA MOUND.
Impact of Preferred Abstraction and Land-use Scenario

Drawn by D.R.A Date 09/09/96

Catchment and Waterways Management Branch

Appendix 1
Environmenal Protection Authority guidelines—Public Environmental Review

Groundwater resource allocation and management plan to allow for the development of Lexia Groundwater scheme, Ellenbrook area.

Overview

All environmental reviews have the objective of protecting the environment, and environmental impact assessment is deliberately a public process in order to obtain broad ranging advice. The review requires the proponent to describe the proposal, receiving environment, potential environmental impacts and the management of issues arising from the environmental impacts, so that the environment is protected to an acceptable level.

Throughout the assessment process it is the objective of the Department of Environmental Protection (DEP) to assist the proponent to improve the proposal so that the environment is protected in the best manner possible. The DEP will co-ordinate relevant government agencies and the public in providing advice about environmental matters during the assessment of the Public Environmental Review for this proposal.

Contents of the PER

The contents reflect the purpose of the PER, which is to:

- communicate clearly with the public (including government agencies), so that the EPA can obtain informed public comment to assist in providing advice to government;
- to describe the proposal adequately, so that the Minister for the Environment can consider approval of a well-defined project; and
- provide the basis for the proponents environmental management programme, which shows that the environmental issues resulting from the proposal can be acceptably managed.

The language used in the body of the PER should; be kept simple and concise, consider the audience includes non-technical people, and extensive, technical detail referenced or appended Remember that the PER will form the legal basis of the Minister for the Environment's approval of the proposal and, therefore, should include a description of all the main and ancillary components of the proposal, including options if necessary.

The environmental management programme for the proposal should be developed in conjunction with the engineering and economic programmes of the proposal. Hence the PER should be designed to be immediately useful at the start of the proposal, and the DEP recommends that the basis for the environmental management and audit programme be developed as a concluding part of the PER.

The objective of the PER is to provide:

- details of the proposed Water Resource Allocation and Management Plan (identification of EWRs and establishment of EWPs); and
- environmental impacts associated with the establishment of the Lexia Groundwater Scheme to the extent that they impact on the regional groundwater table and comply with EWPs.

The contents of the PER should reflect this objective, and include:

- introduction of the proponent, the project and location;
- the legal framework, decision making authorities and involved agencies;
- description of the components of the proposal and identification of the potential impacts;

- description of the receiving environment which may be impacted;
- discussion of the key issues as identified by the Environmental Protection Authority, including an assessment of the significance as related to objectives or standards which may apply;
- discussion of the management of issues, including commitments to appropriate action and contingency plans; and
- a summary of the environmental management programme, including the key commitments, monitoring network and reporting mechanisms/ schedules, management criteria, regular feed back on the monitoring results and implications of this feedback on the future management of borefields.

For this proposal, the environmental review would focus on protecting groundwater levels and associated impacts on native vegetation in the Ellenbrook area.

Key issues

The key issues can be determined from a consideration called scoping.This involves gathering information from various components of the proposal on the potential to impact on people and the receiving environment. The PER should focus on the key issues for the proposal and it is recommended that these be agreed in consultation with the DEP and relevant public and government agencies. A description of the project component and the receiving environment should be directly included with, or referenced to, the discussion of the issue. The technical basis for the measuring of the impact and any objectives or standards for assessing and managing the issue should be provided.

For this proposal, the key issues at this stage include:

- maintenance of acceptable groundwater levels;
- impact on hydrological characteristics of the area;
- direct and cumulative drawdown impacts on immediate and adjacent areas (e.g. 'mound springs', Mirrabooka/Whiteman Park area);
- impact on native vegetation;
- impact on Environmental Protection Policy Lakes;
- impact on identified conservation areas, for example System 6 areas;
- impact on existing private groundwater bores; and
- impact of existing pine plantations on proposed groundwater management plan.

Further key issues may be raised during the preparation of the PER, and on-going consultation with the DEP and relevant agencies is recommended. Minor issues which may be readily managed as part of the normal operations for similar projects may be briefly described. Information used to reach conclusions should be properly referenced, including personal communications. Assessments of the significance of an impact should be soundly based rather than unsubstantiated opinions, and the assessment should lead to the discussion of the management of the issue.

Public consultation

A description should be provided for the public participation and consultation activities, undertaken by the proponent in preparing the PER. It should describe the activities undertaken, the dates, the groups/ individuals involved and the objectives of the activities. Cross reference should be made with the description of the environmental management of the issues which should clearly indicate how community concerns have been addressed. Those concerns are dealt with outside the EPA process can be noted and referenced.

Environmental management commitments

The method of implementation of the proposal and all the commitments made by the proponent in the PER will become legally enforceable under the environmental conditions of approval by the Minister for Environment. Specific commitments to protect the environment, typically related to key issues, should be separately listed, numbered and take the form of: who would do the work; what the work is; when the work would be carried out; and what agencies should be involved. These key commitments show the proponent is committed to actionable and auditable management of the environmental issues.

Appendix 2
Vegetation Community Types in the East Gnangara study area

Community types identified in *A Floristic Survey of the southern Swan Coastal Plain* found within the East Gnangara study area

Community type		Typical species	Other common tree and shrub species	Reservation and conservation status	
Number	**Description**			**Reservation**	**Conservation**
4	*Melaleuca preissiana* damplands	trees & shrubs: *Melaleuca preissiana, Hypocalymma angustifolium, Pericalymma ellipticum, Xanthorrhoea preissii.* herbs: *Dampiera linearis, Dasypogon bromeliifolius, Hypolaena exsulca, Stylidium brunonianum, Stylidium repens.*	*Adenanthos obovatus, Astartea aff. fascicularis.*	well reserved	low risk
5	Mixed shrub damplands	herbs: *Hypochaeris glabra, Hypolaene exsilca, Siloxerus humifusus.*	*Kunzea ericifolia, Pericalymma ellipticum.*	well reserved	low risk
18	Shrublands	shrubs: *Acacia saligna, Hakea varia, Leucopogon parviflorus, Melaleuca incarna, Melaleuca teretifolia, Melaleuca viminea, Xanthorrhoea preissii.* herbs: *Drosera stolonifera, Gahnia trifida, Lepidosperma longitudinale, Leptocarpus canus, Leptomeria cunninghamii, Leptomeria lehmannii, Opercularia vaginata, Parentucellia viscosa, Patersonia occidentalis*	*Logania serpyllifolia.*	poorly reserved	vulnerable
21a	Central *Banksia attenuata-Eucalyptus marginata* woodlands	Trees and shrubs: *Banksia attenuata, Bossiaea eriocarpa, Gompholobium tomentosum, Hibbertia hypericoides, Petrophile linearis.* Herbs: *Briza maxima, Burchardia umbellata, Hypochaeris glabra, Lepido sperma angustatum, Trachymene pilosa.*	*Eucalyptus marginata, Conostephium pendulum, Eriostemon spicatus, Macrozamia riedlei.*	well reserved	low risk

Community types identified in *A Floristic Survey of the southern Swan Coastal Plain* found within the East Gnangara study area (cont.)

Community type		Typical species	Other common tree and shrub species	Reservation and conservation status	
Number	Description			Reservation	Conservation
21c	Low lying *Banksia attenuata* woodlands or shrublands	trees: *Banksia attenuata.* herbs: *Briza maxima, Hypochaeris glabra, Lomandra caespitosa, Lyginia barbata, Thysanotus manglesianus/ patersonii complex, Trachymene pilosa.*	*Banksia menziessii, Gompholobium tomentosum, Kunzea ericifolia, Leucopogon conostephioides, Petrophile linearis, Scholtzia involucrata.*	well reserved	low risk
22	*Banksia ilicifolia* woodlands	trees: *Banksia attenuata, Banksia ilicifolia.* shrubs *Petrophile linearis.* herbs: *Stylidium brunonianum, Stylidium repens.*		poorly reserved	low risk
23a	Central *Banksia attenuata-Banksia menziesii* woodlands	trees: *Banksia menziesii, Banksia attenuata.* shrubs: *Bossiaea eriocarpa, Gompholobium tomentosum, Leucopogon conostephioides, Petrophile linearis, Scholtzia involucrata.* herbs: *Briza maxima, Burchardia umbellata, Conostylis jucea, Dampiera linearis, Drosera erythrorhiza, Hypochaeris glabra, Lomandra hermaphrodita, Lyginia barbata, Patersonia occidentalis, Schoenus curvifolius, Stylidium piliferum, Trachymene pilosa.*	*Adenanthos cygnorum, Calytrix flavescens, Conostephium pendulum, Eriostemon spicatus, Hibbertia hypericoides, Hibbertia subvaginata, Hovea trisperma, Xanthorrhoea preissii.*	well reserved	low risk
23b	Northern *Banksia attenuata-Banksia menziesii* woodlands	trees *Banksia attenuata, Banksia menziesii.* shrubs: *Bossiaea eriocarpa, Calytrix flavescens, Eremaea pauciflora, Eriostemon spicatus, Hibbertia subvaginata, Jacksoniadensiflora/floribunda complex, Petrophile linearis, Scholtzia involucrata.* herbs *Alexgeorgea nitens, Angozanthos humilis, Burchardia umbellata, Lomandra hermaphrodita, Lyginia barbata, Patersonia occidentalis, Schoenus curvifolius, Xanthosia huegelii.*	*Acacia pulchella* var. *pulchella, Beaufortia elegans, Conostephium minus, Conostephium pendulum, Hibbertia hypericoides, Leucopogon conostephioides, Melaleuca* aff. *trichophylla, Stirlingia latifolia.*	unreserved (*Note:* now reserved in Yeal Swamp Nature Reserve and Moore River National Park)	susceptible

Note: Community is considered 'well reserved' if known from at least two national parks and nature reserves ; 'poorly reserved' if known from one national park or nature reserve and 'unreserved' if not known from a national park or nature reserve. For definitions of community conservation status categories see over.

Definition of 'community conservation' status
(Department of Conservation and Land Management, unpubl.)

Community Conservation status	Definition
Presumed destroyed	A community that is totally destroyed or so extensively modified that it is unlikely to re-establish ecosystem processes in the foreseeable future.
Critical	A community with most or all of its known occurrences facing severe modification or destruction in the immediate future.
Endangered	A community in danger of severe modification or destruction throughout its range, if causal factors continue operating.
Vulnerable	A community likely to move into the endangered category in the near future if the causal factors continue operating.
Susceptible	A community of concern because there is evidence that it can be modified or destroyed by human activities , or would be vulnerable to new threatening processes.
Low risk	A community that does not qualify for one of the above categories.
Insufficiently known	A community for which there is inadequate data to assign to one of the above categories.

SOURCE: Gibson. N, Keighery. B.J., Keighery. G. J., Burbidge. A.H. and Lyons. M.N. (1994). A Floristic Survey of the southern Swan Coastal Plain. *Unpublished Report for the Australian Heritage Commission, prepared by Department and Conservation and Land Management and the Conservation Council of Western Australia (Inc.).*

Appendix 3
Definitions of rare and priority species

Declared Rare Flora

R: Declared Rare Flora: - Extant Taxa

Taxa which have been adequately searched for and are deemed to be in the wild either rare, in danger of extinction, or otherwise in need of special protection, and have been gazetted as such.

X: Declared Rare Flora - Presumed Extinct Taxa

Taxa which have not been collected, or otherwise verified, over the past 50 years despite thorough searching, or of which all known wild populations have been destroyed more recently, and have been gazetted as such.

Priority Species

Priority One (P1) - Poorly Known Taxa

Taxa which are known from one or a few (generally <5) populations which are under threat, either due to small population size, or being on lands under immediate threat e.g. road verges, urban areas, farmland, active mineral leases or, the plants are under threat, from disease, grazing by feral animals. Many include taxa with threatened populations on protected lands. Such taxa are under consideration for declaration as 'rare flora', but are in urgent need of further survey.

Priority Two (P2) - Poorly Known Taxa

Taxa which are known from one or a few (generally <5) populations, at least some of which are not believed to be under immediate threat (ie not currently endangered). Such taxa are under consideration for declaration of 'rare flora', but are in urgent need of further survey.

Priority Three (P3) - Poorly Known Taxa

Taxa which are known from several populations, at least some of which are not believed to be under immediate threat (ie not currently endangered). Such taxa are under consideration as 'rare flora' but are in need of further survey.

Priority Four (P4) - Rare Taxa

Taxa which are considered to have been adequately surveyed and which, whilst being rare (in Australia), are not currently threatened by any identifiable factors. These taxa require monitoring every 5-10 years.

SOURCE: Department of Conservation and Land Management Herbarium, 1997.

Appendix 4
Water levels along Semenuik transect in Lexia wetlands (i.e. sites D1-D10)

The table below provides monitoring data from the piezometers that the Semeniuks installed in the eastern Lexia region. Figure 16 illustrates the location of each of the piezometers and 17a is a graph of the water levels at site D8.

Depth to water table (cm) below ground surface in Lexia transct bores throughout 1993

BORE	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
D1S	dry	dry	dry	dry	dry	182	193	195
D1D	360	369	323	298	203	187	219	249
D2	160	149	134	120	97	113	137	147
D3	100	-	60	41	10	17	41	56
D4	150	130	107	87	56	63	78	89
D5	280	267	245	221	172	176	200	213
D6	-	-	566	548	494	489	512	527
D7	250	236	211	191	137	141	164	186
D8S	120	101	78	55	3	7	16	56
D8D	-	98	86	65	16	14	38	71
D9	100	80	57	33	+19	+11	18	40
D10	340	321	296	274	219	220	246	267

D = deep (below perched layer), S = shallow (above perched layer), + = above ground surface.

SOURCE: V&C Semeniuk (1993). Investigations of startigraphy and groundwater in four selected areas of the north-east corridor, Perth metropolitan area. *V&C Semeniuk Research Group, Perth.*

Appendix 5
Results of model runs which experiment with the layout of the Lexia wellfield

At the beginning of the East Gnangara project, the proposed layout preferred by the Water Corporation for the Lexia groundwater scheme was to construct twelve wells to pump from the superficial aquifer and three deeper wells to pump from the Mirrabooka sands aquifer. The Water Corporation also proposed to establish four additional East Mirrabooka wells along Gnangara Road east of the established well M350. The initial proposed locations of wells are illustrated in Figure 28. The aquifers are discussed in Section 2.2 of this document. The proposed quota for the initial scheme was 13.5 x 10^6 kL/yr. The breakdown of allocations to each well is given in the Table below.

The proposed Mirrabooka Sands wells which are to be located in the urban development area are semi-confined, however in the model runs they have been assumed to act like they are drawing directly from the superficial aquifer. This is necessary because the degree of connection between the aquifers is unknown. Assuming the wells are superficial therefore provides the worst case scenario.

The impacts from operating the wellfields with the originally proposed layout and quotas are illustrated in Figure 29. Drawdowns between 0.5 - 5 m occur. There is a drawdown of up to 1.25 m in the vicinity of the Lexia wetlands; 1m at the Egerton seepage; up to 3 m in the native vegetation corridor between Melaleuca Park and Whiteman Park and up to 2 m at the top of Whiteman Park near Gnangara Road. There is minimal drawdown however on Melaleuca Park and Edgecombe seepage. These drawdowns in most areas are considered to be too large. Therefore many other model runs with variations to this original scheme have been carried out. These runs have been conducted in order to find a scenario which will allow a maximum level of groundwater abstraction with a minimum and acceptable environmental impacts. A selection of the runs conducted in the process of finding an acceptable scenario is presented below. Each of these runs includes abstraction from the Lexia and East Mirrabooka production wells and urbanisation. All other land uses are not included within these runs. Other landuses were incorporated once a preferred layout was found. The outcome of the preferred abstraction and land-use scenario is presented in Section 13.2.6.

Run 7

Run 7 included abstraction from wells illustrated in the layout in Figure 28 with abstraction rates as provided in Table 1. The only change to this initial layout was that the semi confined Mirrabooka Sands wells (wells L12, L22, and L32) were excluded. The overall production from the Lexia wells under this scenario would be 8.4 x 10^6 kL/yr and 2.4 x 10^6 kL/yr from the East Mirrabooka wells. The outcome of this scenario is provided in Figure 30. The result of this scenario at the points of environmental significance are:

Originally Proposed Quotas for the Lexia and East Mirrabooka wells

Well Type	Abstraction	Number of wells	Total
Lexia - superficial	0.7 x 10^6 kL/yr	12 (L600-L630, L500-L530, L400-L430)	8.4 x 10^6kL/yr
Lexia - Mirrabooka Sands	0.9 x 10^6 kL/yr	3 (L12, L22, L32)	2.7 x 10^6kL/yr
East Mirrabooka	0.6 x 10^6kL/yr	4 (M360-M390)	2.4 x 10^6 kL/yr
Total			**13.5 x 10^6 kL/yr**

- 0.5 m drawdown in groundwater levels at the Lexia wetlands;
- up to a 3 m drawdown in the native vegetation corridor; and
- 1.5 m drawdown at the top of Whiteman Park.

These drawdowns are considered too large.

Run 11

Run 11 included the wells in Figure 28 and abstraction rates in Table 1, except for the eastern most row of Lexia superficial wells (i.e. L430, L530 and L630). This means production from the Lexia scheme 9×10^6 kL/yr and the East Mirrabooka wells would provide 2.4×10^6 kL/yr. Impacts from this scenario are illustrated in Figure 31. These include:

- 0.5 m drawdown in water levels at the Lexia wetlands;
- 0.5 m drawdown at Egerton spring;
- up to 2 m drawdown in the vegetation corridor; and
- 1.5 m drawdown at the top of Whiteman Park.

The drawdowns on the Lexia wetlands, Egerton seepage and Whiteman Park are considered to be too large.

Run 10

Run 10 combined runs 7 and 11 to exclude the superficial wells L430, L530 and L630 and the semi-confined Mirrabooka Sands wells L12, L22, L32. The full East Mirrabooka scheme is still included. Under this scenario the Lexia scheme would provide 6.3×10^6 kl/ yr. The outcome of the reduced wellfield is shown in Figure 32. The results indicate:

- 0.25 m drawdown at the Lexia wetlands
- 1 m drawdown in a small area at the top of Whiteman Park
- up to 1.25 m in the vegetation corridor

This drawdown is considered too high in Whiteman Park. The other disadvantage to this layout is that the wellfield has been significantly reduced from the initial layout.

Run 13

Run 13 excluded six of the Lexia superficial wells on the eastern side of the wellfield (i.e. L420, L520, L620, L430, L530 and L630). All other wells illustrated in the layout in Figure 28 are included at the abstraction rates in Table 1. The production from the Lexia scheme under this scenario totals 6.9×10^6 kL/yr and 2.4×10^6 kL/yr from East Mirrabooka. The outcome (see Figure 33) in areas of environmental significance are:

- 0.2 5m drawdown at the Lexia wetlands;
- up to a 1.5 m drawdown at the top of Whiteman Park;
- up to 1.5 m drawdown in the vegetation corridor; and
- 0.5 m drawdown at the Egerton spring.

The drawdown under this scenario is too large in Whiteman Park and Egerton seepage, but impacts elsewhere are considered acceptable. However once again production from the wells is low.

Run 17

In an attempt to find a scenario without any greater degree of environmental impact on the Lexia wetlands and vegetation corridor than in run 13; but a scenario where more water can be obtained from the Lexia scheme; run 17 was carried out. Impacts on Whiteman Park were considered and reduced in subsequent runs (which varied the layout of East Mirrabooka. This is discussed below).

Run 17 excluded 4 of the eastern Lexia wells as opposed to six (ie L620, L630, L520 and L530). Production from the Lexia scheme under this scenario would be 8.3×10^6 kL/yr (East Mirrabooka is still at 2.4×10^6 kL/yr). The outcome under this scenario is presented in Figure 34 and includes:

- 0.25 m drawdown at the Lexia wetlands;
- 0.5 m drawdown at the Egerton spring;
- 2 m drawdown at the top of Whiteman Park; and
- up to 3 m in the vegetation corridor.

This scenario is unacceptable due to the drawdown at Egerton seepage and under phreatophytic vegetation in the bottom of the vegetation corridor and Whiteman Park.

Run 22

Run 22 excluded wells L500, L520 and L530. Therefore production from Lexia would be 9×10^6 kL/yr (and 2.4×10^6 kL/yr from East Mirrabooka). Figure 35 illustrates the output. Impacts include:

- drawdown of approximately 0.5 m at the Lexia wetlands;
- 0.5 m drawdown at the Egerton spring;
- 2 m at the top of Whiteman Park; and
- up to 2.5 m in the vegetation corridor.

The drawdowns predicted in all areas make this scenario unacceptable

Run 20

Run 20 excluded the eastern most row of Lexia superficial wells (L430, L530, L630), well L520 and the top Mirrabooka Sands well L32. Production from the Lexia scheme would be 7.4 x 10^6 Lk/yr under this scenario (and 2.4 x 10^6 kL/yr from East Mirrabooka) and the outcome is (see Figure 36):

- drawdown of approximately 0.25 m at the Lexia wetlands;
- 0.25 m upstream of Egerton spring;
- up to a 1.5 m drawdown in the vegetation corridor; and
- 1.5 m at the top of Whiteman Park.

These drawdowns are considered acceptable in areas other than Whiteman Park. After establishing this layout it would be acceptable for the Lexia scheme. Further runs used this layout as a base. The runs that followed aimed at testing whether a greater quantity of water could be obtained from the Lexia scheme without increasing impacts. Therefore further runs experimented with increasing production from the superficial wells in the west and adding wells to the north-west of the other Lexia wells. Eventually the outcome of run 35 (discussed below) was accepted (in terms of the Lexia scheme layout). Following this, impacts on Whiteman Park were considered and the East Mirrabooka wells manipulated to avoid adverse impacts in that area.

Run 35

Run 35 excluded L420, L520, L530, L630 and L32 from the Lexia scheme. Instead it included two additional wells near Melaleuca Park (L700 and L710) and extra abstraction from L700, L400, L500 and L600 (at 1 x 10^6 kL/yr instead of 0.7 x 10^6 kL/yr). Production from the Lexia scheme would be 10 x 10^6 kL/yr. Run 35 still included the initial East Mirrabooka layout however, with an abstraction rate of 2.4 x 10^6 kL/yr.

The impacts are illustrated in Figure 37 and include:

- 0.25 m drawdown at the Lexia wetlands;
- 0.25 m drawdown at dampland 78;
- 0.25 m drawdown upstream of Egerton seepage; and
- up to 2 m in the vegetation corridor.

These impacts are considered acceptable. However the impact on Whiteman Park, of up to 1.75 m in the northern region is unacceptable. Model runs following run 35 therefore experimented with various layout and abstraction rates from the East Mirrabooka wells.

Run 37

In run 36 the East Mirrabooka wells M360 and M370 were excluded to reduce impacts on Whiteman Park. Apart from this the schemes remained the same as in run 35. As this provided an acceptable outcome, in run 37 a new well was added to the east of M390 to replace some of the water lost by M360 and M370. Total abstraction from the East Mirrabooka scheme therefore became 1.8 x 10^6 kL/yr. Total abstraction from Lexia was 10 x 10^6 kL/yr. The impacts of run 37 are illustrated in Figure 38 and include:

- 0.25 m drawdown at the Lexia wetlands
- 0.25 m drawdown at dampland 78
- 0.25 m drawdown upstream of Egerton seepage
- up to a 2 m drawdown in the vegetation corridor
- 0.5 m drawdown at the top of Whiteman Park.

These impacts were considered acceptable. Further runs experimented with various ways of increasing abstraction without increasing drawdown in the above areas. These changes were not successful. Once various scenarios were exhausted, other changes which took place included changes to private abstraction in an attempt to increase the amount of water available, particularly in the Swan Valley. This was successfully done through reducing some public use of water.

Other changes included shifting well M400 south-east away from a proposed petrol station. The Water Corporation also discovered that production from the proposed Mirrabooka Sands wells in the urban area would not yield as much water as first anticipated and may not be worth commissioning. Therefore they were removed. A run reflecting this is discussed below.

Run 73

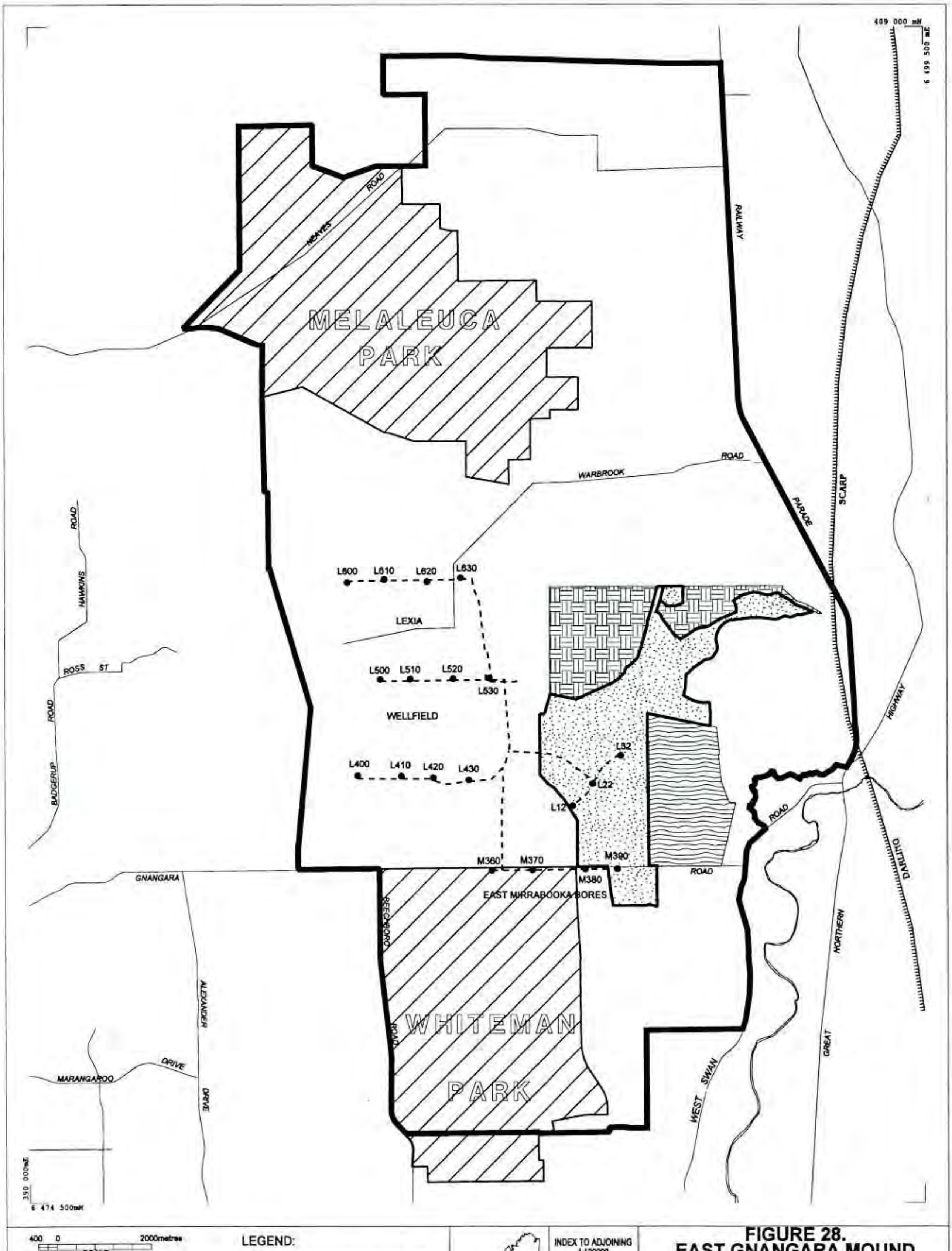
Run 73 excluded wells L610, L630, L520, L530, M360, M370, L12, L22, and L32. Wells L700, L710 and M400 were included. Abstraction rates were modelled at 1 x 10^6 kL/yr for L500, L600 and L700; 0.9 x 10^6 kL/yr for L410; 0.7 x 10^6 kL/yr for L710, L620, L510, L430 and L420 and 0.6 x 10^6 kL/yr for the remainder of the wells. Therefore abstraction totalled 8.4 x 10^6 kL/yr for the Lexia scheme and 1.8 x 10^6 kL/yr for the East Mirrabooka scheme. (Note, Run 73 also incorporated urbanisation and pine plantation management and private abstraction but the outcome in Figure 39 is dominated by public abstraction and the impacts can be inferred.) The impacts are illustrated in Figure 39 and include:

- less than a 0.25 m drawdown at the Lexia wetlands;
- 0.25 m drawdown at dampland 78;
- 2 m in the vegetation corridor; and
- up to 0.75 m at the very top of Whiteman Park.

These impacts were considered acceptable.

Run 85

Following Run 73 some small changes were made but mainly in an attempt to increase the amount of water attainable for public water supply. Run 85 provided the final outcome . The difference to run 73 is the removal of M400 but the addition of a well west of L500 (L490) at 0.95 x10^6 kL/yr, L400 put back in at 1 x 10^6kL/yr and L12 put back in at half the previous abstraction rate; ie 0.45 x10^6 kL/yr. This provides a total allocation of 9.8 x 10^6 kL/yr from the Lexia groundwater scheme and 1.2 x 10^6 kL/yr from the East Mirrabooka groundwater scheme. Run 85 was the final layout accepted as the proposed Lexia groundwater scheme. The layout is illustrated in Figure 2, the breakdown in well abstraction rates is provided in Table 17 and the impacts illustrated in Figure 24 and discussed in Section 13.2.4.



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SCALE

WATER AND RIVERS COMMISSION

LEGEND:

- Initial Proposed Lexia\East Mirrabooka Wellfield
- Egerton Development Area
- Ellenbrook Development Area
- Conservation Area

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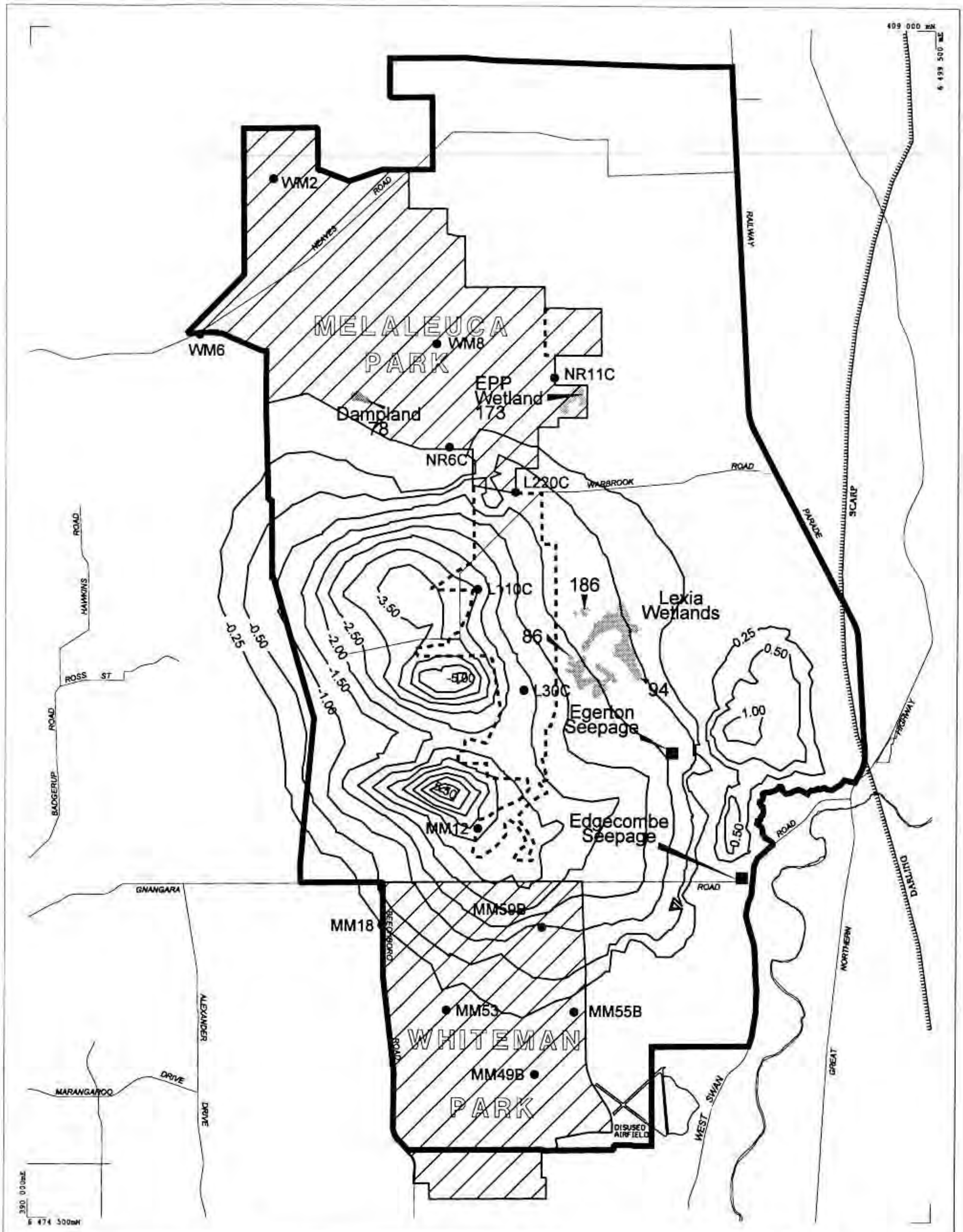
1935	2035	2135
	2034	2134
	2033	2133

FIGURE 28.
EAST GNANGARA MOUND
Location of initial proposed Lexia wellfield.

Drawn by D.R.A Date 09/09/96

Catchment and Waterways Management Branch



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WATER AND RIVERS COMMISSION

LEGEND:
- Study Area
- 1.25 Water Level Difference Contour from 1992 Baseline Levels
- Vegetation Corridor connecting Melaleuca Park & Lexia Wetlands
- 78,86,94 173,186 Criteria Wetlands
- Springs/Seepages
- MM49B ● Monitoring Well with Criteria

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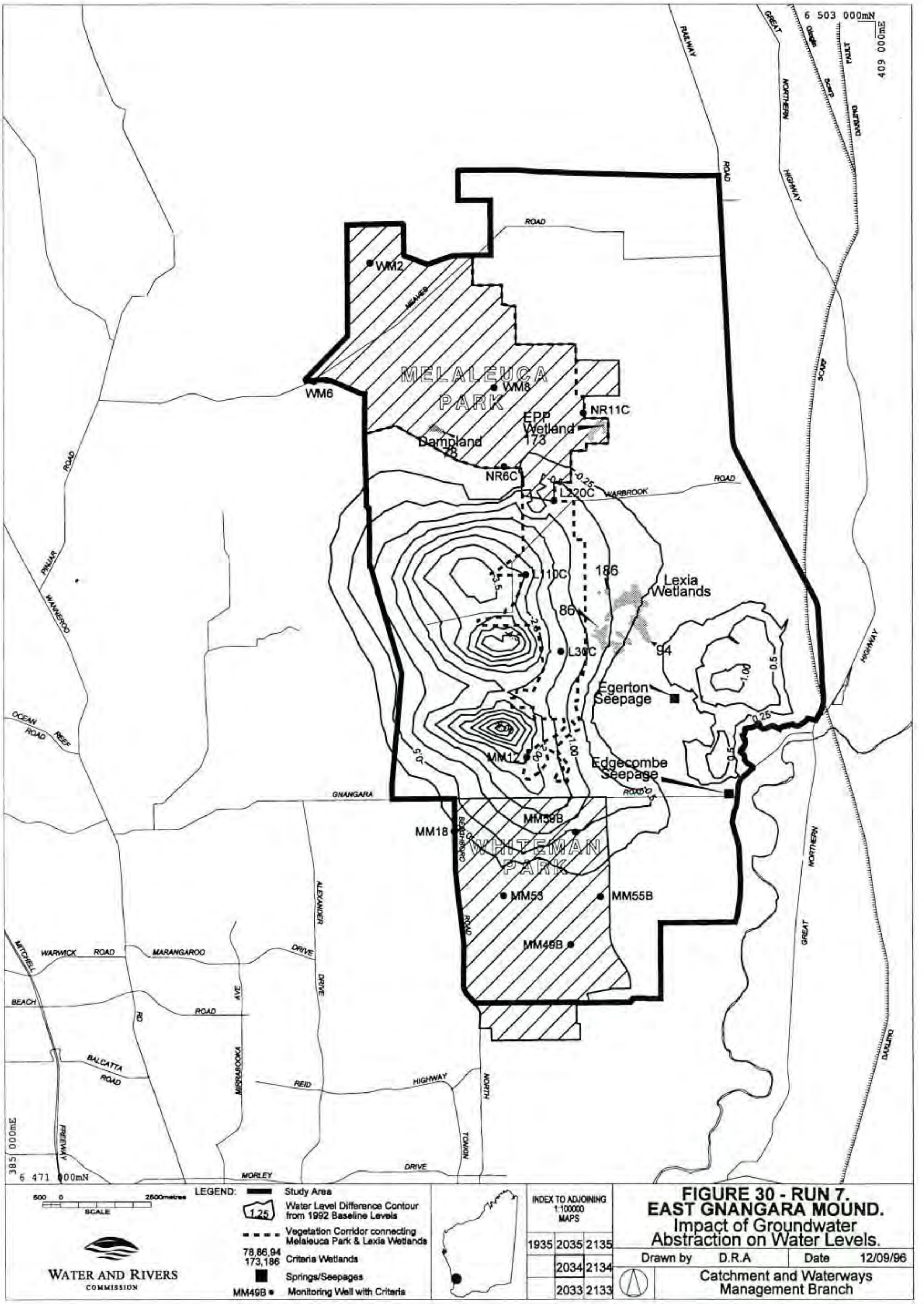
	2034	2134
	2033	2133

FIGURE 29
EAST GNANGARA MOUND.
Impact of Initial Lexia and East Mirrabooka Groundwater Scheme Layout on Water Levels (includes Urbanisation)

Drawn by D.R.A Date 09/09/96

Catchment and Waterways Management Branch



6 503 000mN
409 000mE
385 000mE
6 471 000mN
MELALEUCA PARK
WHITEMAN PARK
WM2
WM6
WM8
NR11C
EPP Wetland 173
Dampland 78
NR6C
L220C
L110C
186
Lexia Wetlands
86
L30C
94
Egerton Seepage
MM12
Edgecombe Seepage
MM59B
MM18
MM53
MM55B
MM49B
GNANGARA
ROAD
YANBROOK
ALEXANDER DRIVE
WARWICK ROAD
MARANGAROO DRIVE
BEACH ROAD
BALCATTA ROAD
REID HIGHWAY
MORLEY DRIVE
MIRRABOOKA AVE
NORTH
TONKIN
OCEAN REEF ROAD
PINJAR
WANNEROO ROAD
MITCHELL FREEWAY
GREAT NORTHERN HIGHWAY
RAILWAY
DARLING SCARP
LEGEND:
Study Area
Water Level Difference Contour from 1992 Baseline Levels
Vegetation Corridor connecting Melaleuca Park & Lexia Wetlands
78,86,94 173,186 Criteria Wetlands
Springs/Seepages
MM49B Monitoring Well with Criteria
SCALE
2500metres
INDEX TO ADJOINING 1:100000 MAPS
1935 2035 2135
2034 2134
2033 2133
FIGURE 30 - RUN 7. EAST GNANGARA MOUND.
Impact of Groundwater Abstraction on Water Levels.
Drawn by D.R.A
Date 12/09/96
Catchment and Waterways Management Branch
WATER AND RIVERS COMMISSION

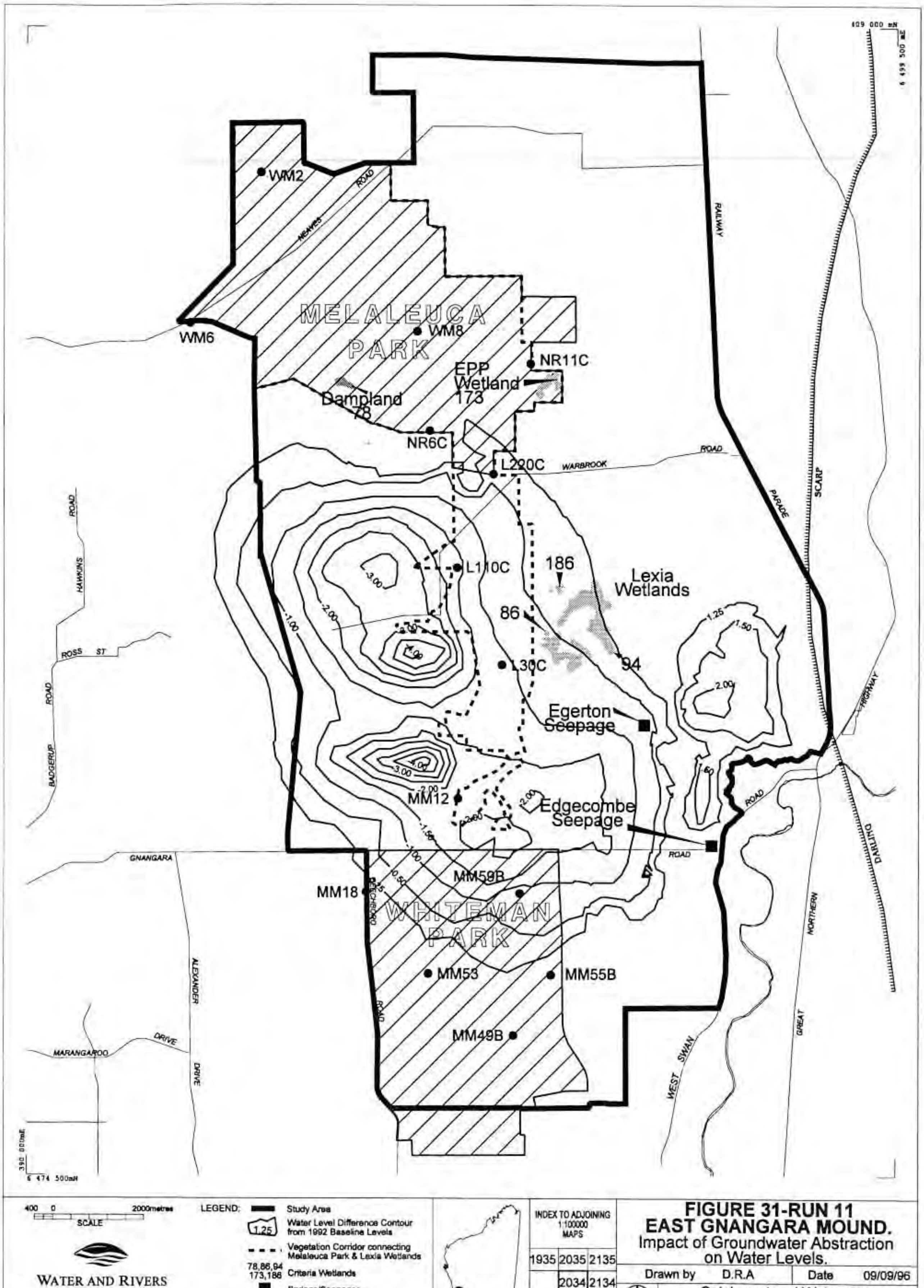


FIGURE 31-RUN 11
EAST GNANGARA MOUND.
Impact of Groundwater Abstraction on Water Levels.

Drawn by D.R.A Date 09/09/96

Catchment and Waterways Management Branch

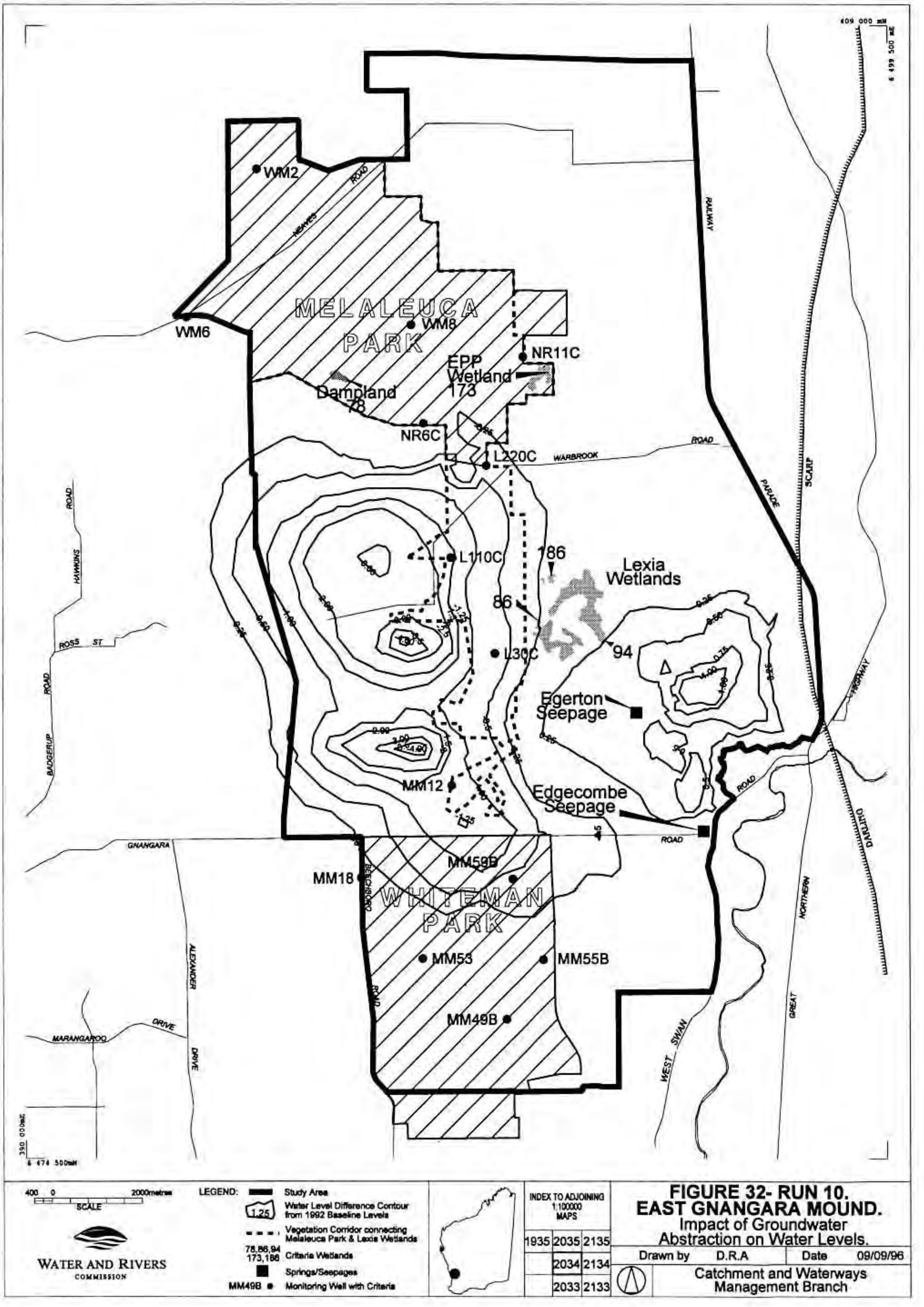
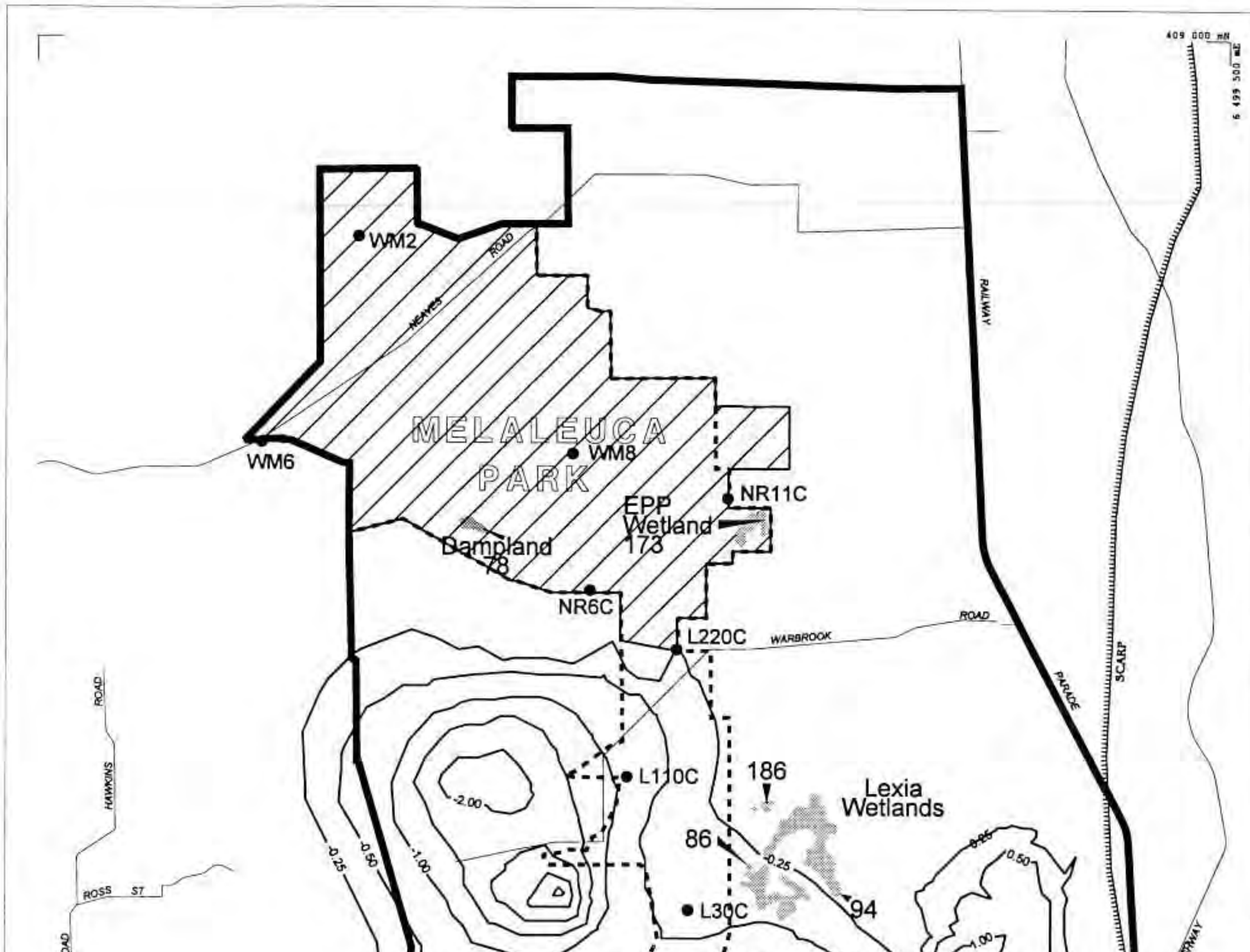


FIGURE 32- RUN 10. EAST GNANGARA MOUND.
Impact of Groundwater Abstraction on Water Levels.



400 0 2000metres
SCALE

WATER AND RIVERS COMMISSION

LEGEND:
- Study Area
- 1.25 Water Level Difference Contour from 1992 Baseline Levels
- Vegetation Corridor connecting Melaleuca Park & Lexia Wetlands
- 78,86,94 173,186 Criteria Wetlands
- Springs/Seepages
- MM49B ● Monitoring Well with Criteria

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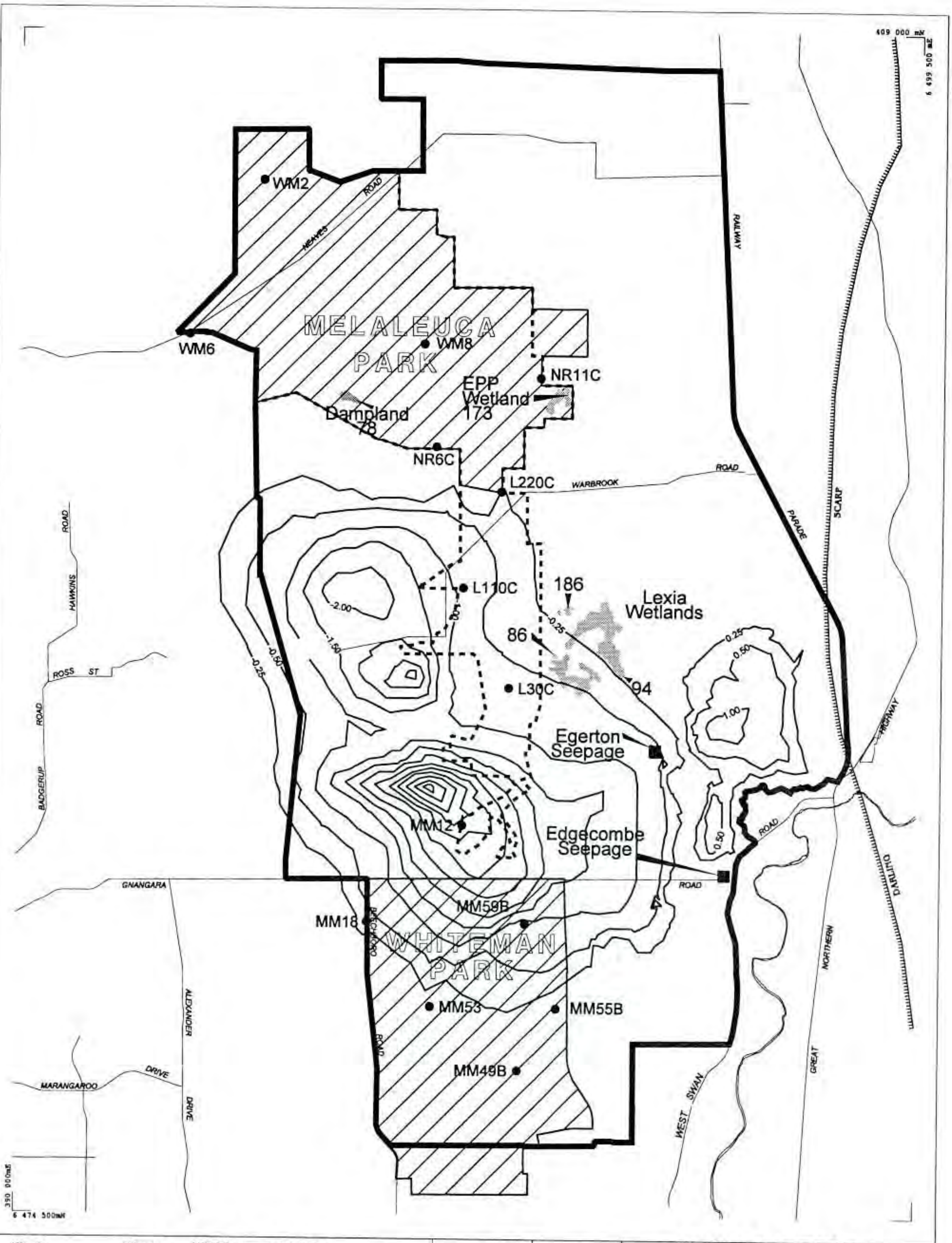
	2034	2134
	2033	2133

FIGURE 33 - RUN 13. EAST GNANGARA MOUND.
Impact of Groundwater Abstraction on Water Levels

Drawn by D.R.A Date 09/09/96

Catchment and Waterways Management Branch



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SCALE

LEGEND:
Study Area
1.25 Water Level Difference Contour from 1992 Baseline Levels
Vegetation Corridor connecting Melaleuca Park & Lexia Wetlands
78,86,94 173,186 Criteria Wetlands
Springs/Seepages
MM49B Monitoring Well with Criteria

WATER AND RIVERS COMMISSION

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	2034	2134
	2033	2133

FIGURE 34 - RUN 17. EAST GNANGARA MOUND.
Impact of Groundwater Abstraction on Water Levels

Drawn by D.R.A Date 09/09/96

Catchment and Waterways Management Branch

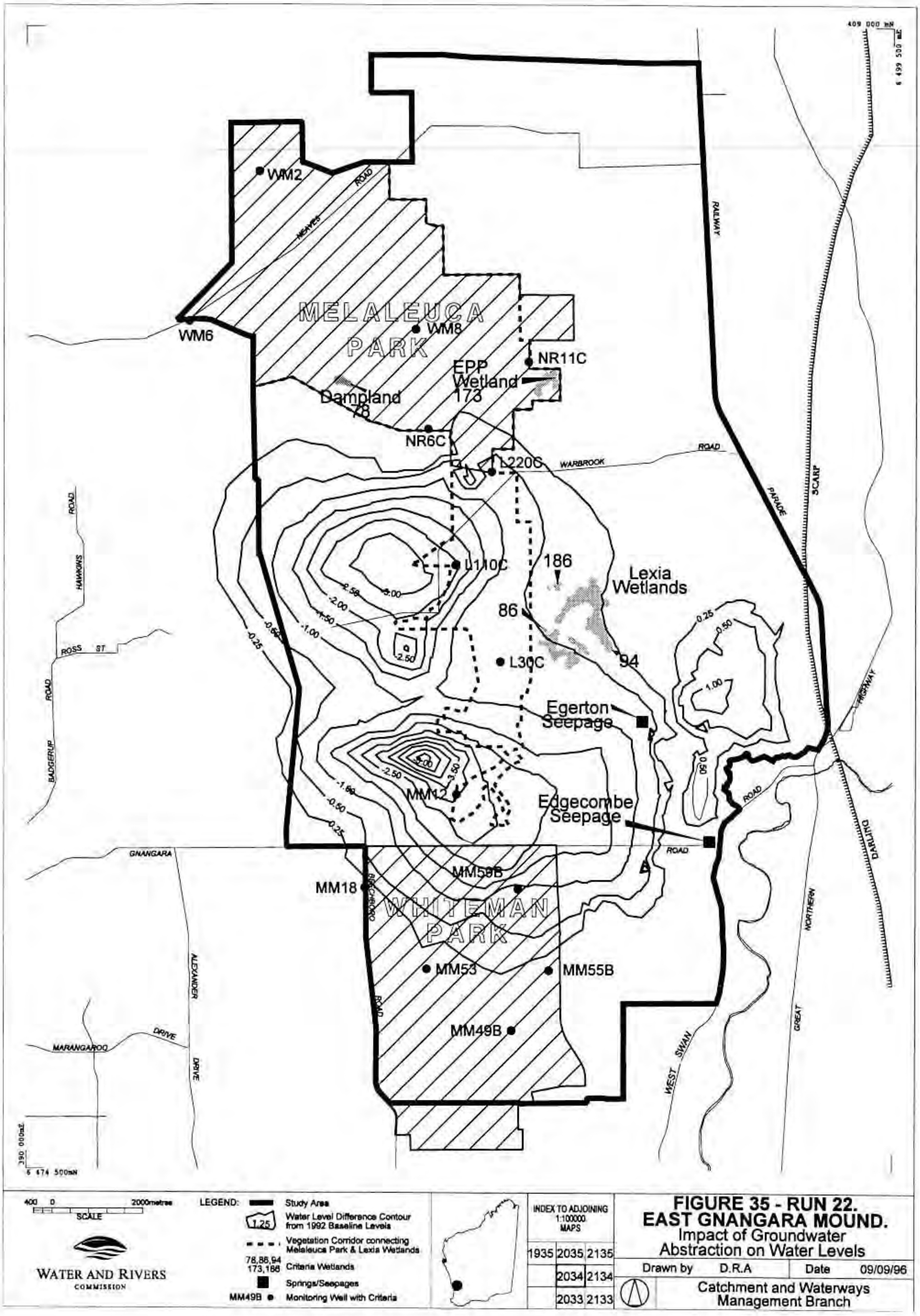


FIGURE 35 - RUN 22.
EAST GNANGARA MOUND.
Impact of Groundwater Abstraction on Water Levels

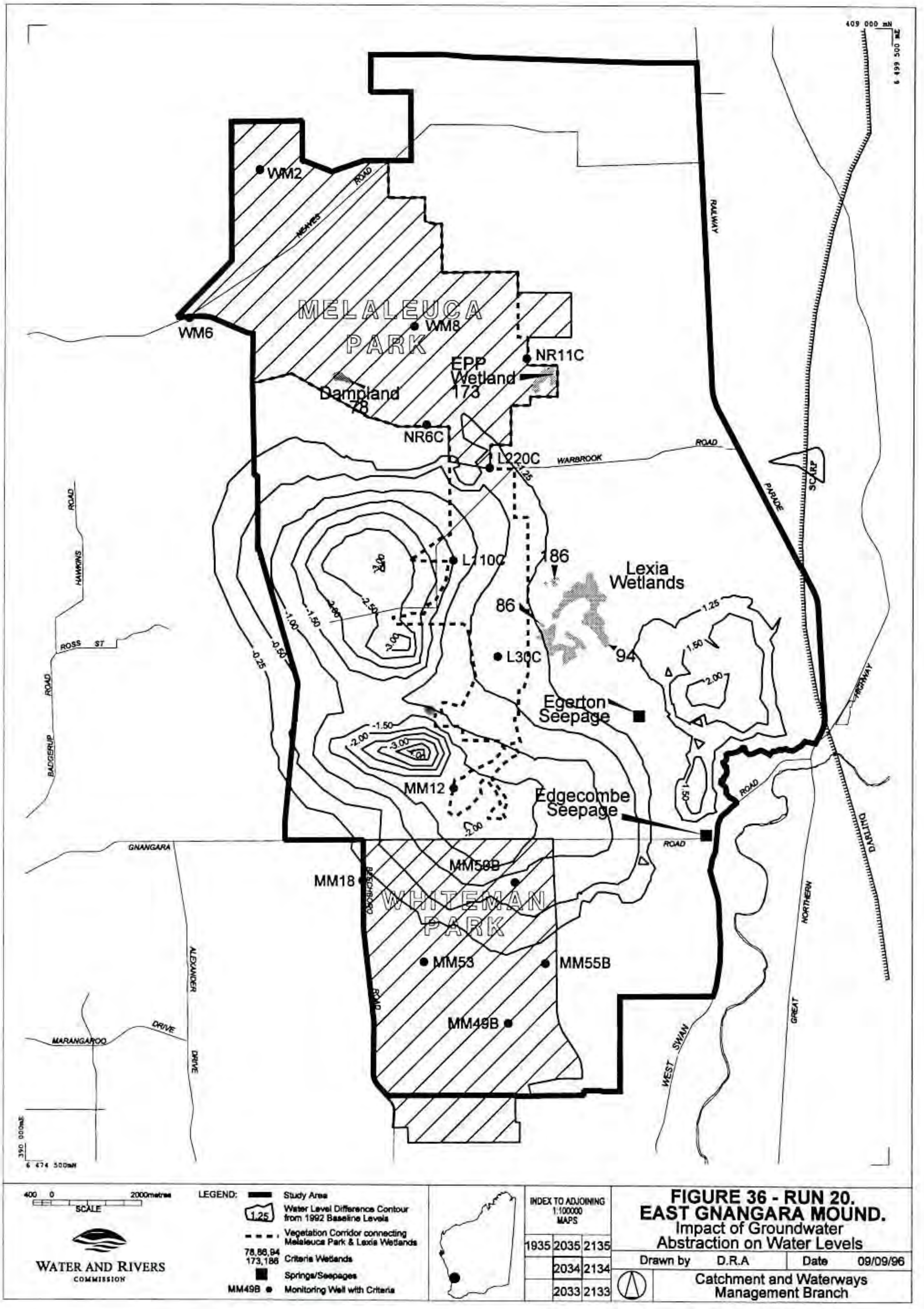


FIGURE 36 - RUN 20.
EAST GNANGARA MOUND.
Impact of Groundwater Abstraction on Water Levels

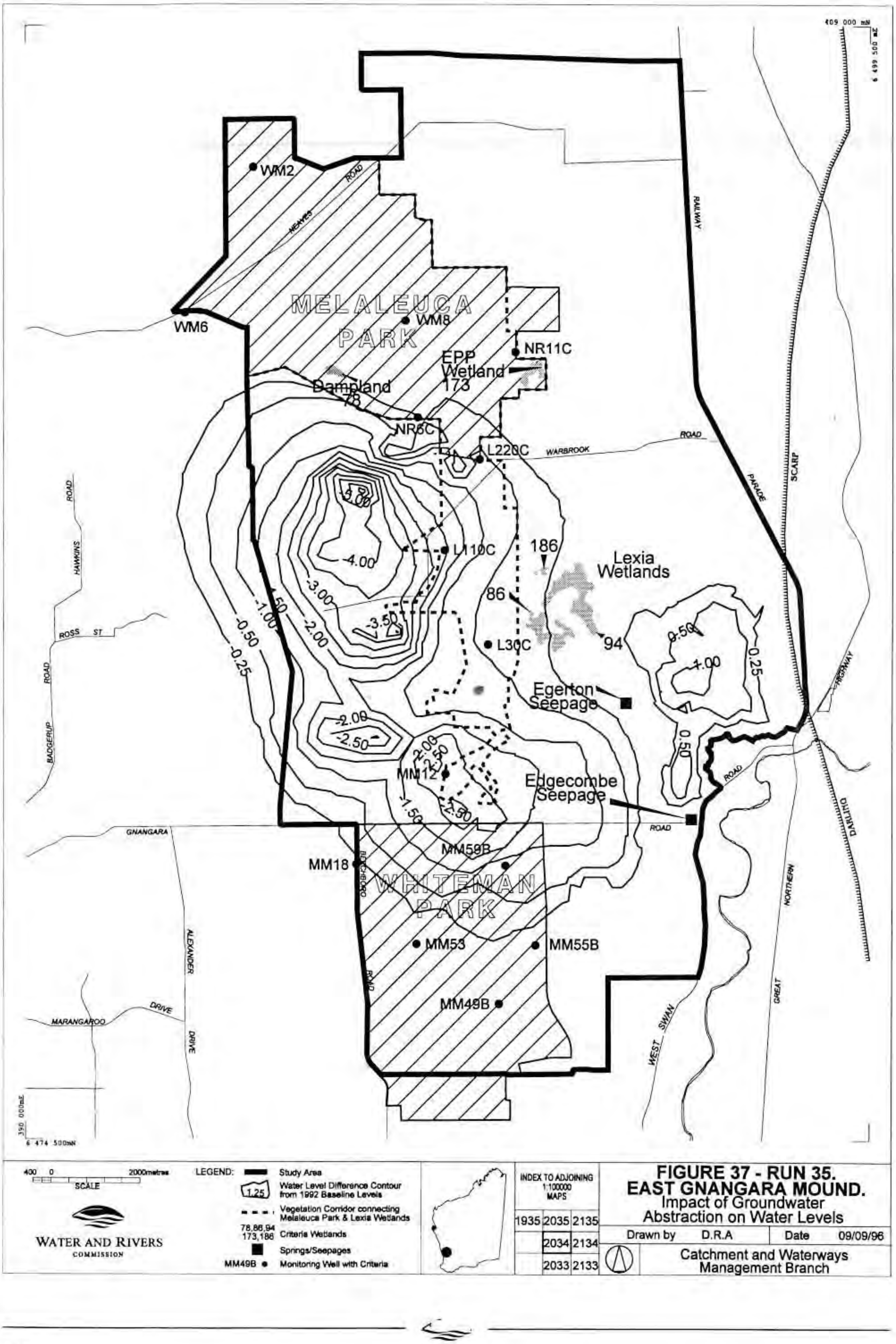
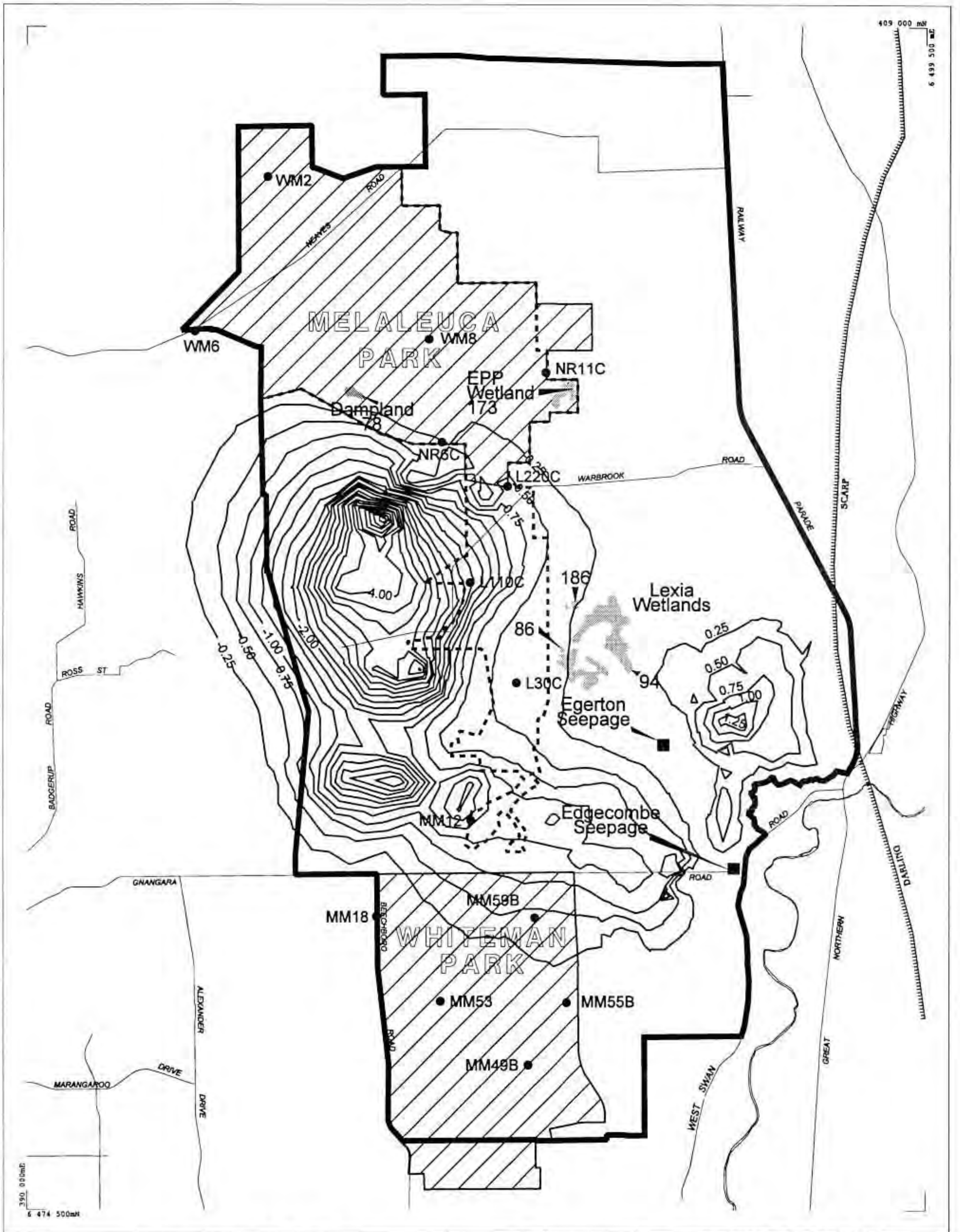


FIGURE 37 - RUN 35. EAST GNANGARA MOUND.
Impact of Groundwater Abstraction on Water Levels



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SCALE

LEGEND: Study Area
1.25 Water Level Difference Contour from 1992 Baseline Levels
Vegetation Corridor connecting Melaleuca Park & Lexia Wetlands
78,86,94 173,186 Criteria Wetlands
Springs/Seepages
MM49B ● Monitoring Well with Criteria

WATER AND RIVERS COMMISSION

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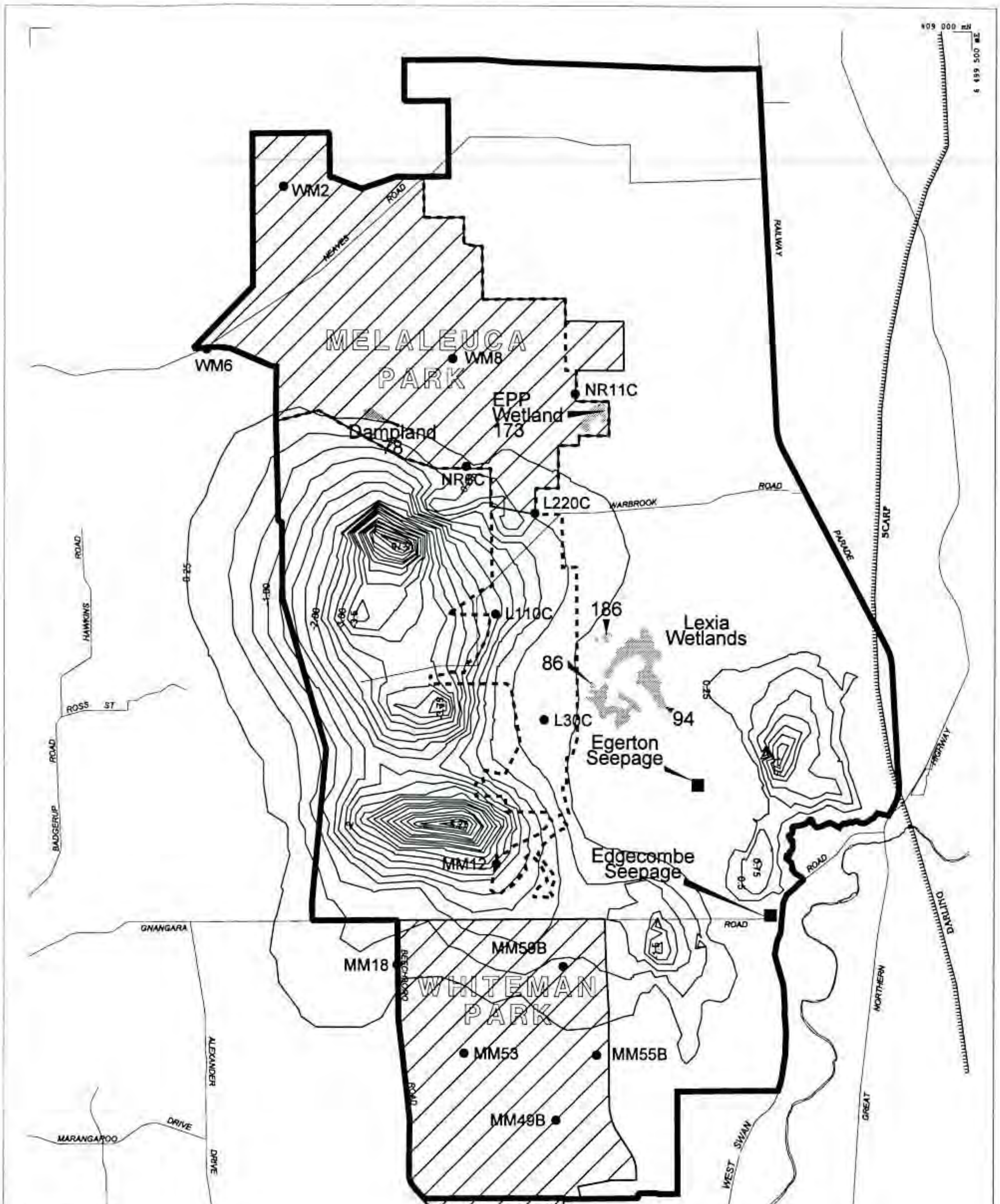
	2034	2134
	2033	2133

FIGURE 38 - RUN 37.
EAST GNANGARA MOUND.
Impact of Groundwater Abstraction on Water Levels.

Drawn by D.R.A Date 09/09/96

Catchment and Waterways Management Branch



400 0 2000metres
SCALE

LEGEND:
Study Area
1.25 Water Level Difference Contour from 1992 Baseline Levels
Vegetation Corridor connecting Melaleuca Park & Lexia Wetlands
78,86,94 173,186 Criteria Wetlands
Springs/Seepages
MM49B • Monitoring Well with Criteria

WATER AND RIVERS COMMISSION

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	2034	2134
	2033	2133

FIGURE 39 - RUN 73.
EAST GNANGARA MOUND.
Impact of Groundwater Abstraction on Water Levels.

Drawn by D.R.A Date 09/09/96

Catchment and Waterways Management Branch

Appendix 6
Data used in modelling the outcome of wet and dry climatic periods on groundwater levels

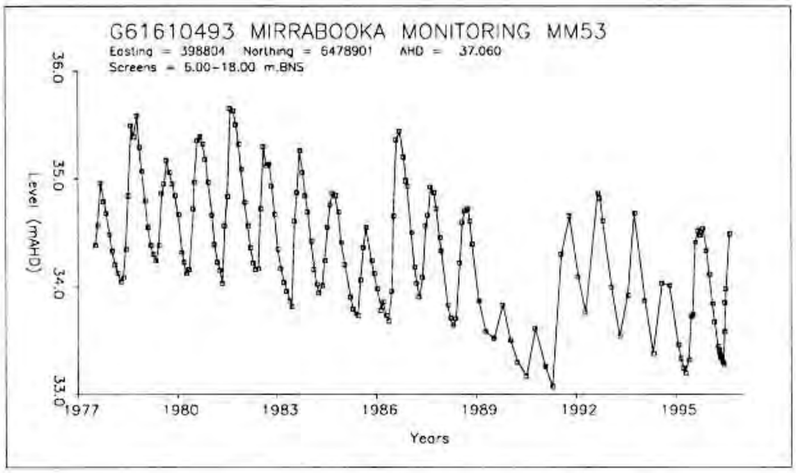
Figures 25 and 26 illustrate the potential variations in groundwater level that may result from certian climatic patterns. Figure 25 looks at the effects of a dry climate in the future by comparing an average 10 year rainfall period to 10 years of below average rainfall. The data used in this model run are provided in the table below. The results are discussed in Section 13.2.5

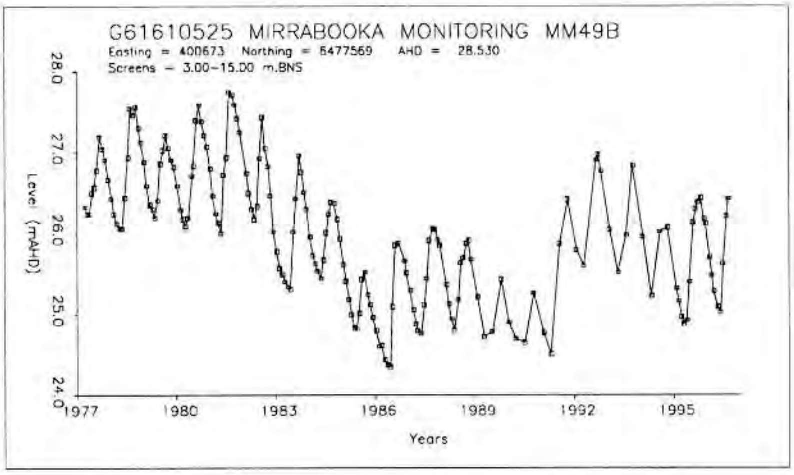
Figure 26 looks at the effects of a wet climate in the future by comparing an average 10 yera rainfall period to 10 years of above average rainfall. The data used in the run are provided in the table and the results are discussed in Section 13.2.5.

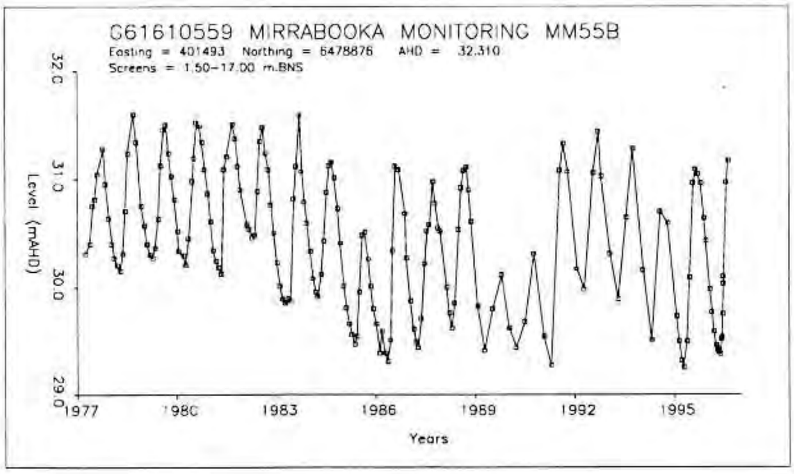
Rainfall Data

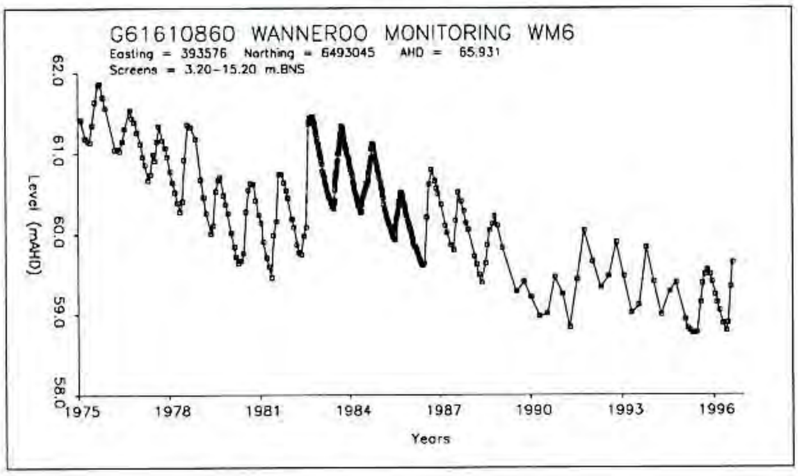
Year	Rainfall (mm)		
	Average Period	Wet Period	Dry Period
1994	800	1130.0	908.5
1995	690	858.5	799.4
1996	807	798.6	611.4
1997	823.5	1250.8	973.8
1998	930.5	930.0	938.1
1999	934.3	1140.6	682.1
2000	688.1	934.4	712.6
2001	907.6	1007.2	607.0
2002	872.5	997.5	922.8
2003	880.0	1001.3	559.6

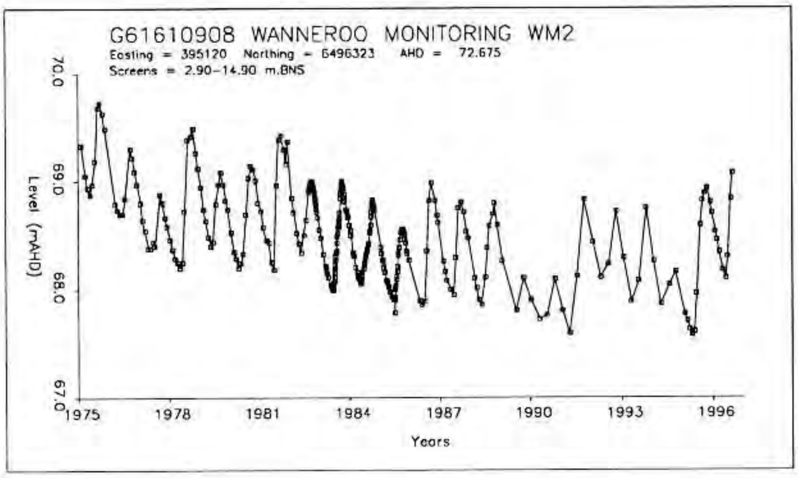
Appendix 7
Hydrographs of monitoring wells in Phreatophytic vegetation

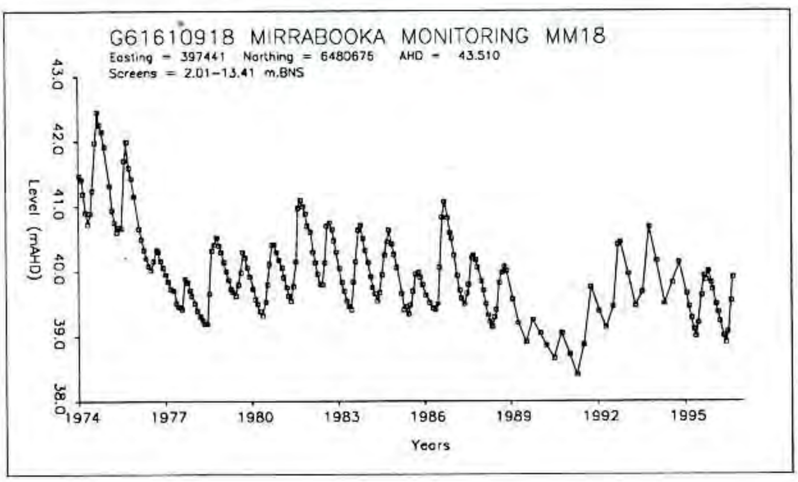


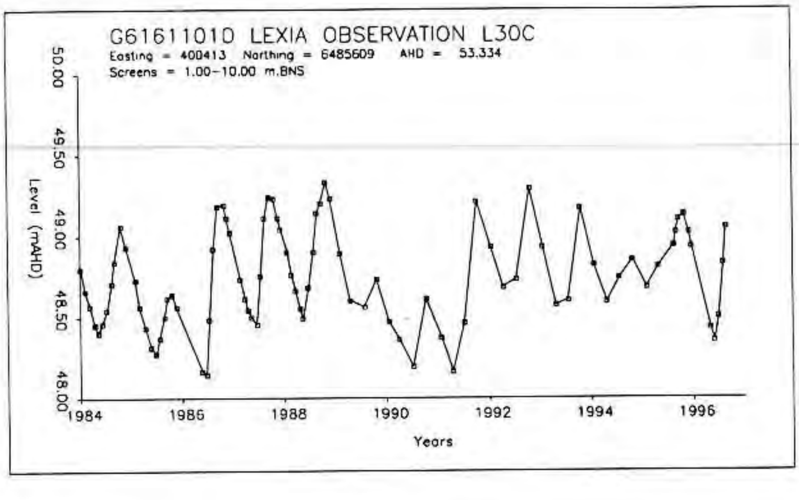


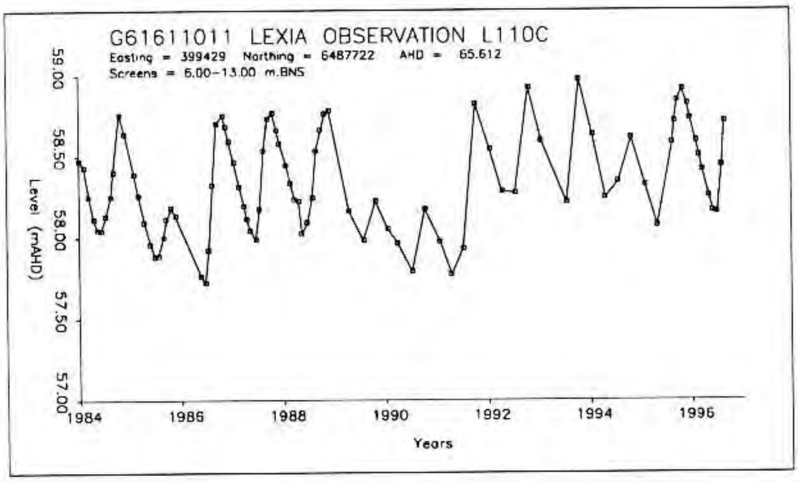


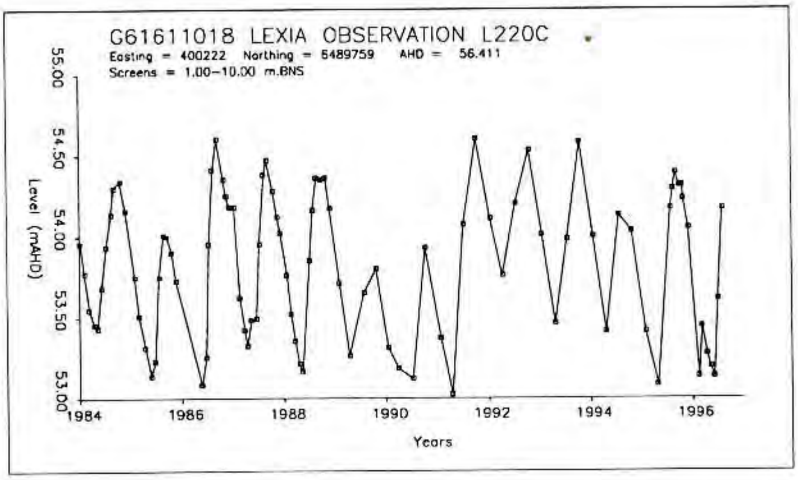

G61610860 WANNEROO MONITORING WM6
Easting = 393576 Northing = 6493045 AHD = 65.931
Screens = 3.20-15.20 m.BNS
Level (mAHD)
Years

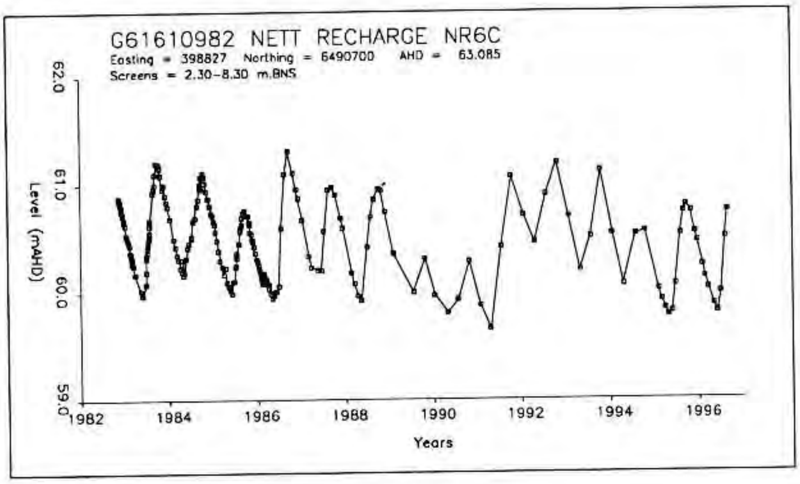

G61610908 WANNEROO MONITORING WM2
Easting = 395120 Northing = 6496323 AHD = 72.675
Screens = 2.90-14.90 m.BNS
Level (mAHD)
Years


G61610918 MIRRABOOKA MONITORING MM18
Easting = 397441 Northing = 6480675 AHD = 43.510
Screens = 2.01-13.41 m.BNS
Level (mAHD)
Years

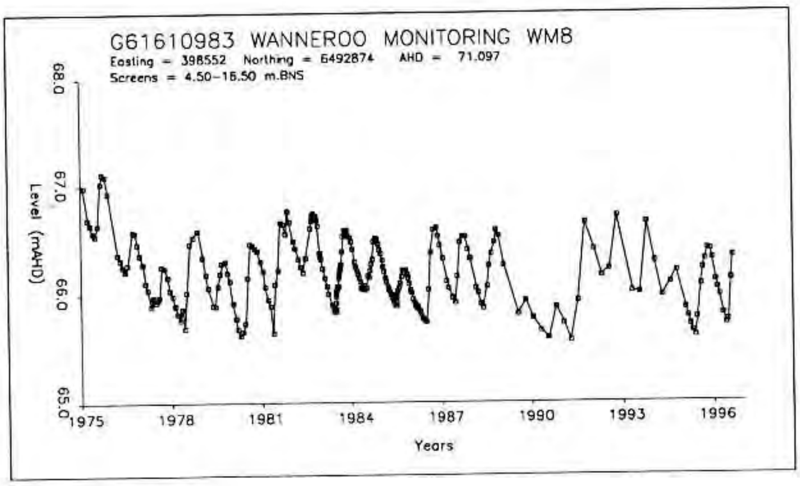

G61611010 LEXIA OBSERVATION L30C
Easting = 400413 Northing = 6485609 AHD = 53.334
Screens = 1.00-10.00 m.BNS
Level (mAHD)
50.00
49.50
49.00
48.50
48.00
1984
1986
1988
1990
1992
1994
1996
Years


G61611011 LEXIA OBSERVATION L110C
Easting = 399429 Northing = 6487722 AHD = 65.612
Screens = 6.00-13.00 m.BNS
Level (mAHD)
59.00
58.50
58.00
57.50
57.00
1984
1986
1988
1990
1992
1994
1996
Years

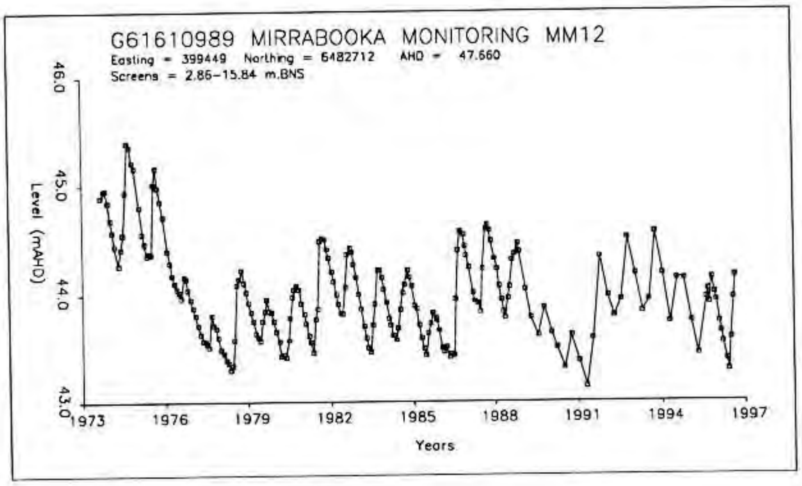

G61611018 LEXIA OBSERVATION L220C
Easting = 400222 Northing = 6489759 AHD = 56.411
Screens = 1.00-10.00 m.BNS
Level (mAHD)
55.00
54.50
54.00
53.50
53.00
1984
1986
1988
1990
1992
1994
1996
Years



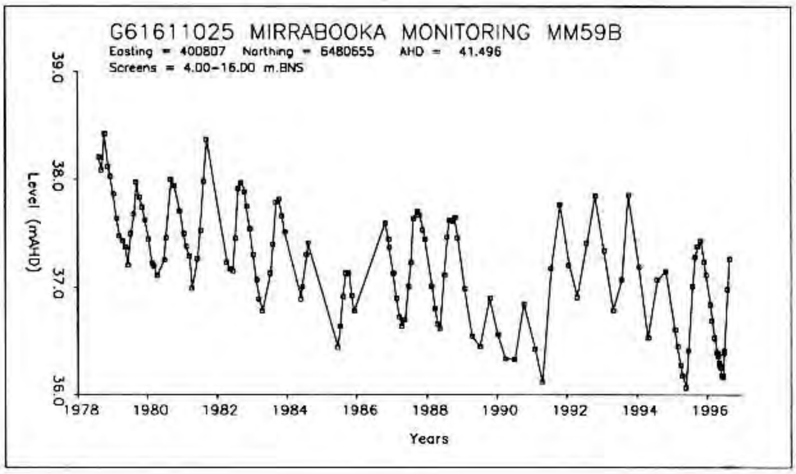
G61610982 NETT RECHARGE NR6C
Easting = 398827 Northing = 6490700 AHD = 63.085
Screens = 2.30-8.30 m.BNS
Level (mAHD)
62.0
61.0
60.0
59.0
1982
1984
1986
1988
1990
1992
1994
1996
Years

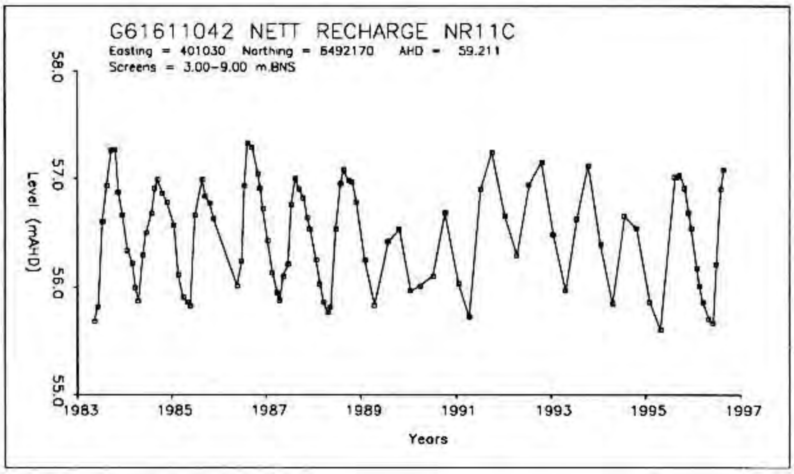


G61610983 WANNEROO MONITORING WM8
Easting = 398552 Northing = 6492874 AHD = 71.097
Screens = 4.50-16.50 m.BNS
Level (mAHD)
68.0
67.0
66.0
65.0
1975
1978
1981
1984
1987
1990
1993
1996
Years



G61610989 MIRRABOOKA MONITORING MM12
Easting = 399449 Northing = 6482712 AHD = 47.660
Screens = 2.86-15.84 m.BNS
Level (mAHD)
46.0
45.0
44.0
43.0
1973
1976
1979
1982
1985
1988
1991
1994
1997
Years


G61611025 MIRRABOOKA MONITORING MM59B
Easting = 400807 Northing = 6480655 AHD = 41.496
Screens = 4.00-16.00 m.BNS
Level (mAHD)
39.0
38.0
37.0
36.0
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
Years


G61611042 NETT RECHARGE NR11C
Easting = 401030 Northing = 6492170 AHD = 59.211
Screens = 3.00-9.00 m.BNS
Level (mAHD)
58.0
57.0
56.0
55.0
1983
1985
1987
1989
1991
1993
1995
1997
Years

Appendix 8
Monitoring results (Spring 1995): EPP wetland 173, Melaleuca Park and Edgecombe seepage

Invertebrate species list

SPECIES	SITE								
	Edgecombe spring	**iron deposit**	**Aux. 1**	**Aux. 2**	**Mel. sw. Baumea**	**Mel. sw. ti-tree**	**Mel. sw. reeds**	**Mel. creek**	**MS total**
CRUSTACEA									0
Cladocera									0
Macrothricidae									0
Ilyocryptus sp.							1		1
Daphniidae									0
Scapholeberis kingi (Sars 1903)			1	1	1		1	1	3
Daphnia ?thomsoni (variab. morph.) bloom			1						0
Chydoridae									0
Alonella clathratula ()			1		1		1		2
Biapertura setigera (Brehm 1931)			1		1	1	1		3
Biaperura rigidicaudis(Smirnov 1971)				1	1	1	1	1	4
Graptoleberis testudinaria (Fischer 1848)					1				1
Monope reticulata (Henry 1922)					1	1	1		3
Rak obtusus (Smirnov and Timms 1983)						1	1		2
? gen. nov. (closest to *Rhynchochydorus*)						1			1
									0
Copepoda									0
Calanoida									0
Calamoecia tasmanica ()				1	1	1	1		3
Cyclopoida									0
Mesocyclops sp1			1	1		1	1	1	3
Paracyclops sp1			1	1	1	1	1	1	4
Paracyclops sp2	1	1							0
Harpacticoida spp	1		1						0
									0
Ostracoda									0
Candona sp1	1								0
Candona sp2		1							0
Darwinula sp	1								0
Ilyodromus sp						1	1		2
									0
Syncarida: Bathenyllacaea sp	1								0
									0
Decapoda									0
Cherax quinquecarinatus			1	1		1	1	1	3
									0

Invertebrate species list (cont.)

SPECIES	SITE								
	Edgecombe spring	iron deposit	Aux. 1	Aux. 2	Mel. sw. Baumea	Mel. sw. ti-tree	Mel. sw. reeds	Mel. creek	MS total
INSECTA: **Diptera**									0
Chironomidae									0
Alotanypus ?dalyupensis								1	1
Chironomus sp.2	1								0
Chironomus sp1			1						0
*Dicrolendipes*sp			1	1					0
Harrisius sp								1	1
Limnophyes pullulus			1		1		1	1	3
Paramerina parva								1	1
Tanytarsus sp								1	1
									0
Tipulididae (larvae) sp	1								0
									0
ACARINA									0
Hydracarina: Pionidae sp1			1			1		1	2
sp2								1	1
Limnohalacarida: *Lobohalacarus* sp.	1	1							0
Oribatida spp	1	1	1					1	1
									0
ROTIFERA spp	1	1							0
									0
OLIGOCHAETA: Naididae									0
*Pristina*sp (new record for Australia)	1	1							0
Pristinella jenkinae (Stephenson 1931)			1	1		1	1		2
									0
TURBELLARIA									0
Macrostomium sp		1							0
Rhabdocoelomate turbellarians sp	1								0
									0
NEMATODA spp	1	1	1	1	1	1	1		3

Water Temperatures in Melaleuca EPP wetland 173 and creek

CREEK: Temperatures measured at 14 .00 hours, 4 November 1995

Air temperature (°C)	Water temperature[1] (°C)	Water temperature[2] (°C)
26.9	27.7	25.4

Water temperature[1]: 4 cm depth, in shade.
Water temperature[2]: in deepest channel.

SWAMP: Temperature measurement commenced 16.20 hours, concluded 17.20 hours. Air temperature 28.8°C

Water depth (cm)	Water temperature (°C)		
	Site 1	Site 2	Site 3
Surface	24.9	25	24.9
10	18.8	22.2	18.8
17			6.7

This temperature gradient could not be fully measured on 4 November 1995 because it was impossible to read the thermometer at depths >17 cm. Consequently, temperature measurements were repeated on 15 November 1995, using a LF 95 WTW Conductivity Meter, with results as follows.

	SITE				
	MSa	MSb	MS 1	MS 2	MS 3
Time of day (hours)	11.00	12.00	14.30	13.30	14.00
Air temperature (°C)	25.3	27.5	25.5	24.6	25
Depth (cm)	**Water temperatures (°C)**				
2			29.5	26.8	26.7
5	21.6	21.7	25.5		23.0
10	21.0	21.0	21.6	19.9	20.0
20	16.9	19.0	17.8	16.8	16.9
30	16.6	17.7	17.0	15.9	16.2
40			15.8	15.4	15.5
50			15.3		15.3
60			14.9		14.9
65	16.1		14.8		14.9

Total Dissolved Solids & Salinity of Melaleuca EPP wetland 173 and creek and Edgecombe Seepage

SALINITY

Results of measurements of samples collected on 4 November 1995

Site	Temperature (°C)	µS/cm
Edgecombe Seepage	12.7 13.8 - 15	195 198
Melaleuca Swamp	13.5 9.5	347 331
Melaleuca, creek	11.5	338

Results of measurements on 15 November 1995 are as follows

	SITES									
	MSa		MSb		MS 1		MS 2		MS 3	
Depth (cm)	mg/L	µS/cm	mg/L	µS/cm	mg/L	µS/cm	mg/L	µS/cm	mg/L	µS/cm
2	263	355					270	358		365
5			252	335	270	351			275	365
10	272	358	255	343	274	355	279	370	278	365
20			257	343	275	369	284	378	282	375
30	275	366	259	343	277	368	285	381	283	379
40					275	369	285	381	284	380
50					275	366			284	380
60	278	370			275	366			284	380
65					276	370			284	380

pH of Melaleuca EPP wetland 173 and creek and Edgecombe Seepage

pH was measured on 4 November 1995

SITE	pH
Edgecombe Seepage	5.71
Melaleuca Swamp	3.80
Melaleuca, creek	3.70

Nutrient Concentrations in Melaleuca EPP wetland 173 and Edgecombe Seepage

Analyte	Unit	SITES		
		Edgecombe seepage	Melaleuca swamp	Melaleuca creek
Chloro_a	mg/L	<0.001	<0.001	<0.001
Chloro_b	mg/L	0.001	0.003	0.001
Chloro_c	mg/L	0.001	0.004	0.001
Phaeoph_a	mg/L	0.001	0.012	0.005
Colour	TCU	8	1200	1200
N_NH_3	mg/L	<0.02	0.09	0.10
N_NO_3	mg/L	2.5	0.06	0.06
N_total	mg/L	3.2	2.4	2.1
P_SR	mg/L	0.02	0.02	0.01
P_total	mg/L	0.02	0.01	0.01