Department of Environment

SECTION 46 REVIEW OF
ENVIRONMENTAL CONDITIONS ON
MANAGEMENT OF THE
GNANGARA AND JANDAKOT MOUNDS

SECTION 46
PROGRESS REPORT

STATE OF THE
GNANGARA MOUND

July 2005

Acknowledgments

This report was prepared by the Resource Management Division of the Department of Environment. The contribution of data, information and draft text by the Department's staff and external consultants is gratefully acknowledged.

For more information contact:

Ron Colman
Water Resources Division

PO Box 6740
Hay Street East
East Perth WA 6892

Telephone (08) 9278 0300
Facsimile (08) 9278 0585

Recommended Reference

The recommended reference for this publication is: Department of Environment 2005, *Section 46 Progress Report—State of the Gnangara Mound,* Department of Environment, Government of Western Australia.

We welcome your feedback
A publication feedback form can be found at the back of this publication.

ISBN 1 921094 02 8

Printed on recycled stock

July 2005

Cover photograph:

Terrestrialisation of Lexia Wetland adjacent to monitoring bore GNM16

Contents

Figures

Tables

Appendices

Executive Summary

This report has been prepared to provide information on progress during 2004–05 with reviewing environmental conditions that apply to management of the groundwater resources of the Gnangara and Jandakot Mounds under the *Environmental Protection Act 1986* (EPA) section 46 review process. The report describes the individual projects proposed as part of the overall review of environmental conditions, to the extent that they have been scoped or completed at this time.

Completed works

- An assessment of the ecological water requirements of groundwater dependent ecosystems.
- An assessment of groundwater–wetland water level relationships.
- Determination of management zones for the Gnangara Mound to assist in developing appropriate local area management strategies.
- Holding of a major stakeholder workshop on the historical water level changes on the Gnangara Mound.
- Identification of areas on the Mounds where the Commission has reasonable potential to manage groundwater levels and consequential environmental outcomes.
- Submission of a Stage 1 review to the EPA seeking to amend or remove the criteria for specific wetlands and terrestrial vegetation sites where a review showed the environmental values no longer exist or do not justify protection under statutory environmental conditions.
- Awarding of tenders for a $6M project (over three years) to install cumulative flowmeters on licensed allocations above 5,000kL/a in selected areas of the Gnangara Mound, commencing with Carabooda and Nowergup subareas of the Wanneroo Groundwater Area.
- Commenced Waterwise on the Farm program in joint venture with Department of Agriculture and Swan Catchment Council, including success in gaining a $300,000 National Landcare Program grant to extend the program by installing field sites in Carabooda and Neerabup to demonstrate water use efficiency.
- An assessment of ecological condition for the ministerial sites under future climate scenarios.

Work in progress

- Modelling of various management scenarios to determine the implications for water level change in the next ten years.
- Investigation of sites identified in groundwater-wetland water level relationships as being anomalous.
- Continuation of metering project to install cumulative flowmeters on licensed allocations above 5,000kL/a in selected areas of the Gnangara Mound, next phase to include Mariginiup and Bullsbrook.
- Continuation of the Waterwise on the Farm program.
- Commencement of the public consultation process with an initial major stakeholder issues scoping study.
- Commencement of a cultural values study to identify those Aboriginal cultural values associated with groundwater dependent features.

- Commencement of an economic values study to identify the economic values of the groundwater resources to the various users, in terms of current and future water usage, economic value of the water usage and marginal costs of alternative sources of water; and
- Commencement of a study to determine the palaeohydrology and palaeoclimate across the Gnangara Mound.

Climate considerations

It is widely acknowledged that around the mid 1970s, there was a shift to consistently drier winter conditions in South West Western Australia, which have continued to this day. Impacts on surface and groundwater resources, on natural ecosystems and agriculture have been observed. The ongoing significant decrease in rainfall experienced since 1998 has had a major impact on recharge and water levels on the Gnangara Mound over that period. This has been reflected in the significant increase in the number of sites breaching minimum water level conditions (up from two in 1996 to 16 in 2005).

However, it should be noted that these non-compliances have not been manifested in wholesale collapses in the groundwater dependent vegetation communities they are representing. Rather, what has been observed is a *terrestrialisation* or shift to a drier climate vegetation complex (ie. Moving from a phreatophytic to xerophytic vegetation community; an example is the Lexia wetland adjacent to monitoring bore GNM16, which is shown on the cover of this report). Therefore, the original environmental values may have changed or even been lost—but they have been replaced by another set of values reflecting the changed environmental conditions.

Simulations of future climate with enhanced greenhouse gases by the Indian Ocean Climate Initiative (IOCI) indicate that a similar pattern of drier conditions for the South West of Western Australia is highly likely. An assessment of the impact on ecological condition for the ministerial condition sites on the Gnangara Mound under future climate scenarios was undertaken to highlight the potential consequences of climate change to groundwater dependent ecosystems on the Mound.

Based on use of the Perth Regional Aquifer Modelling System (PRAMS), two climate scenarios were assessed to determine the implications for water level change in the next ten years. The climate scenarios were based on the last 28 years and last eight years of rainfall respectively. The *business as usual* base case scenario, which was used to assess the two climate scenarios over the period 2005-2015, was developed upon the following assumptions:

- Water Corporation abstraction at 135 GL/yr.
- Private abstraction was maintained at 100% of 2002 licensed allocation levels.
- Climate (rainfall) at the medium term (last 28 years and last eight years)—monthly-based median.
- Pines thinned as per the present Forest Products Commission LVL based plans.
- Banksia annual burning/thinning at 2.5% of the native vegetation area of Gnangara Mound.
- No additional urbanisation of rural land.

The modelling assessment concluded that under the 28 year rainfall scenario significant to severe impacts will occur on parts of the Mound if the current management regime continues ("business as usual" scenario). With the 8 year rainfall scenario, the impacts will be broader and more severe.

Several management scenarios were assessed to determine the outcome with respect to achieving water level recovery. The scenarios were based on the following considerations:

- Reduction in Water Corporation abstraction to 105 GL/yr

- Reduction in private allocation pumping to 80% of 2002 levels.
- Annual burning/thinning of banksia increased to 7.5% of the native vegetation area of the Mound.
- Total immediate clearfell of all pine plantations and retention as managed pasture.

The modelling of these scenarios indicated that localised recovery in water levels could be achieved in response to management changes. However, the extent of water level recovery is very dependent on local conditions and no broad scale (eg. Mound wide) recovery is possible in the short term with climate change proving to be a major factor. In particular, it was concluded that even with greater management under the eight year scenario, the impacts are likely to be widespread and significant.

Future work (2005–06)

The main focus of future work will be the preparation of a draft management plan for the Gnangara Mound. This plan will consider revised allocation limits, including environmental water provisions (EWPs), policies and approaches to amendment of groundwater abstraction as required.

The Department of Environment, via the Gnangara Co-ordinating Committee, will pursue the development of an integrated strategy with other government agencies to better manage the impacts of pine plantations, native vegetation and land use planning decisions on groundwater levels. Through this work, the Department aims to foster whole of Government action for the more effective management of the Gnangara and Jandakot Mounds. The following initiatives will be investigated:

- Managed aquifer recharge (MAR) with recycled water;
- Increased burning frequency of native vegetation; and
- Accelerated and/or concentrated pine felling to reduce impacts on certain groundwater dependent ecosystems or to provide for continued abstraction from public water supply bores.

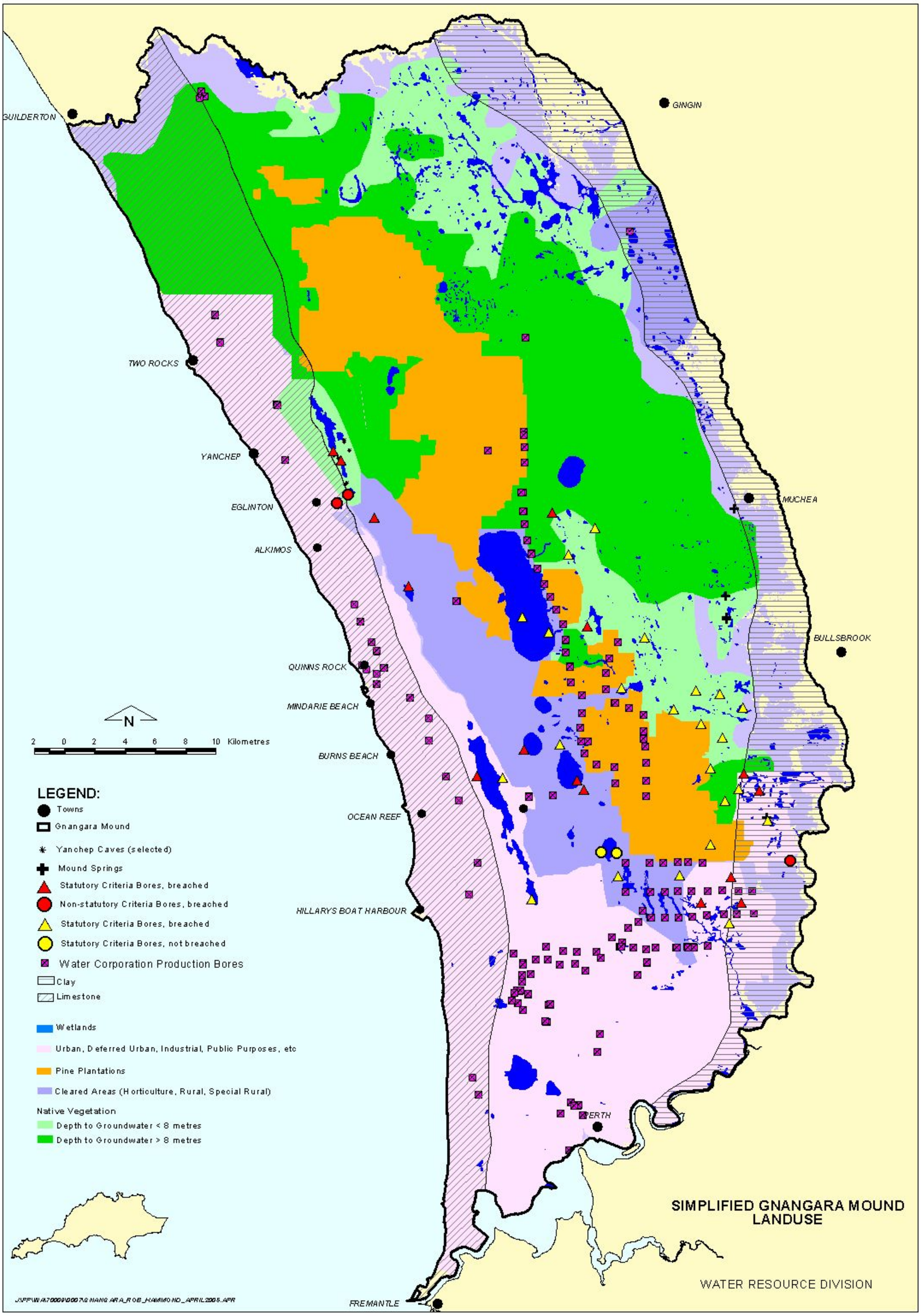


Figure I: Simplified land use for the Gnangara Mound

1 Introduction

1.1 Background

In 1986, the *Environmental Review and Management Program for the Gnangara Mound* was published by the former Water Authority of Western Australia. It was the first major attempt in Australia to consider cumulative impacts on the environment of groundwater abstraction within a large area.

As a result of that report, the Environmental Protection Authority (EPA) set individual water level criteria as Ministerial conditions on the Water Authority in 1988. The criteria were set on the basis of environmental knowledge at the time and were considered by the Water Authority to provide a reasonable level of maintenance of environmental values of key elements of the environment. The criteria took into account planned groundwater abstraction limits for the region, future land use expectations and rainfall variations. Some of the minimum water levels recommended by the EPA were significantly higher than had been experienced under 'natural' conditions.

In 1995, the Water Authority reviewed the Ministerial conditions. The importance of climate as a factor affecting groundwater levels was highlighted and the uncertainty of predicting future groundwater levels. The report also acknowledged that non-compliances with wetland water levels were likely under the climate regime actually experienced, particularly if the anticipated pine thinning and urbanisation of the area did not occur within the expected timings.

The Water Authority maintained that the proposed criteria were a compromise between ecological water requirements and the full wellfield quota and that non-compliances with criteria would occur in up to 30% of years. Measures were put in place to minimise non-compliances, such as reduced abstraction in dry years and artificial maintenance of wetlands.

In recent years, wetland and groundwater levels on the Gnangara and Jandakot Mounds have been under considerable pressure. This has been due to a combination of:

- an extended and ongoing dry climate sequence since the mid 1970s which has been exacerbated by an exceptionally dry period over the last 5–6 years
- pine plantations reaching maturity (and lack of thinning) substantially limiting the net recharge to groundwater
- public and private abstraction reaching previously set management limits.

1.2 Purpose of this Report

In 2001, the Water and Rivers Commission (WRC) requested a review of the existing Ministerial conditions. The Minister for the Environment consequently asked the Environmental Protection Authority (EPA) to "inquire into and advise on changes to the existing Ministerial conditions" under section 46 of the *Environmental Protection Act 1986*. The Water and Rivers Commission then commenced the section 46 review of the environmental conditions set for the Gnangara

Mound, East Gnangara and Jandakot Groundwater Scheme Stage 2 in response to a subsequent request from the EPA.

This report has been prepared to provide information to the EPA on progress during 2004/05 with review of the environmental conditions that apply to management of the groundwater resources of the Gnangara and Jandakot Mounds under the EPA section 46 review process. The report briefly describes the individual projects proposed as part of the overall review of environmental conditions, to the extent that they have been scoped or completed at this time. Focus is then drawn to the current state of the Gnangara Mound and the possible future condition in light of climate change.

2 Section 46 progress

2.1 Background

The Water and Rivers Commission is undertaking a review of the environmental conditions of approval for management of the groundwater resources of the Gnangara and Jandakot mounds under section 46 of the *Environmental Protection Act 1986*.

Wetland and groundwater levels on the Gnangara and Jandakot mounds have been under considerable pressure in recent years due to a combination of:

- an extended and ongoing dry climate sequence since the mid 1970s;
- pine plantations reaching maturity and substantially limiting the net recharge to groundwater Gnangara Mound);
- public and private abstraction reaching previously set management limits; and
- modifications to drainage management and interactions with wetlands (Jandakot Mound).

WRC is managing the groundwater resources of these areas, primarily through controlling abstractions that might affect environmental values associated with groundwater dependent ecosystems over critical areas of the mounds.

Environmental approval of groundwater management proposals by the Commission (and previously the Water Authority of Western Australia) was given, subject to commitments by the proponents and conditions set by the Minister for Environment, for the:

- Gnangara Mound Groundwater Resources (Assessment 697, Statement 438);
- East Gnangara Groundwater Resources (Assessment 932, Statement 496); and
- Jandakot Groundwater Scheme Stage 2 (Assessment 196, Statement 253).

The Water and Rivers Commission is required, as a condition of these environmental approvals, to report annually to the Environmental Protection Authority on performance of the Gnangara Mound and Jandakot Mound groundwater systems and effects on associated environmental values. Detailed reports are required on a triennial basis.

Over recent years, a number of environmental conditions for the two mounds have been consistently transgressed, despite significant efforts to reduce public abstraction in sensitive areas. However, preliminary investigations indicate that in many cases the environmental values identified as the protection objective of these conditions may not have been materially affected.

In 2001, the Water and Rivers Commission requested a review of the existing Ministerial conditions. The Minister for the Environment consequently asked the Environmental Protection Authority (EPA) to "inquire into and advise on changes to the existing Ministerial conditions" under section 46 of the *Environmental Protection Act 1986*. The Water and Rivers Commission then commenced the section 46 review of the environmental conditions set for the Gnangara Mound, East Gnangara and Jandakot Groundwater Scheme Stage 2 in response to a subsequent request from the EPA.

On 13 September 2001, the Environmental Protection Authority (EPA) endorsed a two-stage approach to the section 46 review. Stage I of the review comprised an initial investigation into the critical areas where breaches of environmental conditions have occurred and a proposal for a short-term management strategy for the summers of 2001–02 and 2002–03. Management beyond this timeframe was to be considered under the Stage II review. The EPA endorsed the Stage I review in December 2001.

Stage II is to involve a rigorous investigation and review of environmental criteria, climate variability, long-term groundwater level behaviour, management of public and private abstraction and pine management plus offsetting factors such as urbanisation (including water sensitive urban design) and the Gnangara Park options. This is expected to provide the basis for a comprehensively revised management program for the relevant groundwater resources with respect to their groundwater dependent ecosystems, abstraction, pine clearing and Gnangara Park revegetation.

2.2 Ecological Water Requirements Study

As part of this review, it has been identified that there is a need to employ a specialist consultant to undertake an ecological water requirements study on the Gnangara and Jandakot mounds. This work is required as one of several studies to fulfil the requirements of the section 46 review.

There was a need undertake an ecological water requirement study on the Gnangara and Jandakot Mounds to assist in developing environmental water provisions (EWPs) that took into consideration land use and climate changes. The study needed to consider ecological water requirements (EWRs), environmental criteria, the form of future environmental conditions; and biological monitoring techniques and programs. Work on the S46 review of EWRs on the Gnangara Mound was undertaken by the Centre for Ecosystem Management at ECU and is complete. There were five tasks:

Task 1: Identification and Reevaluation of Ecological Values

Task one is complete and documented in Froend *et al* (2004a). The report reviews ecological values of Gnangara groundwater dependant ecosystems (GDEs) and describes how they have changed since first described—1995 *Section 46 Review (Gnangara)*, 1997 *East Gnangara Environmental Water Provisions Plan*, and 1991 *Public Environmental Review*). Ecological values of GDEs that have not previously been recognised are identified. The report also describes how ecological values may change under a dry climate scenario or other land use changes was considered and areas where there is a high level of degradation risk were identified.

Task 2: Determination of Ecological Water Requirements

This task is complete and documented in Froend *et al* (2004b). The report describes water levels EWRs considered necessary to support the values identified in Task 1.

Task 3: Parameter Identification

Task 3 and 5 were combined and documented in Froend *et al* (2004c). The report describes parameters that reflect the condition of ecological values of Gnangara GDEs. It also reviews the existing monitoring programs within the study areas and providing advice on a revised program.

Task 4: Adoption into a Management Framework

A draft report for task four was received in May 2005—Froend *et al* 2005—which is currently being reviewed by the WRC. The contract involved providing the Commission with a hierarchical response based management framework. The aim is to develop model Ministerial environmental conditions that reflect the ecological values (Task 1), EWRs (Task 2), and monitoring program (Task 3).

A more detailed summary is provided in Appendix 1.

2.3 Groundwater-Wetland Water Level Relationship Study

As part of the review into environmental management on the Gnangara and Jandakot mounds, Rockwater was commissioned to investigate the relationship between monitored wetland and groundwater levels for 28 wetland sites: 18 on the Gnangara Mound and 10 on the Jandakot Mound.

Monitoring results from the wetlands and all monitoring bores within a 500m radius were reviewed. The relationship between wetland and groundwater hydrographs and topographic data were compared and assessed. The results of this were described in a progress report (Rockwater, 2003). In this report only surface water data and data from a criteria bore (or suitable bore) are described, and conclusions provided. These data and results are summarised in Appendix 2.

From the review it is concluded that:

1. The relationship between surface water levels and groundwater levels is complex and no general relationship can be applied to all wetlands in the Perth region.

2. Water levels in wetlands are controlled by a variety of factors such as size, depth, physiographical location, nature and thickness of the sedimentary deposits in the wetlands, nature of the superficial aquifer, groundwater flow to or from underlying Mesozoic aquifers, land use in capture zones, groundwater abstraction, urbanisation, and drainage to and from wetlands.

3. Each wetland has a specific water balance controlled by the relative size of components making up the balance, and the size and depth of the wetland.

4. The wetlands on the Bassendean Dunes and Pinjarra Plain are mainly flow-through systems with an upstream capture zone, and a downstream release zone, which maintains a plume of higher salinity groundwater.

5. The wetlands in karstic areas of the Spearwood Dunes vary from partly to completely dominated by groundwater flow in cave systems.

6. Relatively impermeable biogenic sediments are deposited in wetland basins. The thickness and nature of the sediments may affect the location of inflow and outflow from a wetland.

7. All wetlands on the coastal plain are permanently or seasonally in some degree of hydraulic connection with the regional water table. Perching of groundwater in wetlands probably only occurs for a short period after the onset of heavy rainfall.

8. The situation where water levels in a wetland were apparently identical in level and character was only found at two sites.

9. At many locations there were regular differences between surface and groundwater levels.

10. Without a detailed investigation it is very difficult to locate groundwater monitoring bores which accurately reflect surface water levels in wetlands.

11. The effects of groundwater inflow and outflow from the Superficial formations to the Leederville aquifer is inferred to be contributing to the decline in some water levels on the western side of the Gnangara Mound.

12. A team needs to be assembled to ensure a suitable and reliable monitoring network is established and maintained.

2.4 Gnangara Mound Management Zones

For the purposes of management, the Gnangara Mound has been divided into ten functional zones as shown in Figure 1. The definition of the individual zones has been based on the particular combination of land uses, groundwater dependent ecosystems in the regions and abstraction. These are summarised in Table 1.

2.5 Gnangara Workshop

Following is a summary of the major stakeholder workshop held on 16 November 2004 at the Royal Freshwater Bay Yacht Club. The workshop was held to begin, but certainly not complete, the task of planning for improvement in the management of the Gnangara Groundwater Mound. The full report of the workshop outcomes is presented in Appendix 4.

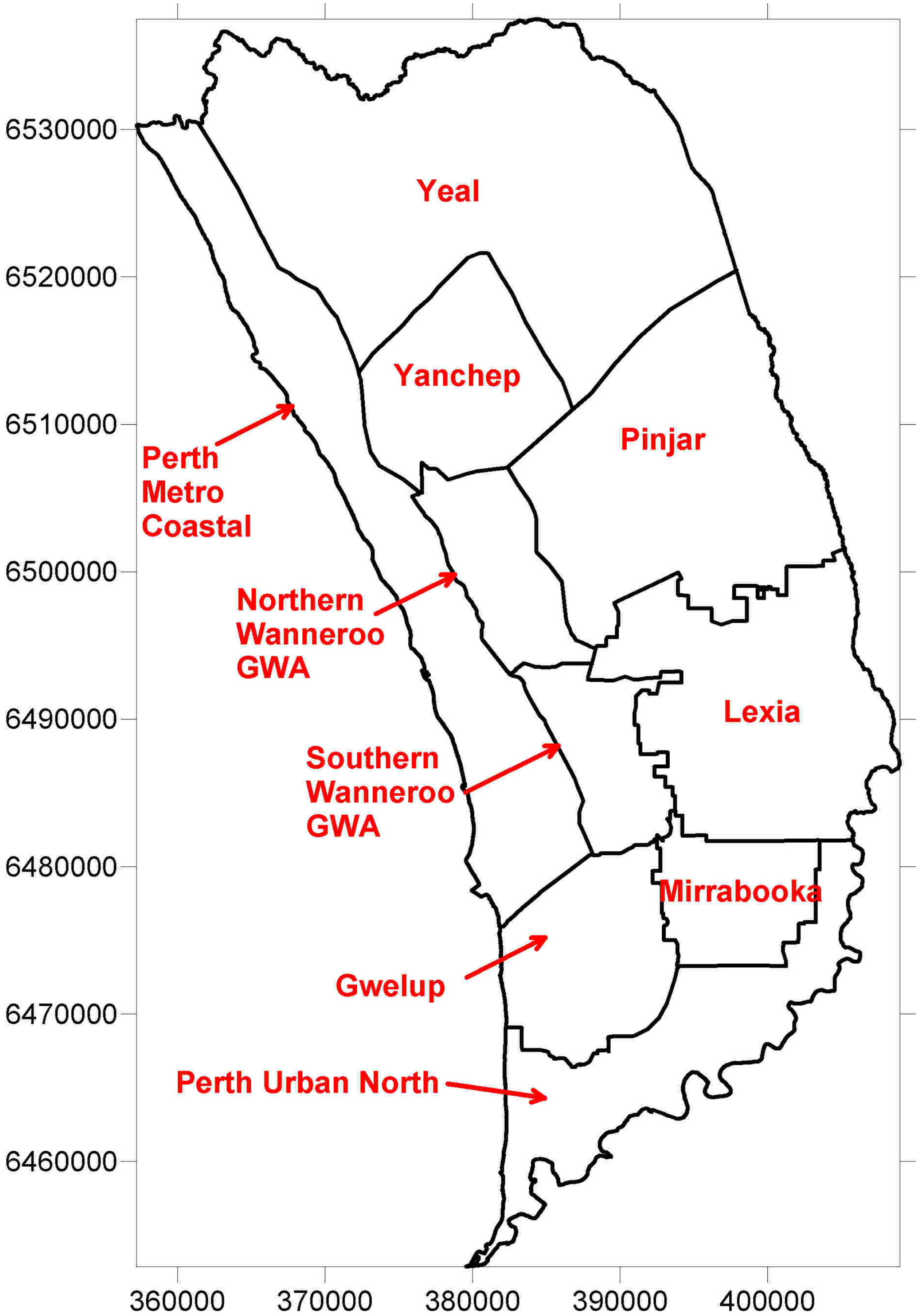


Figure 1: Gnangara Mound Management zones.

Table 1: Gnangara Mound Management Zones and Potential Decline Factors

Area	Land use	Abstraction	Climate	Comments
Yanchep	-1 Native veg density -2 Pine veg density	-1 Private -0.5 Water Corp	-3	Climate effects dominate impacts in terms of landuse impact; near the caves the native vegetation dominates while further to the east pines become more influential.
Wanneroo North	-2 Pine veg density	-3 Private	-1	Highly concentrated private abstraction with pines upgradient.
Wanneroo South	-1 Pine veg density +1 Urbanisation	-3 Private -1 Water Corp	-1	In the east the Water Corp impacts dominate while in the west private abstraction effects dominate.
Yeal	-2 Native veg density -1 Pine veg density	0	-3	Climate impacts appear to dominate with native vegetation in the east and pines in the west producing significant impacts.
Lexia	-1 Native veg density -1 Pine veg density	-2 Water Corp -0.5 Private	-2	
Mirrabooka	-0.5 Pine veg density -0.5 Native veg density +1 Urbanisation	-3 Water Corp	-2	
Gwelup	+1 Urbanisation	-2 Water Corp -2 Private	-1	In the years pre 1990, private abstraction dominated but during the drought years Water Corp abstraction has progressively become the more dominant
Pinjar	-1 Pine veg density -1 Native veg density	-2 Water Corp		Climate is driving the declines in this area but in the west pine impacts are more dominant while in the east native vegetation impacts are significant.
Perth Urban North	+1 Urbanisation	-1 Private	-1	Water levels are artificially maintained by subsurface drainage system.
Perth Coastal	+1 Urbanisation	-1 Private	-1	

Impact Ranking System	
Negative	**Positive**
0 = No impact -1 = Minor -2 = Significant -3 = Major	+1 = Minor +2 = Significant +3 = Major

The objectives of the workshop were:

- For participants to gain a common understanding of what we know about the current state of the Mound, and projected trends in groundwater levels under current patterns of land and water use.
- To hear from the key decision-making agencies about what they see as the key issues in land and water use and management, and the constraints and opportunities for improving the Mound.
- To initiate the development of a range of scenarios for improving the Mound that can be tested, refined and serve as a major input to the planning processes.

The main issues identified are summarised below:

- The Gnangara Groundwater Mound is a vital contributor to the water supply in the Perth Region.
- Groundwater levels are generally falling across the Gnangara Mound.
- The cause of the falling water levels is understood to be significantly reduced rainfall, land use changes and increased groundwater abstraction.
- Some wetlands and groundwater dependent ecosystems (eg. Yanchep Caves) are severely impacted.
- Emerging issues, such as oxidation of Acid Sulphate Soils in the Superficial Aquifer, in response to decreases in groundwater levels, require further investigation understanding.
- Various management practices constrain and/or compromise competing management objectives.
- The Water Corporation has altered and restricted abstraction from its superficial production bores in an attempt to reduce impacts.
- In some areas the groundwater allocation limit has been reached and water trading is occurring within the constraints of acceptable impacts on the environment and other users. There is potential for this to create problems when land use change is occurring to mitigate environmental impacts.
- Increasing reliance is being placed on domestic bores to meet water needs.

Five State agencies (DPI, CALM, FPC, WC, and DoE) have direct responsibilities in managing land and water use in the area delineated as the Gnangara Groundwater Mound (GGM). These five agencies were invited to make presentations to the workshop, addressing the following issues.

- Role and responsibilities in GGM management.
- Current and planned activities in the GGM
- Opportunities and constraints for further intervention

The DoE made presentations on the development of an integrated management strategy, groundwater level history and assessment of groundwater level fluctuations due to climate, abstraction and landuse changes using hydrograph analysis (CDFM) and PRAMS.

The Mound was divided into nine zones and actions, barriers and drivers were workshopped for each of the zones. The zones were Yeal, Pinjar, Yanchep, North Wanneroo, South Wanneroo, Perth Metro Coastal, Lexia, Mirrabooka, and Gwelup. Hydrograph analysis (CDFM) and

PRAMS were used to provide guidance on the relative impact of climate, abstraction and landuse changes on each of the zones.

Plenary discussions throughout the workshop identified the following key findings, observations and conclusions. These considered the state of the Gnangara Mound, the pressures on it, and the required management responses. Additional commentary considered the outstanding uncertainties that need to be addressed through further research and development. Policy and institutional needs were also itemised.

The presentations at the workshop confirmed that groundwater levels are dropping at nearly all locations across the GGM. The context for this decline is the drying climate, which is also affecting wetlands, other GDEs and the distribution of some biodiversity. The physical environment's response to climate change is a series of step-wise processes and it is unlikely to collapse in functionality. However, the community and Government need to understand that change in the biophysical state of the Mound is inevitable. Further, stakeholders need to be aware that the predictions from the modelling are probabilities not certainties.

At the end of the workshop, discussion about the required management responses focused on four themes.

- Deciding what 'we' want for the Mound. This will need engagement of the community in considering options and ultimately decisions to be taken at a whole-of-government level.
- The need for 'informed adaptation' in a dynamic environment. Decisions need to be made now, given existing technical information and understanding of system behaviour, with a capacity to adjust those decisions, as new information becomes available.
- The imperative of changing land and water use. Participants at the workshop recognised that the responsible agencies may need to 'give some ground' in making whole of government decisions that address the overall health of the Mound.
- Implications for resources. Workshop participants also recognised that decisions required will have significant resource implications.

The presentations and discussions at the workshop highlighted the need for a broader, more long-term strategy that coordinates management in deciding the actions that all relevant agencies can take. This strategy also needs to confirm the overall responsibility for managing the Mound, which is an issue that should be discussed by the GCC.

Finally, the presentations and discussions at the workshop have highlighted the urgency of the issues, and the need to take action now, based on current knowledge—we cannot afford to wait for results from more research. The documentation of the issues, the possible scenarios, potential outcomes and needs for change identified in the Report need to promote action.

2.6 Metering Project

To properly manage private abstraction on the Gnangara Mound, particularly the irrigated horticultural component, it has been identified that metering of abstraction would be required. Through a State Water Strategy initiative, the Government (via the Cabinet Sub-Committee on Water) has approved expenditure of $2 Million per annum for three years to enable the Department of Environment to develop and implement a metering program on the Gnangara Mound.

This initiative provides a basis for the department to assess current water use, measure for water use efficiency gains and provide benchmarking for introducing reductions in allocations if required.

The Department will manage the supply, installation, maintenance and reading of meters on private abstraction in key areas of the Gnangara Mound with entitlements between 5,000 and 500,000 kilolitres (kL) per annum. Allocations above 500,000 kL must install meters as a condition of the licensing process.

The first phase of the metering project will cover the Carabooda and Nowergup areas of the Wanneroo Groundwater Area, where intensive horticultural irrigation is concentrated. Subsequent phases will target other areas of the Wanneroo Groundwater Area including Mariginiup and Jandabup plus areas of the Swan Groundwater Area such as Bullsbrook, Ellenbrook and Upper Swan.

There are 131 licenses issued in Carabooda, 100 of which will be effected by the metering project. The total licensed draw for the Carabooda subarea is 8.75 GL from a total area of 18.2 square kilometres. There are 29 licences issued for 5,000 kL or less and two licences issued for draw from the confined aquifers. The Carabooda trial installations have met the requirements of the original project scope and have provided the Department with a sound basis to decide on future needs and adapt future phases to suit those needs.

2.7 Waterwise on the Farm

The Waterwise on the Farm program is being promoted as a component of the $6m project to install meters on private irrigation abstraction in the Wanneroo Groundwater Area. The program is being introduced to educate irrigators in developing better water management practices with a target of achieving a 20% reduction in abstraction through irrigation efficiency gains.

Implementation of the program involves the Department of Environment in a joint venture with the Department of Agriculture and the Swan Catchment Council. It has included success in gaining a $300,000 National Landcare Program grant to extend the program by installing field sites in Carabooda and Neerabup to demonstrate water use efficiency

The connection with the Swan Catchment Council is based on meeting key priority targets within the Swan Region Strategy for natural resource management through improved water use efficiency. This will assist in managing declining water levels in environmentally sensitive areas that are impacting upon biodiversity. Examples are the protection of wetland ecosystems, and internationally significant species such as the stygofauna in the Yanchep Caves and the Western Swamp Tortoise.

2.8 Section 46 Stage 1 Report

In mid 2004, based on elements of the section 46 works and available information sufficient to justify any changes, a *Stage 1* review was submitted to the EPA seeking to change or eliminate the criteria for specific wetlands where a review showed the environmental values no longer exist or do not justify protection under statutory environmental conditions (Department of Environment, 2004c).

This interim review of the environmental conditions applying to Jandakot Groundwater Scheme Stage 2, the Gnangara Mound, and East Gnangara proposed changes to a number of conditions and commitments, and to management criteria that applied to a number of environmental features and values within the subject areas. The review did not address the issue of groundwater allocations and allocation limits as the information required to support an analysis of the relevant issues was still under development. This will be addressed in the next stage of the section 46 review.

There were several aspects to the amendments proposed in the Stage 1 review:

- amendments to specific environmental water level criteria, including removal of some of the sites to which criteria apply;
- removal of conditions and commitments that did not apply to the Department of Environment (formally Water and Rivers Commission), or where there were inconsistencies between conditions and commitments;
- modifications to several conditions and commitments to improve the consistency of approach between the Gnangara and Jandakot Mounds; and
- consolidation of the Gnangara and East Gnangara conditions and commitments

The current conditions and commitments carry a requirement for the Commission to achieve specific groundwater and wetland water level criteria as outcomes of management of the groundwater resources of the Gnangara and Jandakot Mounds. These criteria (environmental water provisions) were intended to reflect the water regimes considered necessary to maintain groundwater dependent ecosystems within the subject areas at an acceptable level of risk. Several of these criteria have been reviewed and have been proposed for amendment, including suspension and removal.

The main amendments to criteria were various combinations of:

- criteria values amended though application of updated information; and
- removal of site because of loss of associated environmental values, low groundwater dependence of existing/remaining terrestrial vegetation or low representativeness of terrestrial vegetation; and
- temporary suspension of criteria pending investigations.

These amendments are set out in summarised form in the table below. It should be noted that the majority of the proposed amendments related to the Jandakot Mound.

Table 2: Summarised amendments to environmental criteria sites

Criteria site	Proposed Amendment
Jandakot	
Forrestdale Lake	Absolute minimum criteria applying to Forrestdale Lake needs to be modified to incorporate groundwater-wetland relationship.
North Lake	Criteria for North Lake needs to be modified to include recognition of wetland-groundwater level relationship as currently established (and as revised from time to time as more data becomes available). Some level of non-compliance with criteria should be expected because of diversion of poor quality drainage water away from wetland as an EPA requirement.
Shirley Balla Swamp	Change to criteria as significance as a bird habitat is limited. Criteria proposed for protection of fringing vegetation and avoidance of potential acidification.
Monitoring well J310	Remove as site not representative of terrestrial vegetation and no rare flora is documented as being present.
Monitoring well JE1B	Removal as criteria site because of current and planned substantial loss of values and associated vegetation has low groundwater dependence.
Monitoring well JE12C	Removal as criteria site because associated vegetation has low groundwater dependence.
Monitoring well JE17C	Criteria modified to provide for low level of risk to terrestrial phreatophytic vegetation, based on updated information.
Monitoring well JE18C	Removal as criteria site because of substantial loss of values.
Monitoring well JE19C	Remove as site not representative of terrestrial vegetation and no rare flora is documented as being present.
Monitoring well JE20C	Removal as criteria site because of substantial loss of values and associated vegetation has low groundwater dependence.
Monitoring well JE23C	Remove as criteria site as native vegetation has been significantly cleared and values lost.
Monitoring well JM5	Remove as criteria location as native vegetation has been significantly cleared, area has been urbanised, and values lost.
Monitoring well JM7	Criteria modified to provide for low level of risk to terrestrial phreatophytic vegetation, based on updated information.
Monitoring well JM8	Criteria modified to provide for low level of risk to terrestrial phreatophytic vegetation, based on updated information.
Monitoring well JM15	Remove as criteria site as native vegetation has been significantly cleared and values lost.
Monitoring well JM18	Remove as criteria site as native vegetation has been significantly cleared and values lost.
Monitoring well JM19	Temporary suspension (to end of 2005) to assess prognosis for site and associated land uses.
Monitoring well JM24	Remove as criteria site as native vegetation has been significantly cleared and values lost.
Monitoring well JM27	Remove as criteria site as native vegetation has been significantly cleared and values lost.
Monitoring well JM29	Remove as criteria site as native vegetation has been significantly cleared and values lost.
Monitoring well JM31	Remove as criteria site as native vegetation has been significantly cleared and values lost.
Monitoring well JM33	Remove as criteria site as native vegetation has been significantly cleared and planned future clearing will result in loss of values.

Criteria site	Proposed Amendment
Monitoring well JM45	Criteria modified to provide for low level of risk to terrestrial phreatophytic vegetation, based on updated information.
Gnangara	
Coogee Springs	Removal as criteria site due to loss of values and scientific review of management options.
Lake Nowergup	Propose modification to criteria to meet modified management objectives including avoidance of acidification.
Monitoring well JB5	Remove as criteria site as native vegetation has been significantly cleared and values lost.
Monitoring well PM6	Removal as criteria site because associated vegetation is not groundwater dependent.
Monitoring well PM7	Removal as criteria site because associated vegetation is not groundwater dependent.

While these changes result in a lower number of criteria monitoring sites, they do not affect the overall structure and approach to groundwater management by the Commission. The reduction in sites effectively requiring protection has largely been a consequence of land use and land management changes effectively removing the values that formed the original objectives for groundwater management. The proposed changes do not affect the level of protection available to the sites that remain.

A key issue that becomes apparent in considering the proposed amendments to criteria sites is the influence of land use changes on the environmental values that provided management objectives for these sites. Through those land use changes (mainly clearing for urban and semi-rural development), the environmental values of a number of sites have been lost. In several of these locations, particularly where water level criteria were not being met, further allocation of groundwater was being restricted in efforts to minimise the extent of non-compliances. This had social and economic consequences for those affected landholders, but it was considered reasonable within the aim of providing an appropriate level of environmental protection through management of groundwater abstractions.

Compromising of the stated management objectives at these sites through decisions by other arms of Government indicates the need for significant improvement in the integration of natural resource planning and management across Government (including local government). An important aspect is defining the role of the EPA in seeking the appropriate management of the pine plantations on the Gnangara Mound through revision of the Gnangara Mound Crown Land Environmental Protection Policy to achieve the stated water management objectives.

2.9 Social Values Study

The DoE has responsibility for developing a management plan for the Gnangara groundwater resources. As one of the initial steps in the determination of social values for the planning process, interviews were conducted with representatives of the many groups and organisations with an interest in the future of the Gnangara groundwater resources. The goal was to acquire an overview of the various views and perspectives of key stakeholders regarding the current and future management of the resources.

The objectives of the interview process were to:

- provide stakeholders with background information on why a groundwater management plan is needed;
- identify stakeholder issues and concerns regarding existing and future uses of the Gnangara groundwater resources;
- identify issues on which consensus exists and those where there are differences.
- access the local knowledge of stakeholders;
- explore how best to involve stakeholders and the public in planning the future of the Gnangara groundwater resources; and
- build working relationships with key stakeholders.

The full report, which is presented in Appendix 4, describes the study methodology and provides an analysis of stakeholder perspectives on the current and future management of the Gnangara groundwater resources.

In total, 76 individuals were interviewed in the period 15 February to 19 April 2005. Collectively, these individuals represented a cross-section of the many private and public sector stakeholders associated with the Gnangara groundwater resources. Interviews were conducted with representatives of community groups, environmental groups, university-based academics, industry groups, agricultural interests, state government agencies, local governments, and ratepayer groups.

2.9.1 Study Conclusions

A number of key messages emerged from the interviews. There was consensus among those interviewed that the Gnangara groundwater resources are under pressure and need to be effectively managed.

The number of competing uses, the high demand for water and the absence of a full understanding of current use were seen as adding to the complexity of sustainable resource management. These factors made both protection of the resource and the allocation of water a challenge for resource managers. Yet, the majority of interviewees were adamant that these factors could not be used as an excuse for inaction.

The DoE's intention to develop a groundwater management plan for the resource was viewed favourably. But the majority of those interviewed believed that such a plan would need to involve multiple government agencies.

A common view was that multiple government agencies had contributed to creating the current problem and as such the solutions would need to draw on the skills and powers of many of the agencies involved in land use planning and water resource management. A whole of government approach was viewed as desirable but many interviewees were aware that inter-agency coordination and political will were key determinants of success or failure.

Concern was expressed that not enough is known about how much groundwater is actually being abstracted by licensed and unlicensed private bores. The new metering program was viewed as a positive step although some complained that the process for installing meters had already taken too long.

There was agreement that groundwater levels were dropping but not all understood that this was happening to varying degrees across the resources. The drop in water levels was largely attributed to over abstraction for public and private supply. The declining annual rainfall levels were viewed by most as only a secondary factor affecting groundwater levels. The pine plantations were viewed by many as a major water user but they were not viewed as a component of the natural environment.

Allocating groundwater among the competing users was viewed as an important but difficult task. Done poorly, it could result in inequitable and negative outcomes for groundwater users. A tension was seen to exist between the desire to conserve ecological values and also meet the needs of other water users (eg. horticulture and public water supply). Under certain conditions, many stakeholders were willing to have other water users take priority over the environment with respect to water allocation.

Several individuals advocated water trading whereby licensed users could sell their excess water to the highest bidder. Many of those who had heard of water trading had limited knowledge of the existing DoE policies related to water trading or cases of water trading that have occurred in WA. The view of some that water entitlement is similar to a property right is inconsistent with state policy, which treats water as a common good. Overall, only a small proportion of interviewees raised water trading as an option. This may in part reflect a lack of awareness of water trading as a concept that is already in use in WA albeit on a small scale.

Thinning or clearing the pine plantations was frequently suggested in the hope that significant gains in recharge could be attained in this manner. However, a few interviewees believed the groundwater gains might not be as great as others were anticipating.

Improved demand management was seen as a means of reducing the pressure on the groundwater resources. More efficient water use, effective water pricing and greater wastewater reuse were the most commonly identified demand management measures. The ideas put forward by interviewees were very similar to those raised by the public during the drafting of the State Water Conservation Strategy.

Many of those outside the horticulture industry believed that significant gains in water use efficiency could be achieved by the industry. Unlicensed private bores were also viewed by some as an inefficient water use. Some perceived current rules for unlicensed private bores as not only inefficient but inequitable when compared with the rules for consumers on the public water supply system.

Wastewater was seen as a valuable but unutilised resource. The potential to recharge aquifers using wastewater was raised by only a small number of interviewees. However, those who advocated its use did not identify any barriers to successful implementation.

Many from within and outside the industry would like to see horticulture have a sustainable future in the Wanneroo area. However, issues of land security and groundwater availability appear to be threatening its long term viability in the Wanneroo area. Some pointed to a land use proposal to establish a new horticulture precinct where one of the pine plantations currently exists as a solution.

While some horticulturalists were somewhat optimistic about the future of horticulture in the area, others had a bleak outlook fearing the industry would eventually be squeezed out. If that occurred some horticulturalists would leave the industry while others might relocate to an area such as Gingin, provided suitable land and water is available which may not be the case. If horticulturalists were forced by government decisions to either retire or relocate, a number of the interviewees expected that the horticulturalists would receive fair compensation in return.

There was broad support for the involvement of key stakeholders and the wider community in planning the future for the Gnangara groundwater resources. The wider community was generally viewed as taking a less active role than that played by key stakeholders in the planning process. The primary role of the community was seen to be that of information receiver with education the community involvement objective. It was important that any information provided to the community be complete, truthful and unbiased. There was a common perception that the community was not aware of the problems facing the groundwater resources, nor had they been given reasons to be concerned about how it will be managed in the future.

The key stakeholders sought higher levels of involvement that extended beyond information and education. Few favoured the creation of more committees, which were characterised as diversionary, ineffective and frustrating for participants. Rather, processes that allowed more voices to be heard in a transparent fashion were advocated (eg. public meetings). It appeared that beyond committees and public meetings, many stakeholders were unaware of the variety of techniques that could be used to meet their public involvement objectives.

2.10 Cultural Values Study

The Department of Environment (DoE) awarded a contract to Estill & Associates in January 2005. The intent of this study is to provide identification of Aboriginal cultural values associated with groundwater dependent water features and sensitivity of these values to water level changes to assist in determining EWPs.

The study should deliver the following outputs:

- Identify and provide an overview (including a map) of groundwater dependent environmental features and ecological processes regarded as culturally and socially important to Aboriginal communities within the study area.
- Describe the Aboriginal cultural values associated with these groundwater dependent features and how those values may be affected by water-level changes.
- Identify appropriate and practical mechanisms for Aboriginal involvement in the development of the Management Plan and ongoing management to ensure the protection of water dependent Aboriginal cultural values.
- Integrate the findings in a report that ensures the outcomes of this study are understood and endorsed by the Aboriginal people involved.

A draft was received in July 2005 and the report is expected to be finalised in August 2005.

2.11 Economic Values Study

The Department of Environment (DoE) let a tender in May 2005 to identify the economic values of the groundwater resources of the Gnangara Mound, in terms of current and future water usage, economic value of the water usage, and marginal costs of alternative sources of water. The call for tenders closed 13 June 2005. The contract will be awarded in August and it is anticipated that the study will be completed by November 2005.

The consultant should deliver the following outputs:

- Identify major groundwater uses and usages in the 10 zones across the region that are based on hydrogeology, dominant user group(s) and management areas.
- Identify the constraints (eg restrictions tied to land and water policies), drivers (eg access to new water sources, trading) and opportunities (eg new markets) to growth for each major user group in consultation with key agencies and stakeholders.
- Provide an estimate of the economic value-added and a derived value for the water used by each user group (current and future).
- Estimate the potential economic impact of a range of water supply restrictions on each main user group. These should relate to the foregone value of production associated with the groundwater supply; financial costs of improved efficiency; financial costs of reductions in water consumption.
- Estimate the potential costs to each user group of alternative water sources (eg purchasing water entitlements from other licensees, accessing alternative water sources).
- Brief evaluation of the regional impacts of reductions in water availability.
- Develop an economic evaluation model to model the economic impacts of a range of water restrictions (eg 10%, 20% and 50%) and water entitlement re-distributions on each water user group.

3 State of the Gnangara Mound

3.1 Background

The primary factor limiting ecosystem production, standing biomass and species diversity of most ecosystems in the South West of Western Australia is water. This is especially the case with groundwater dependant ecosystems on the Gnangara mound. Climate, rainfall, soil moisture, groundwater recharge, abstraction from aquifers, landuse and competition from other species that use groundwater water (eg. pine plantations) all affect the spatial extent, and condition of GDEs. Changes in climate and groundwater levels will also determine how GDEs change and evolve over time.

GDEs include phreatophytic terrestrial vegetation, wetlands, lakes, swamps, sumplands and damplands, aquifer and cave ecosystems, river baseflow systems, terrestrial fauna (species that use groundwater for purposes other than habitat) and estuarine and near-shore marine ecosystems.

It is assumed that GDEs on the Gnangara mound occur in areas where minimum depth to groundwater is less than about 10metres. How GDEs respond to a drying climate depends on the degree of dependency on groundwater. Some GDEs may not respond until a threshold is exceeded after which the change may be severe and catastrophic. Other GDEs may change gradually in structure, composition or health as they adapt to the new water regime.

For any ecosystem, the degree of dependence on groundwater is related to the proportion of its annual water budget that is derived from groundwater. Hatton and Evans, (1998) described five levels of dependence on groundwater:

- **Entirely dependent**. These ecosystems respond rapidly and permanently to changes in groundwater level and may be lost completely in response to any change. An example of these ecosystems is the karst groundwater systems and associated stygofauna found in the Yanchep caves.
- **Highly dependent**. Short-term and moderate changes in groundwater levels may affect health and induce measurable changes in community structure and species composition. Examples included permanent lakes and wetlands associated with the Gnangara groundwater system.
- **Proportional dependence**. These systems have some resilience to changes in groundwater levels but persistent change in groundwater levels will affect health, species composition and structure. Examples include damplands, sumplands and base-flow dependent river systems.
- **Opportunistic dependence**. These are ecosystems that use groundwater to a limited extent such as only during periods of drought or seasonally at the end of the dry season. These ecosystems may not show any obvious response to short-term reductions in depth to groundwater but may respond to moderate to large changes in the longer-term. The Banksia woodlands are an example of this type of dependence.

3.1.1 Terrestrial Vegetation

For this report, a qualitative level of risk to phreatophytic vegetation of groundwater declines was ascribed within the following groundwater depth categories 0-3m, 3-6m, 6-10m and >10m. This is based on the assumption that the risk of adverse response to groundwater declines with deceasing dependency. GDEs in areas of highest water tables (0-3m) are most highly dependent on groundwater and are therefore at greater risk of impact from the same degree of groundwater decline than populations at 3-6m and 6-10m.

3.1.1.1 Ecosystem Structure

Large areas of woodland open Banksia occur across the Gnangara Mound. *Banksia attenuata* (Candle Banksia) and *B. menziesii* (Firewood Banksia) are the dominant trees on the slopes and ridges of the Bassendean dunes, while *B. illicifolia* (Holly Leaf Banksia), *Melaleuca preissiana* (Paperbark) and *Allocasuarina fraseriana* (Sheoak) are more common in the wetter low lying areas between the dunes. The understorey of the woodlands is a diverse community of Myrtaceous shrubs.

On the Spearwood dunes, Jarrah, Marri and Tuart also occur in the Banksia woodlands. On the shallower Spearwood sands overlying limestone the vegetation is a dense shrubland containing a mix of *Dryandra sessilus* (Parrot Bush), *M. huegelii* (Honeymyrtle) with species of Grevillea and Acacia. Wetter areas may be dominated by *Eucalyptus rudis* (Flooded Gum), *B. littoralis* (Swamp Banksia), and paperbarks such as *M. preissiana* and *M. rhaphiophylla*. The Quindalup Dunes to the west support an open shrubland dominated by *E. gomphecphala* (Tuart), *D. sessilus*, and various species of Acacia. In the low moist areas jarrah and marri may also be found.

Groundwater dependent terrestrial vegetation provides habitat and food for fauna such as insects, birds, mammals and reptiles.

3.1.1.2 Groundwater Dependence

The dependence of Banksia woodland on groundwater and its tolerance to groundwater declines is related to the historic proximity of groundwater to the soil surface, the availability of water in the unsaturated zone and plant root depth and morphology. Healthy stands of Banksia woodland have been found in areas where depth to groundwater ranges from 2.5 to 30 m below the ground surface. In areas where the depth to groundwater is >10m, the Banksia woodlands are considered not to be phreatophytic (based on research on B. attenuata and B. menziesii by Froend & Zencich, 2001). Banksia woodland in areas where groundwater is between 0-3 and 3-6m ranges is most dependent on groundwater and intolerant of groundwater decline. Phreatophytic Banksia woodland in the 6-10 m range use proportionately more water from the upper layers of the soil profile (Froend *et al* 2004).

Relatively little is known on the groundwater dependency of terrestrial fauna. Groundwater dependent terrestrial vegetation provides habitat and food for fauna such as insects, birds, mammals and reptiles, which are also therefore groundwater dependent (Sinclair Knight Merz, 2001). Some animals depend on groundwater directly as a source of drinking water and therefore are opportunistically dependent on groundwater. This group is dominated by birds and larger mammals, as respiration supplies many small mammals with their water requirements (Sinclair Knight Merz, 2001). Some species of macropod are known to dig to shallow groundwater while numbers of both native and exotic species have increased as a result of the extensive use of groundwater for livestock watering.

Where *M. preissiana, E. rudis* and/or *B. littoralis* occurred together within an area where groundwater level is within 0-3m of the land surface, the site is generally regarded as a wetland.

3.1.1.3 Response of Phreatophytic Vegetation to Change in Groundwater Level

Phreatophytic vegetation may respond to groundwater decline at three different levels; individual, population or community. At the population level changes in abundance can be described in terms of reduction in canopy cover, loss of mature plants, increase in mortality rates, reduced seedlings establishment and constriction in distribution towards remaining areas of shallower depth to groundwater.

The diversity and composition of phreatophytic terrestrial vegetation, changes in response to prolonged water stress. In severe cases species that cannot tolerate prolonged dry periods may become locally extinct. Therefore the diversity and distribution of relatively intolerant species may be significantly reduced, while the distribution of xerophytic species may increase. With more moderate levels of decline, replacement of mesophytic species with xerophytes will offset any potential reductions in diversity. Weed species that are drought tolerant or have avoidance mechanisms may replace native species.

Primary production in groundwater dependent terrestrial vegetation is disrupted by groundwater decline, as individual plants become water stressed leading to reduced vigor and growth rates. Loss of vigour may in turn lead to reduced nutrient uptake from soils and therefore disrupt nutrient cycles. Food chains may also be disrupted as vegetation structure changes.

There has been a decline in the condition of some phreatophytic vegetation on the Gnangara Mound due to decreased rainfall and declining groundwater levels. Trees adapted to a wetter environment have generally contracted in distribution or are showing declines in vigour since 1990, although this is partly offset by seedling establishment at some sites. The decline in condition of vegetation is most evident in areas on the lower slopes and naturally wetter areas around Lexia and Neaves in Wanneroo. It is concerning that there are indications that species known to be tolerant of dry conditions are now showing signs of water stress.

3.1.2 Wetlands

3.1.2.1 Ecosystem Structure

Permanent and quasi-permanent wetlands are found in low areas with shallow watertables (0-0.5 m below surface) where soils are saturated for at least part of the year. The waterlogging produces characteristic organic soils and vegetation associations. *E. rudis* can usually be found fringing the more permanent wetlands on the Gnangara Mound. Tree species such as *M. preissiana, M. rhaphiophylla* and *B. littoralis* are common around both seasonal and permanent wetlands. The emergent sedges and rushes *Baumea articulata, B. juncea* and *Typha orientalis* are found in the shallow fringes of lakes and wetlands. Wetlands also support a diverse range of fauna including invertebrates, fish and birds.

3.1.2.2 Groundwater Dependence

The superficial aquifers of the Gnangara region are recharged by annual rainfall which means wetland levels vary closely with rainfall and tend to be higher in years of high rainfall and lower during poor rainfall years. Water levels in wetlands also fluctuate seasonally in response to rainfall recharge and groundwater level. The groundwater dependence of wetlands ranges from entirely dependent to highly dependent and proportionally dependent, according to the permanence of the water body. For example permanent lakes are generally entirely dependent on groundwater, while seasonally wet or waterlogged wetlands supporting fringing vegetation communities may be proportionally dependent.

Local groundwater level affects the depth and duration of seasonal flooding in wetlands. A number of components of the water regime influence wetland vegetation including season and frequency of flooding, the interval between flooding, the rate and depth of water level fluctuations (Froend *et al* 2004).

There is a strong relationship between the depth and duration of flooding and the distribution and condition of wetland vegetation (Froend *et al* 2004). The significance of change in groundwater levels, water depth and duration of high water depends on species tolerance of flooding (plant morphology and physiological adaptations to the local environment). For example, large species as a rule tolerate high water for longer than smaller species. Duration of flooding can determine how some species reproduce (sexually or vegetatively). The historic depth and duration of wetland flooding produces the sequential bands of vegetation types that exist around many wetlands with each successive band being less tolerant of inundation.

Emergent wetland plants such as sedges and rushes are adapted to shallower water tables (shallow rooted) and respond rapidly to altered water regimes. How wetland plants respond to water level variations can also depend on the rate of change (Froend *et al* 2004). If depth increases rapidly emergents may be inundated and lost because they are unable to photosynthesize and respire. If water rises gradually plants may be able migrate upslope to more suitable dept ranges. With declining groundwater levels species are either lost from a wetland or migrated into the wetland basin depending on the rate of decline. In a dry period wetland species will be replaced by more xeric (dry adapted) species.

The distribution and composition of perennial wetland shrubs, herbs and ferns are also influenced by water level gradients. These species generally tolerate lower depths and periods of inundation and emergent macrophytes or trees and are often more prominent as fringing species. However, changed water regimes will affect these species in a similar fashion to the emergent macrophytes as they are either lost or migrate to more suitable water levels. Wetland trees are tend to be more tolerant of and respond more slowly to changes in water levels than other wetland plants because of their size, life span and root systems.

Some invertebrate species do not require permanent surface water due to a desiccation resistant life-stage or to a long-lived, non-aquatic adult stage. Invertebrates do require water to complete life cycles and are dependent on emergent wetland vegetation for habitat and food. Some invertebrate and fish species depend on permanent water in all life-stages. Waterbirds rely on wetlands as breeding sites, feeding grounds and drought refuges. Species diversity in some groups, such as frogs, is influenced by recent extremely low water levels, which allow only the more tolerant species to survive. Successful breeding of frogs requires the presence of surface water for a minimum period required for the maturation of tadpoles (approximately 3 months).

Period of inundation is also important for species such as tortoises, which prefer permanent to near permanent water (least six months of the year). For other groups, however, variation in water levels over a number of years has a greater influence on the abundance and presence of species. Waterbirds such as waders may prefer permanent surface water and seasonal variation in depth and shoreline and Winter/Spring inundation of fringing and emergent vegetation to stimulate production of food items such as invertebrates.

3.1.2.3 Wetland Ecosystem Response to Change In Groundwater Levels

The drying of wetlands changes the physical and bio-chemical characteristics of the water column and sediments. Wetlands may display symptoms of eutrophication due to changes in oxygen, redox and sediment absorption capacity. Nutrient levels may increase due to mineralisation of dead aquatic organisms and plants. Acidification may also occur in susceptible wetlands. Due the change in rainfall, high fire risk and drought induced acidification now threaten over half the wetlands of the Gnangara system. There is a high risk of fire in wetlands in the Coogee Springs area, around Lexia and Melaleuca Park and Lake Mariginiup[1]. Acidification due to drying and oxygenation of sediments is a concern at Lake Gnangara, Jandabup, Mariginiup and the Melaleuca Park and Lexia wetlands.

Decreasing groundwater and wetland depth results in the colonisation of the wetland basin by more xerophytic species (more tolerant of drier conditions). Terrestrialisation of wetlands occurs when the water requirements of wetland species are not met and the replacement of mesophytic wetland species with species with lower water requirements and may lead to a reduction in the abundance and areal distribution of wetland vegetation species. Most wetlands in the Gnangara region have suffered declines in the condition of fringing trees and shrubs. Seedlings of tress and shrubs have been colonising in zones previously occupied by water adapted sedges such as *Baumea sp*. The degree of terrestrialisation is greater if drying results in canopy decline and increase invasion by (exotic) weed species due to the improved light environment. Declines in the condition of wetland trees have been observed in Gnangara wetlands since the mid-1990s, however since 1992 there have been marked declines in canopy density at wetlands such as Lake Nowergup and Wilgarup. The potential for weed invasion following decreases in canopy density depends on the proximity of propagule sources (eg. from nearby agricultural land uses) and local site conditions. Rapid and extensive weed growth may prevent native species seedling establishment and increase the risk of fire. Invasive species (such as *T. orientalis*) may dominate wetland vegetation in rare cases.

The process of terrestrialisation is not permanent. Higher water levels in periods of good rainfall initiate a return to wetland species within the basin. It is important that the capacity for recovery in response to wetter periods is not compromised through land use change and abstraction.

Any change in groundwater levels that affects spring peaks, period of inundation and wetland permanence will influence vertebrate ecology. Declining water levels will generally also negatively impact the abundance of vertebrate and invertebrate fauna reliant on wetlands and/or wetland vegetation for habitat, breeding grounds, feeding, or as a direct source of water. Reduced or lost structural diversity and populations of aquatic fauna may occur in response to water level decline. Reduced area of open water in permanent wetlands may reduce available habitat for water birds and macro-invertebrates. Groundwater decline may disrupt life cycles by preventing reproduction and maturation of aquatic invertebrate species.

[1] In the summer of 1995 Lake Mariginiup was severely burnt.

Recent reductions in invertebrate family richness in Lake Joondalup and Melaleuca Park for example have been linked to reduced inundation of littoral vegetation and reduced habitat complexity. In some wetland systems invertebrate richness may vary more between years, as wetlands become increasingly dry and more enriched with available nutrients. This may have led to observed increases in family richness at some Lakes such as Goollelal, Jandabup, Loch McNess and Pipidinny Lake. Increases in diversity and abundance may be indicative of water quality changes as systems dry. Some Lakes such as Coogee Springs, Gnangara, the Lexia wetlands, Mariginiup, Wilgarup and the northern shore of Loch McNess are now completely or partially dry at times of the year when they used to contain water and considerable invertebrate diversity.

3.2 Current Ecological Condition

Based on the considerations outlined in the previous section and Froend *et al* (2004), an assessment of the current ecological condition of the Ministerial sites on the Gnangara Mound was undertaken. The detailed assessment results are presented in Appendix 6 and are summarised in Table 3.

Table 3: Current Ecological Condition (after Froend, *et al.* 2004)

Current Condition			
Impact	**Wetland**	**Terrestrial**	**Total**
Non significant	1	9	10
Moderate	12	10	22
Significant	5	1	6
Severe	0	1	1
Total	18	20	38
% significant or severe	27.78	10.00	18.42

In summary, 28 out of a total of 38 sites have already experienced some degree of impact on the originally stated environmental values upon which the Ministerial conditions were set. However, it should be noted that even at those sites that are non-compliant, there been no wholesale collapses in the groundwater dependent vegetation communities they are representing. Rather, what has been observed is a *terrestrialisation* or shift to a drier climate vegetation complex (ie. moving from a phreatophytic to xerophytic vegetation community; an example is the Lexia wetland adjacent to monitoring bore GNM16 which is shown on the cover of this report).

3.3 Climate Considerations

The annual rainfall in the South West of Western Australia has declined by about 11% since the mid 1970s. Rainfall in the South West is strongly dominated by winter rainfall. The annual rainfall decline has been mostly due to a decrease in autumn and early winter rainfall. There has been little change in rainfall totals in late winter and spring, with a slight increase in summer.

Average rainfall over the Mound for the period 1914 to 2003 is 782 mm. However, depending on the period selected rainfall and subsequent recharge to the Mound has varied significantly as shown in Table 1. The shift to a drier climate state since the mid-1970s represents a decline of 11.0% when compared to the wetter period between 1914 to 1975. When comparing recent years between 1997 and 2003 with the 1976 to 2003 period a 4.1% decline is observed while the rainfall for the 2000 to 2003 period is 5.3% less. This recent decline poses a significant challenge for water planners. Declines in rainfall isohyets for different periods as derived using weighted Silo patch point rainfall data for the area are outlined in Figure 2.

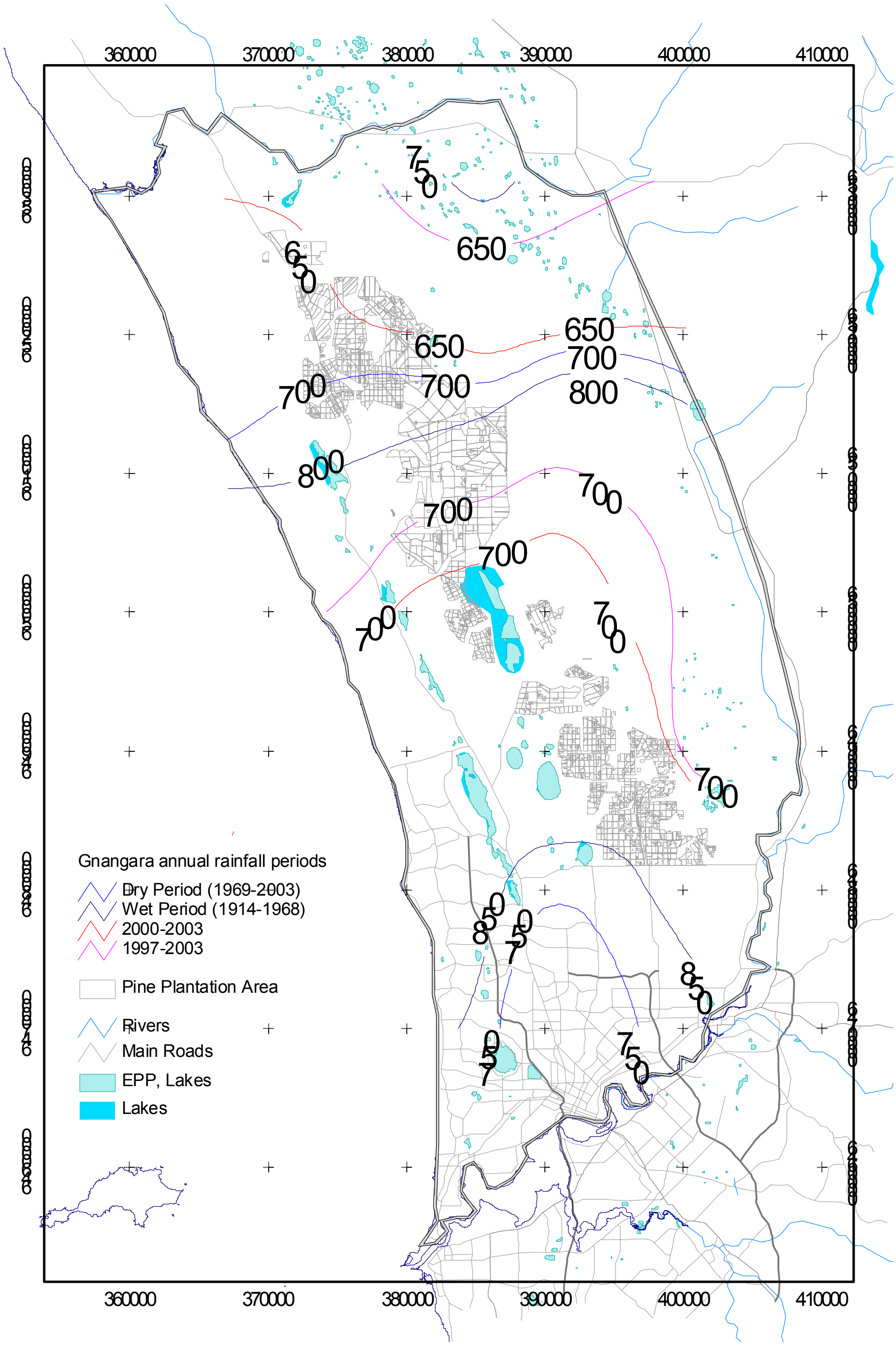


Figure 2: Gnangara rainfall isohyte variation for different periods

Table 4: Average annual rainfall for selected periods

Period	Average annual rainfall (mm) *	Percentage of period 1914–1968
1889–2003	781.4	95.3
1914–2003	781.9	95.3
1914–1968	820.4	100
1914–1975	809.5	98.7
1969–2003	721.4	87.9
1969–1996	725.7	88.5
1976–1996	728.2	88.8
1976–2003	720.7	87.9
1997–2003	698.4	85.1
2000–2003	689.7	84.1

* Annual rainfall derived using weighted averages from the SILO database.

Recent research on synoptic climate features for the South West characterise the decline in rainfall as follows (Hope, 2004):

- ‘Wet’ synoptic types have decreased
- ‘Dry’ types have increased, to a lesser extent
- Rain linked with northerly flow types has decreased
- Increase in rainfall is linked to southerly flow types
- Average South West rainfall links well with ‘wet’ synoptic types.

Mound groundwater levels have declined progressively since the early 1970s as shown in Figure 3 and Figure 4 with the decline most notable over the last six years. The decline reflects a decreased amount of recharge to the Mound and also shows the additive impacts of land management and both public and private water uses. Lack of sufficient groundwater level monitoring data prior to the late 1970s limits the selection of a representative baseline year. The choice of 1979 as the baseline year was carefully selected as being the most representative, considering the limitations of the data (Yesertener, 2002). Although the 1979 groundwater levels reflect the climate in preceding years along with abstraction and land use changes, the relative stability of groundwater levels across the Mound at this time provide a useful reference for subsequent observed groundwater level declines.

The observed changes, which have occurred in various aspects of Western Australian climate in recent decades, are summarised in an IOCI note *Changed Climate in Western Australia: How has our Rainfall Changed? – the South West*, provided in Appendix 7.

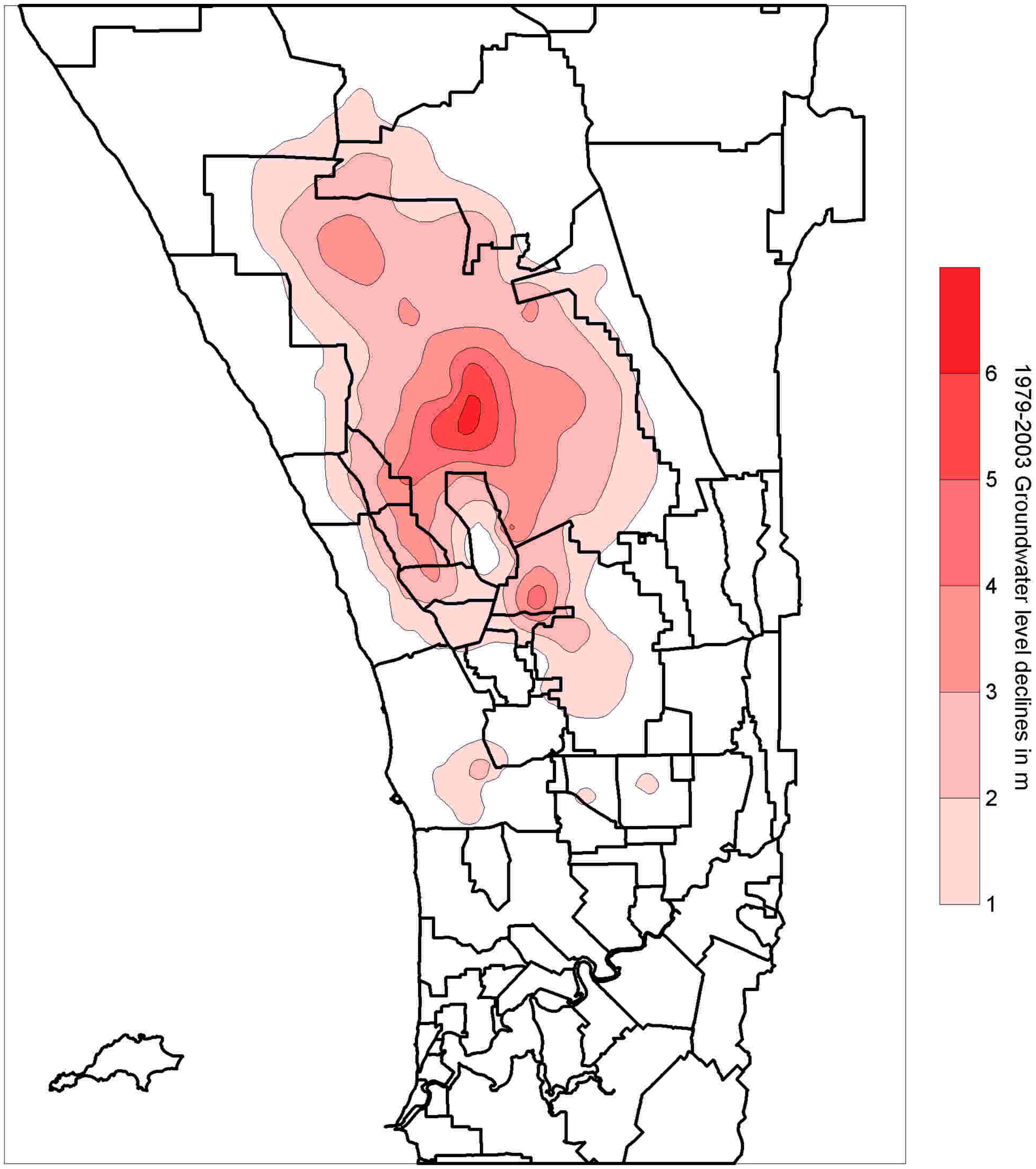


Figure 3: Groundwater level declines from 1979 to 2003

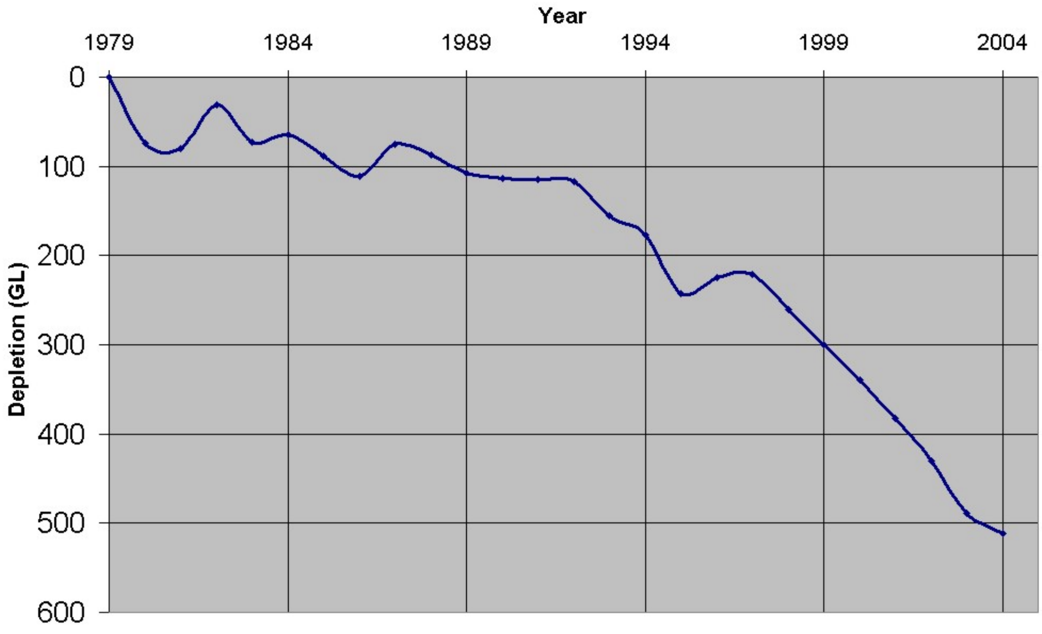


Figure 4: Gnangara Mound superficial aquifer depletion

3.4 Future Ecological Condition

The following section presents an analysis of the future possible ecological condition of criteria wetlands and terrestrial vegetation on the Gnangara Mound that are subject to Ministerial Conditions.

The predicted risk of impact and level of impact to GDEs on the Gnangara groundwater mound, from groundwater change, was calculated using Froend *et al* (2004) method. This method uses 'susceptibility' and 'predicted groundwater level change' to determine the risk and level of possible impact to GDEs.

Susceptibility is the sensitivity of a GDE to any change in groundwater level. GDEs in areas of historically shallow groundwater, like Gnangara GDEs, that are already under stress from recent groundwater declines are most susceptible.

The susceptibility score was calculated as the sum of a conservation score, a current depth to groundwater score (Table 5) and a score based on historic groundwater change (Table 6). Current depths to groundwater for wetlands and terrestrial vegetation were based on phreatophytic categories (0-3m, 3-6m, 6-10m and >10m), with the shallowest depths rated as the most likely to be at risk. Details of these calculations can be found in Froend *et al* (2004).

Table 5: Wetland and terrestrial vegetation depth to groundwater ratings.

Depth to groundwater (2003) category	Rating
>10m	4
6-10m	3
3-6m	2
0-3m	1

Table 6: Historic groundwater level change of wetlands. Any change in areas where level >10m the rating was set to 5. Where there has be no change or an increase, the rating was = 4.

Wetland Category	Low	Moderate	High
0-3m	<0.25m	0.25 to 0.5m	>0.5m
3-6m	<0.75m	0.75-1m	>1m
6-10m	<1.25m	1.25-1.5	>1.5m
Rating	3	2	1

Two modelling scenarios were then used to predict groundwater level changes over a ten year period (2005 – 2015). Groundwater changes were modelled under rainfall predictions based on annual average over the last 28 years (1977 – 2005) and 8 year average (1997 – 2005) given business as usual abstraction given the removal of pines.

Modelling predicted that groundwater will decline generally over the Gnangara Mound at high rates of decline between 2005 to approximately 2008/09 and at a slower rate thereafter as groundwater levels stabilise to 2015 (see Section 4.2 for details). For this analysis however, rate of change was calculated as a linear trend over the 10-year period (that is, rate of change = predicted magnitude/number of yrs). If groundwater was predicted to rise, magnitude was assumed to be zero rather than a rise.

The magnitude and rate of drawdown was then used to determine a 'predicted groundwater level change score' of low (4), moderate (3), high (2) or severe (1) using Figure 5.

Rapid rates of decline over a short period will generally have a more noticeable impact than low-rate, longer-term declines (>20 years), as ecosystem components cannot adapt to changes or migrate to more suitable habitats quickly enough. For example, Banksias respond to drawdown by growing new roots to access deeper water. However, this strategy to adapt morphologically to a drying environment is effective only if water tables changes are gradual and of a relatively small magnitude.

The 'susceptibility to groundwater decline score' added to the 'predicted GWL change score' gives the 'risk of impact'. The 'risk of impact score' is used to categorise the GDE's response into one of four classes of impact. A risk of impact score from 4-6 was rated as a severe response, 7-9 as significant, 10-12 as moderate and 13-15 as not significant. They are 'not significant', 'moderate', 'significant' and 'severe'. Once the level of possible impact was determined, the consequences of that impact on the current condition of the GDE were predicted with help from Appendix-Wetlands or Terrestrial, Froend *et al* (2004), which possible responses to drawdown of key ecosystem elements depending on the severity of the 'risk of impact'.

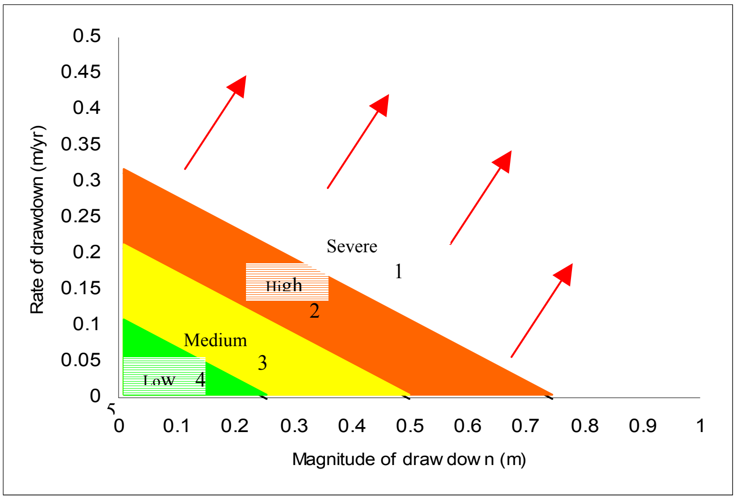


Figure 5: Example of risk of impact categories for wetland ecosystems using rate and magnitude of groundwater decline.

Based on Froend *et al* (2004), the assessment of the future ecological condition of the Ministerial sites on the Gnangara Mound is summarised in Table 7. The detailed assessment results are presented in Appendix 6.

Table 7: Future Ecological Condition Scenarios

	8 Year Climate Trend			**28 Year Climate Trend**		
Risk of Impact	**Wetland**	**Terrestrial**	**Total**	**Wetland**	**terrestrial**	**Total**
Non significant	0	3	3	1	7	8
Moderate	0	5	5	2	8	10
Significant	7	11	18	7	5	12
Severe	10	1	11	7	0	7
Total	17	20	37	17	20	37
% significant or severe	100.00	60.00	78.38	82.35	25.00	51.35

In summary, this assessment has concluded that under the 28 year rainfall scenario significant to severe impacts will occur on parts of the Mound if the current management regime continues (‘business as usual’ scenario). With the eight year rainfall scenario, the impacts will be broader and more severe.

4 Management Considerations

4.1 Background

Change in Gnangara Mound groundwater levels is an attenuated response to variations in the climate regime, upon which abstraction and land use impacts are superimposed. Climate change in the South West of Western Australia has caused a significant decrease in rainfall, which is predicted to continue (IOCI, 2002; Yesertener, 2002). Within this background of declining groundwater levels, factors contributing to breaches of environmental conditions set under section 46 of the *Environmental Protection Act 1986* reflect the combined impact of site specific factors. To better understand the implications of regional climate variability and change, it is desirable to model the range of recorded and likely future water level changes, based on the extent of known and possible future climate regimes. This will enable us to better understand and manage groundwater abstraction and land use from an overall systems perspective.

Currently, the Perth Regional Aquifer Modelling System (PRAMS) model is sufficiently calibrated for assessing the relative benefit of permutations of individual parameters. The model has accurate, reliable water balances and is a powerful tool for looking at the area of influence of an individual parameter, with the result being the water table difference maps. The scenarios used to produce the water table difference maps are being refined and will contribute to the development of future management plans. These scenarios and modelling work are also being used to identify where the present calibration is inadequate and identify where model parameters and relationships need to be refined to improve calibration.

The relative impact of abstraction reduction has been modelled and shows the nature and magnitude of expected recoveries from reduction in licensed self-supply and Water Corporation abstraction. Impacts from Water Corporation abstraction appear to be smaller in aerial extent but much larger in magnitude than licensed self-supply impacts. It is critical that the allocation database contains accurate water use information to improve the calibration of groundwater models and the representation of likely impacts from different management or climate regimes.

Land use changes can be beneficial by increasing recharge, and detrimental by decreasing recharge. Urbanisation is a good local scale outcome for increasing groundwater recharge and thus mitigating water table decline impacts, while increases in pine and native vegetation density can reduce recharge to almost zero. Appropriate management of pine plantations in terms of thinning and clear felling, will provide additional recharge to the Gnangara Mound. The Forest Products Commission (FPC) could attempt to maximise recharge under their pine plantations, while meeting the requirements of the Lumber Veneer Laminate (LVL) state agreement. This analysis may change however, as the model parameters are refined, but that is unlikely.

The burning regime of native vegetation by Department of Conservation and Land Management (CALM) over the last 25 years has reduced recharge, leading to additional water table declines. Unlike pine plantations, which actually have a positive impact on groundwater recharge levels for the first 5-10 years following clearing, native vegetation (banksia woodland) density has increased and hence recharge has dropped substantially.

Groundwater flow modelling indicates the following points.

- Climate is the dominant influence on the superficial aquifer groundwater levels, which are likely to continue to fall, in many parts of the mound, unless annual rainfall increases by 100-200 mm/yr.
- Groundwater flow modelling, using reduced rainfall scenarios is not ideal because at this stage the model input data needs to be generated from the re-working of actual data. The natural variability of rainfall in the Perth Metropolitan Region means that it is unlikely that lower than average rainfall is recorded in all areas of the PRAMS domain in the same year.
- The impact of varied groundwater abstraction can be modelled with a fair degree of certainty. The impact of public water supply abstraction is shown to have a significant impact on groundwater levels but the drawdown is very localised, whereas private abstraction is shown to have the potential to have less drawdown but over a much wider area.
- The available records of private abstraction are not adequate, leading to poor calibration and intractable errors in some parts of the PRAMS domain. There is a need to record actual abstraction as opposed to allocation to improve the present calibration of the model for future predictive modelling.
- The impact of pine plantations on groundwater levels is somewhat localised to the areas directly overlain by pine plantations. Of similar significance to groundwater levels are the far larger areas of native vegetation. Burning frequency in the native vegetation areas may possibly be a major factor affecting groundwater recharge and hence groundwater levels.
- Urbanisation and 'special ruralisation' of exiting rural zones can be a useful way to increase groundwater recharge, reduce abstraction and hence increase groundwater levels. Care must be taken to ensure that the environmental benefits of this land use change are not compromised by the amount of abstraction that occurs in newly created urban but more particularly, special rural zones.

Further studies are required to understand the influence of each model input and component. This work should be undertaken in close cooperation with individual stakeholders to ensure that the scenarios are realistic, relevant and will provide a diverse range able to be utilised in the process to sustainably manage groundwater resources now underway. It is recommended that individual model inputs, such as banksia density, be assessed by the DoE in cooperation with the relevant agencies, to optimise recharge and minimise groundwater level decline impacts.

PRAMS calibration was considered adequate for the scenarios in this report. Further advances in the model to improve calibration are possible but this is dependent on making improvements that include the following actions.

- Allocation database improvements by more accurately determining the relationship between what is allocated and how much is actually abstracted. This is required for the present, with the use of meters, and if possible for the past.
- Specifically designed climate scenarios need to be created. New methodologies for improving the climate scenario inputs are presently being investigated.
- Studies to better determine pine plantation absolute water use and the ability of the pine trees on Gnangara Mound to directly access groundwater.
- Studies to better estimate native vegetation absolute water use.
- Improved calibration of satellite imagery to reduce the error and LAI 'drift' between satellite images. More ground measurements (under story verses canopy and ground base LAI determinations) are required to improve the modelling of LAI based PRAMS land uses.

- The impact of bush wild fires, controlled burns, and native vegetation thinning on groundwater recharge needs to be better understood.
- The impact of an increased native vegetation-burning regime needs to be studied and evaluated from both a groundwater recharge and biological perspective.

4.2 Modelling of Management Scenarios

Based on use of the Perth Regional Aquifer Modelling System (PRAMS), two climate scenarios were assessed to determine the implications for water level change in the next ten years. The climate scenarios were based on the last 28 years and last eight years of rainfall respectively. The *business as usual* base case scenario, which was used to assess the two climate scenarios over the period 2005-2015, was developed upon the following assumptions:

- Water Corporation abstraction at 135 GL/yr.
- Private abstraction was maintained at 100% of 2002 licensed allocation levels (128 GL).
- Climate (rainfall) at the medium term (last 28 years and last eight years) monthly-based median.
- Pines thinned as per the present Forest Products Commission LVL based plans.
- Banksia annual burning/thinning at 2.5% of the native vegetation area of Gnangara Mound.
- No additional urbanisation of rural land.

The modelling assessment concluded that under the 28 year rainfall scenario significant to severe impacts will occur on parts of the Mound if the current management regime continues ('business as usual' scenario). With the eight year rainfall scenario, the impacts will be broader and more severe.

Several management scenarios were assessed to determine the outcome with respect to achieving water level recovery. The scenarios were based on the following considerations:

- Reduction in Water Corporation abstraction to 105 GL/yr
- Reduction in private allocation pumping to 80% of 2002 levels.
- Annual burning/thinning of banksia increased to 7.5% of the native vegetation area of the Mound.
- Total immediate clearfell of all pine plantations and retention as managed pasture.

The modelling of these scenarios indicated that localised recovery in water levels could be achieved in response to management changes. However, the extent of water level recovery is very dependent on local conditions and no broad scale (eg. mound wide) recovery is possible in the short term with climate change proving to be a major factor. In particular, it was concluded that even with greater management under the eight year scenario, the impacts are likely to be widespread and significant.

The sites for hydrograph analysis have been selected from the well-calibrated bores in PRAMS (Perth Regional Aquifer Modelling System), screened in the upper part of the Superficial Aquifer, distributed across Gnangara Mound. The use of the section 46 (S46) criteria bores for this hydrograph analysis was considered but rejected due to the following:

- The criteria bores are not very well calibrated. This is due to their proximity to surface water bodies/wetlands, which are not incorporated into PRAMS in enough detail to sufficiently model the nuances of surface water/groundwater interaction. In fact this could never be possible in a model the size and scale of PRAMS. If we had used the S46 criteria bores it could have given some very misleading results.
- The impact of local 'perching', water retaining or flow retarding layers often present in Superficial Aquifer in the vicinity of wetlands need to be investigated. These layers are definitely present but the distribution of them is unclear. These hydrogeologically pertinent layers need to be incorporated prior to using PRAMS for this type of very detailed predictive analysis (hydrograph analysis).

The impact of these scenarios, at the following locations (Figure 6), are presented in Figures 7–23 with the observed and predictive hydrographs included on the one plot.

Table 8: Bore Locations

NAME	ZONE	EASTING	NORTHING
MM26	50	399487	6479758
MM59B	50	400957	6480757
GA7	50	372241	6516584
GA8	50	377814	6516460
GA9	50	384084	6516569
GA14	50	378464	6519488
JP9	50	386859	6490629
JP19	50	378159	6502989
PM29	50	379620	6504614
PM4	50	390409	6506351
PM12	50	390545	6499600
WM32	50	397880	6489254
YN8	50	376244	6506452
WM28	50	388914	6484322
GB15	50	377757	6527956
GC9	50	392240	6521849
NR10c	50	399099	6494279

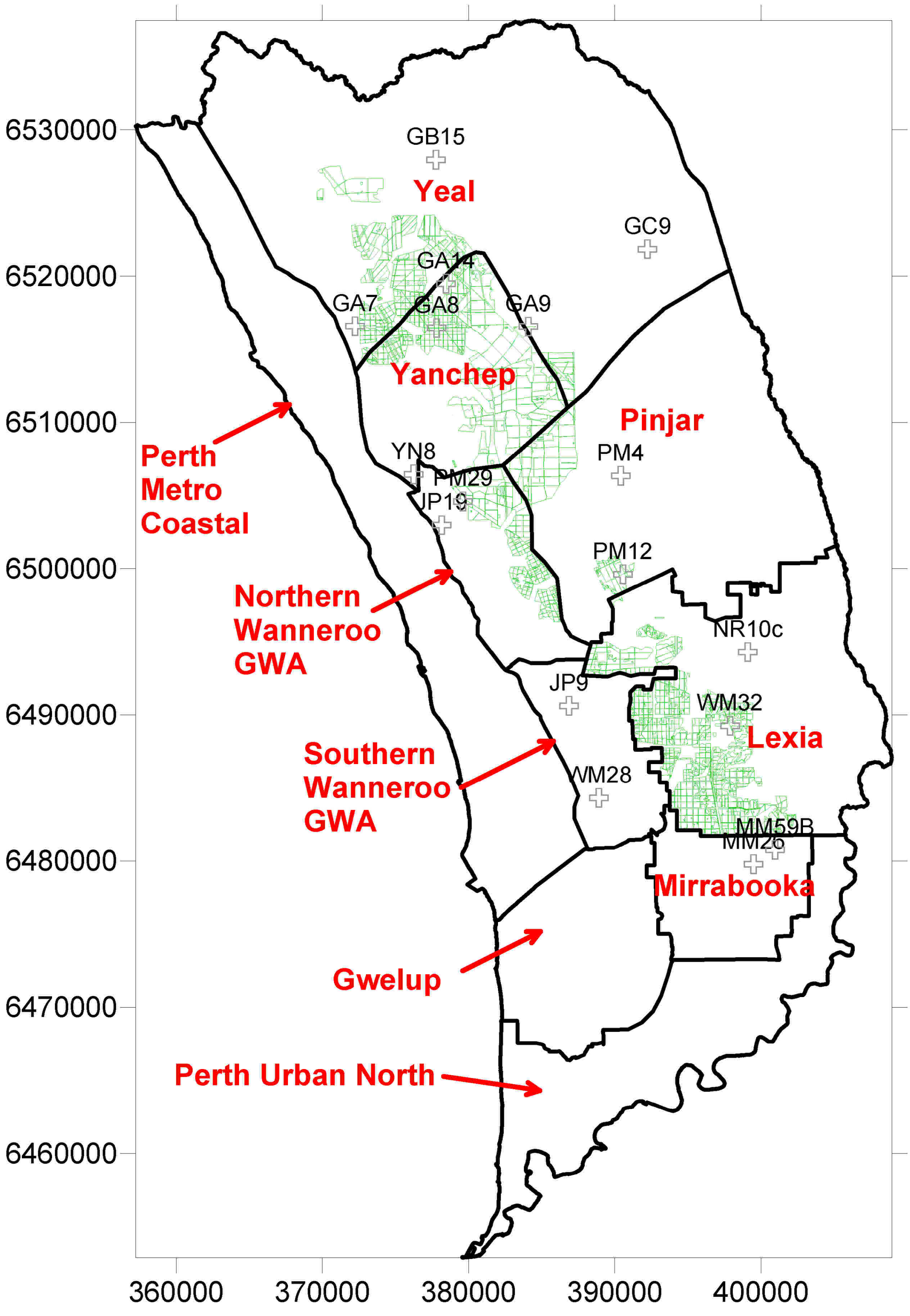


Figure 6: Gnangara Mound Predictive Hydrograph Locations

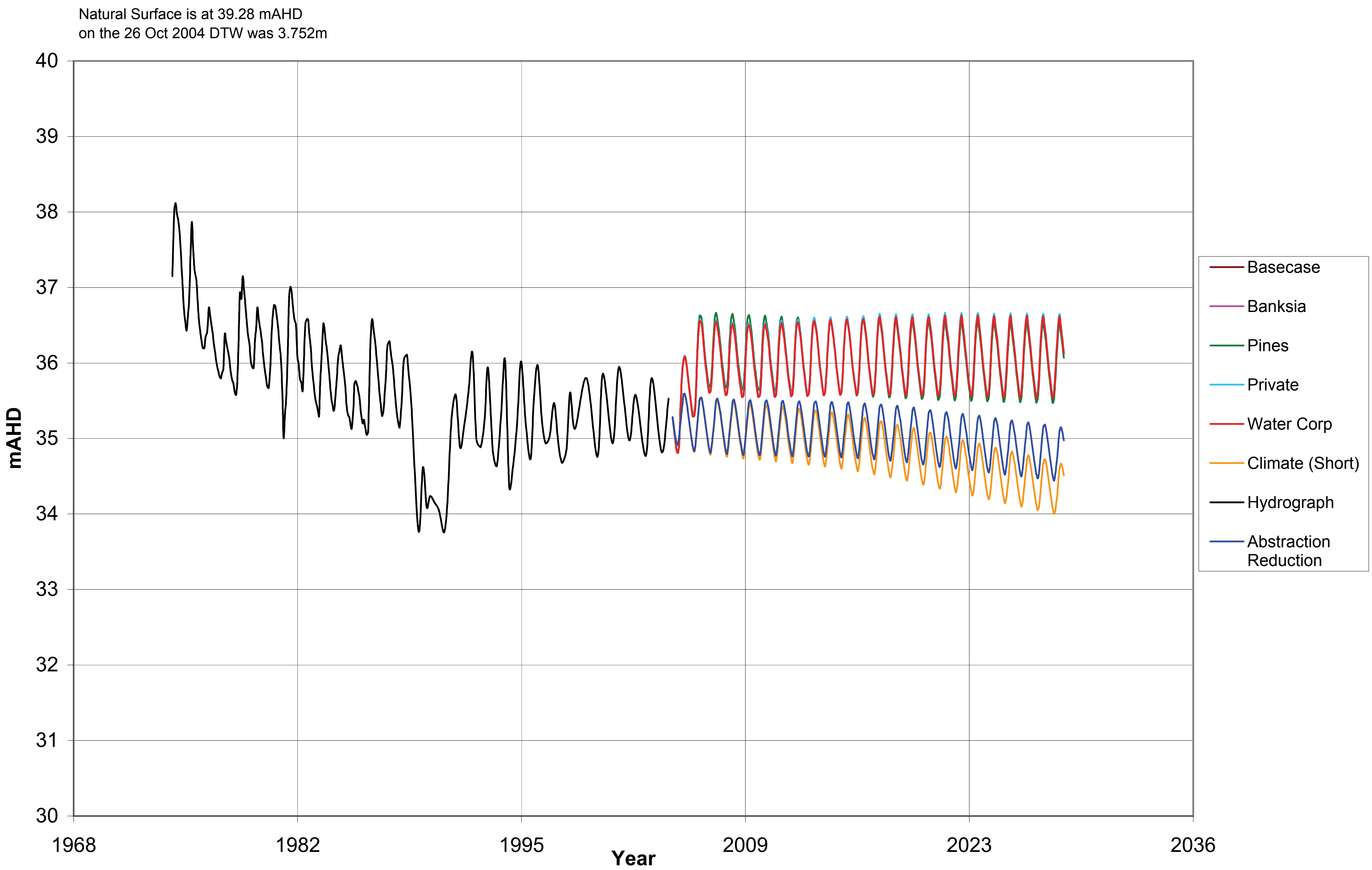


Figure 7: Observed and Predictive Hydrograph MM26

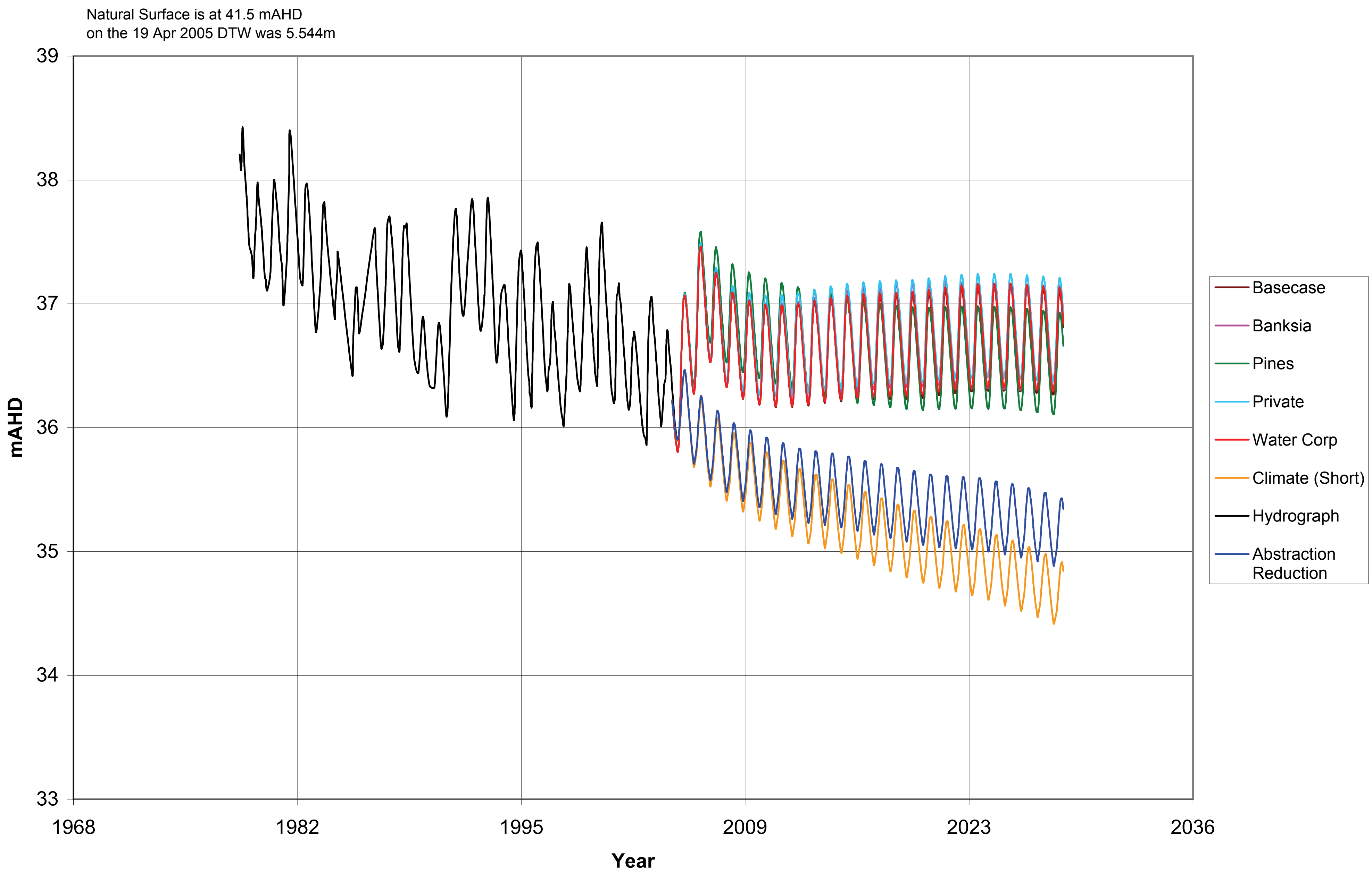


Figure 8: Observed and Predictive Hydrograph MM59B

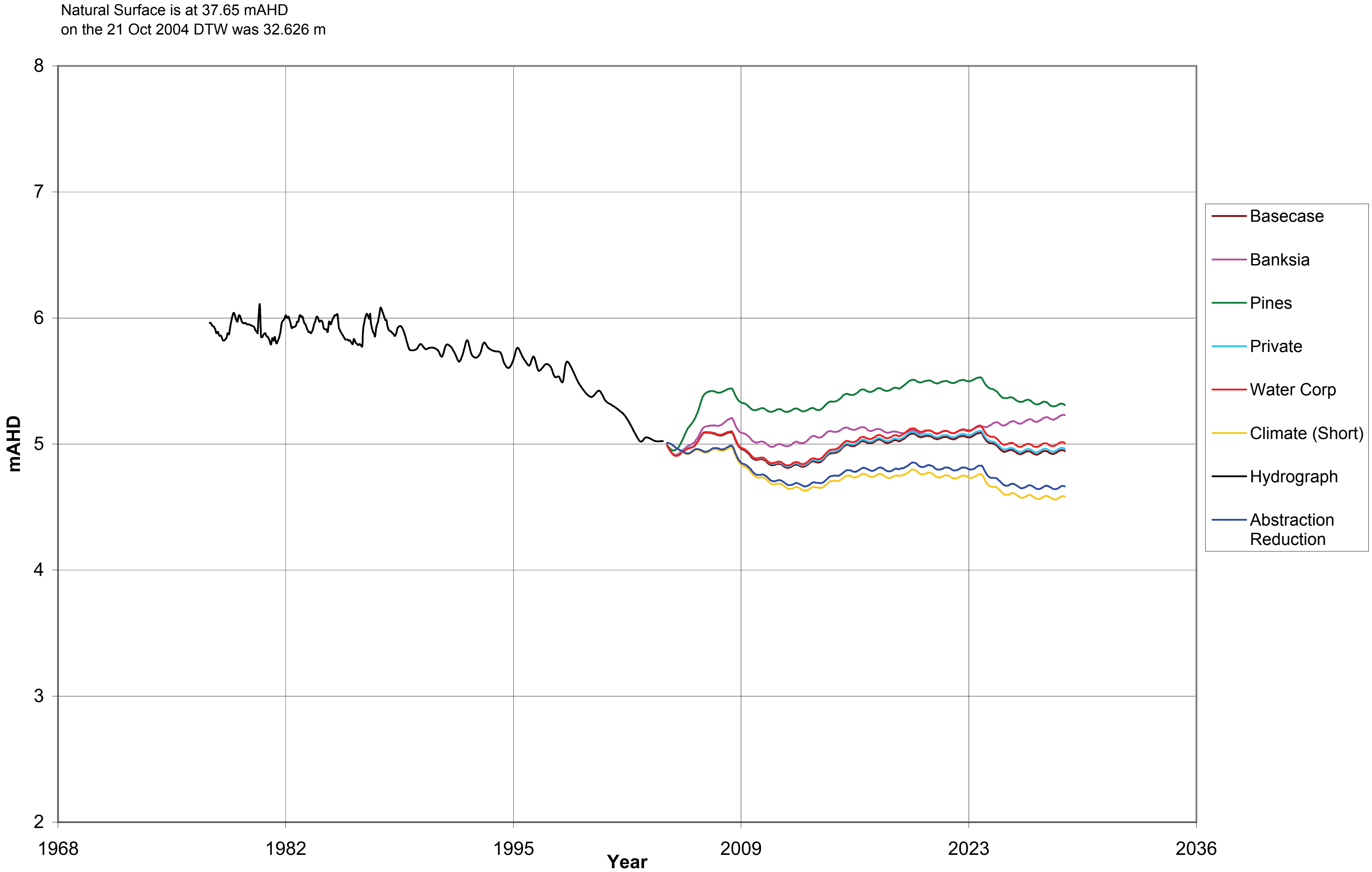


Figure 9: Observed and Predictive Hydrograph GA7

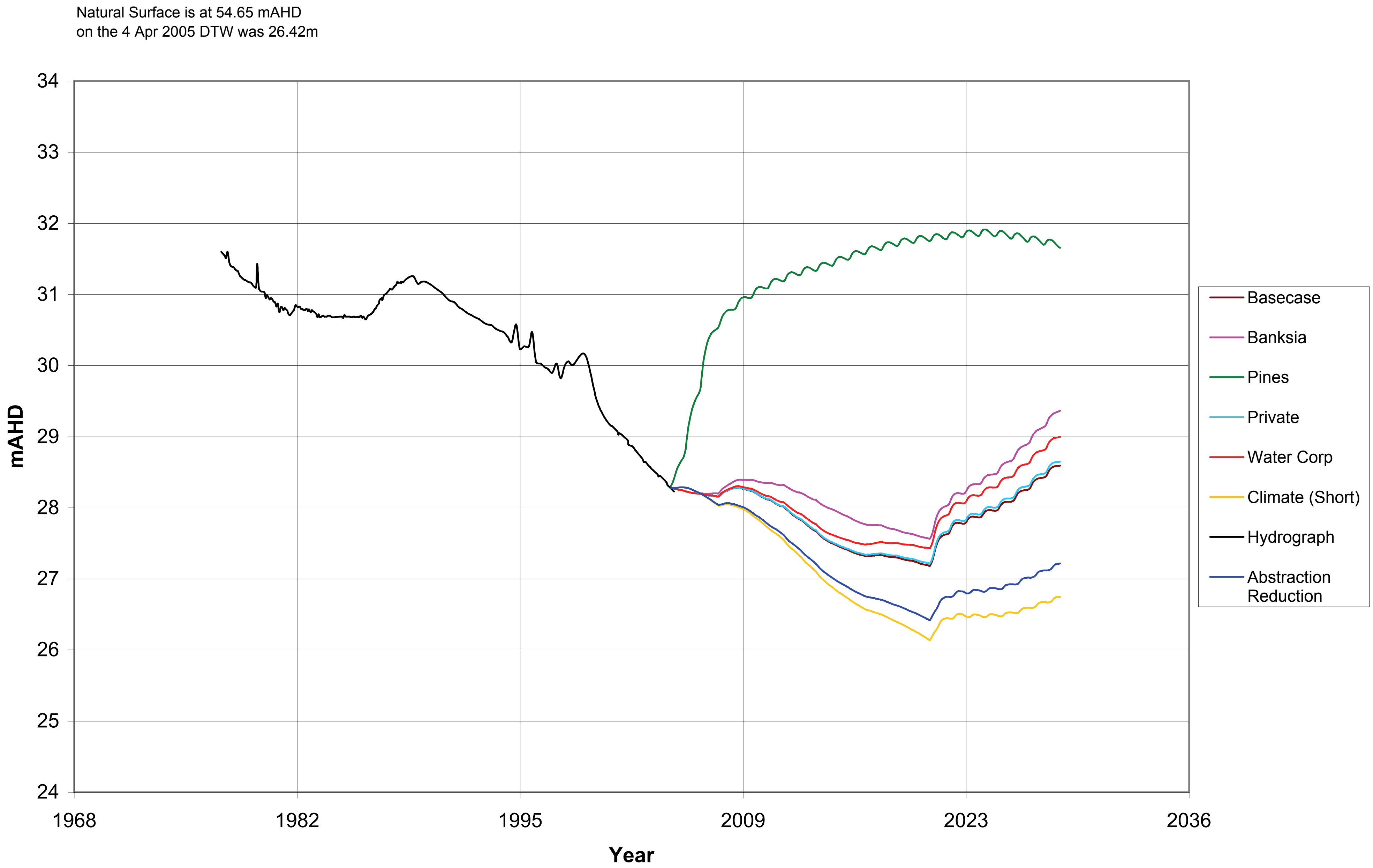


Figure 10: Observed and Predictive Hydrograph GA8

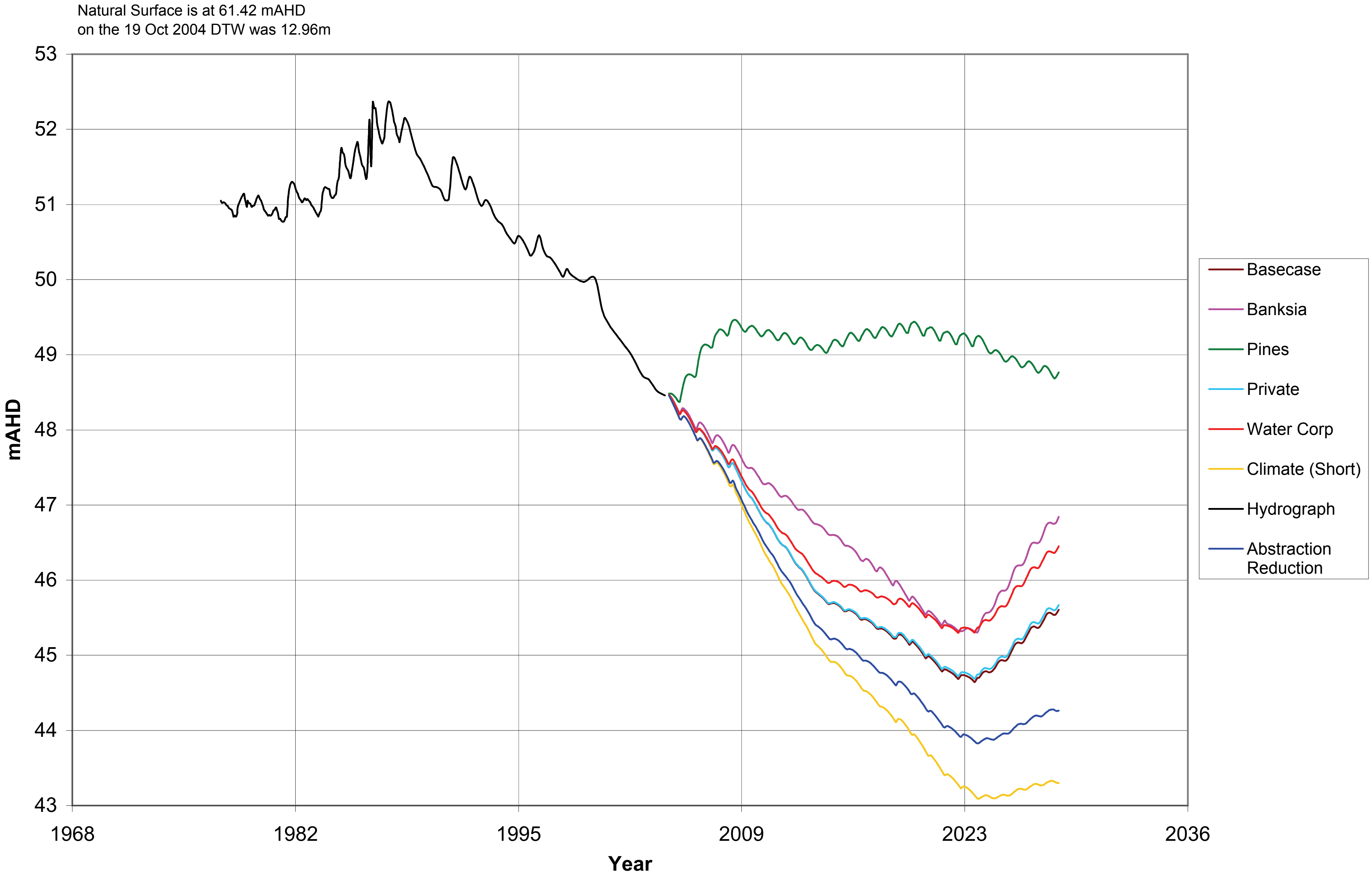


Figure 11: Observed and Predictive Hydrograph GA9

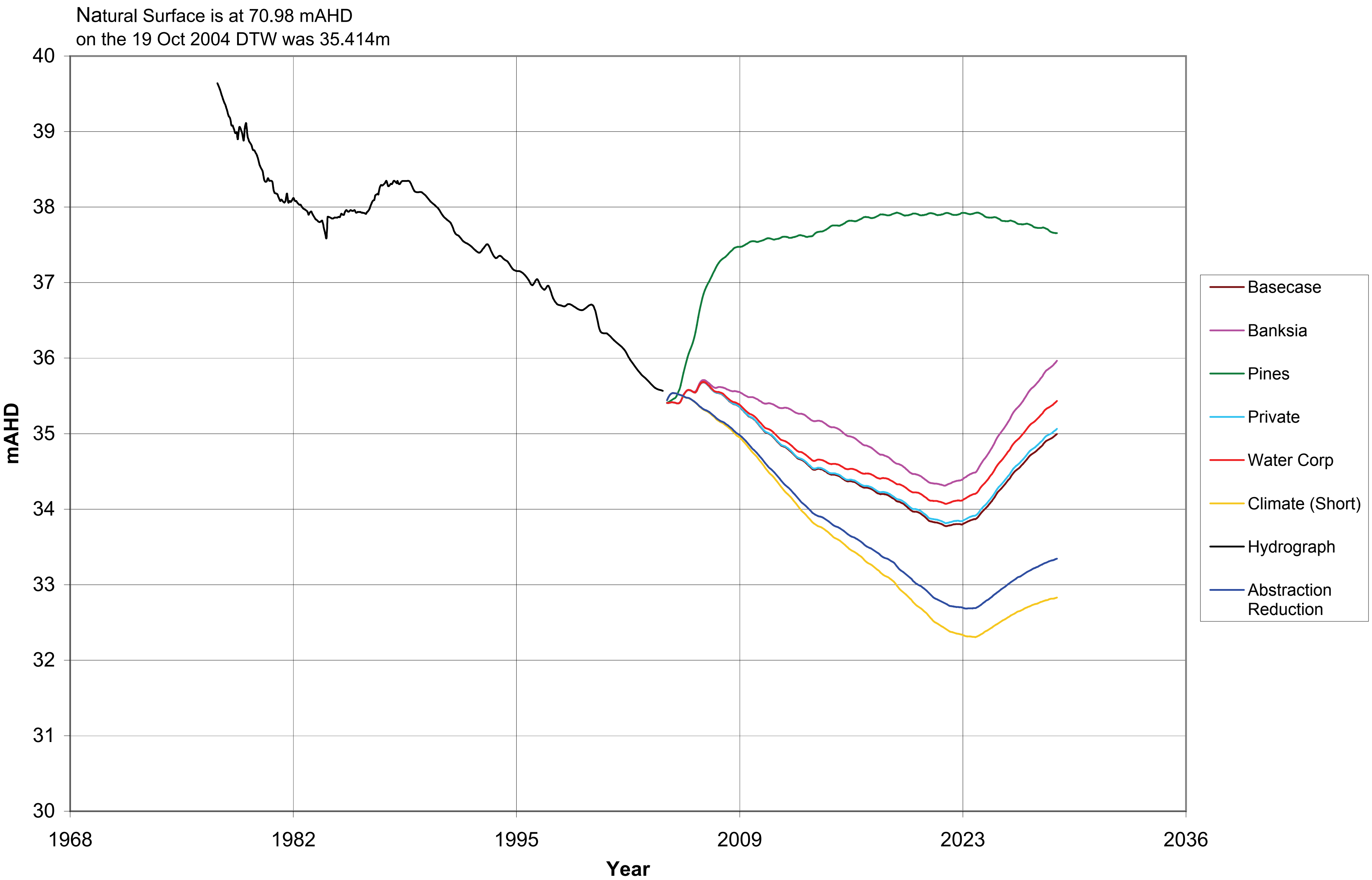


Figure 12: Observed and Predictive Hydrograph GA14

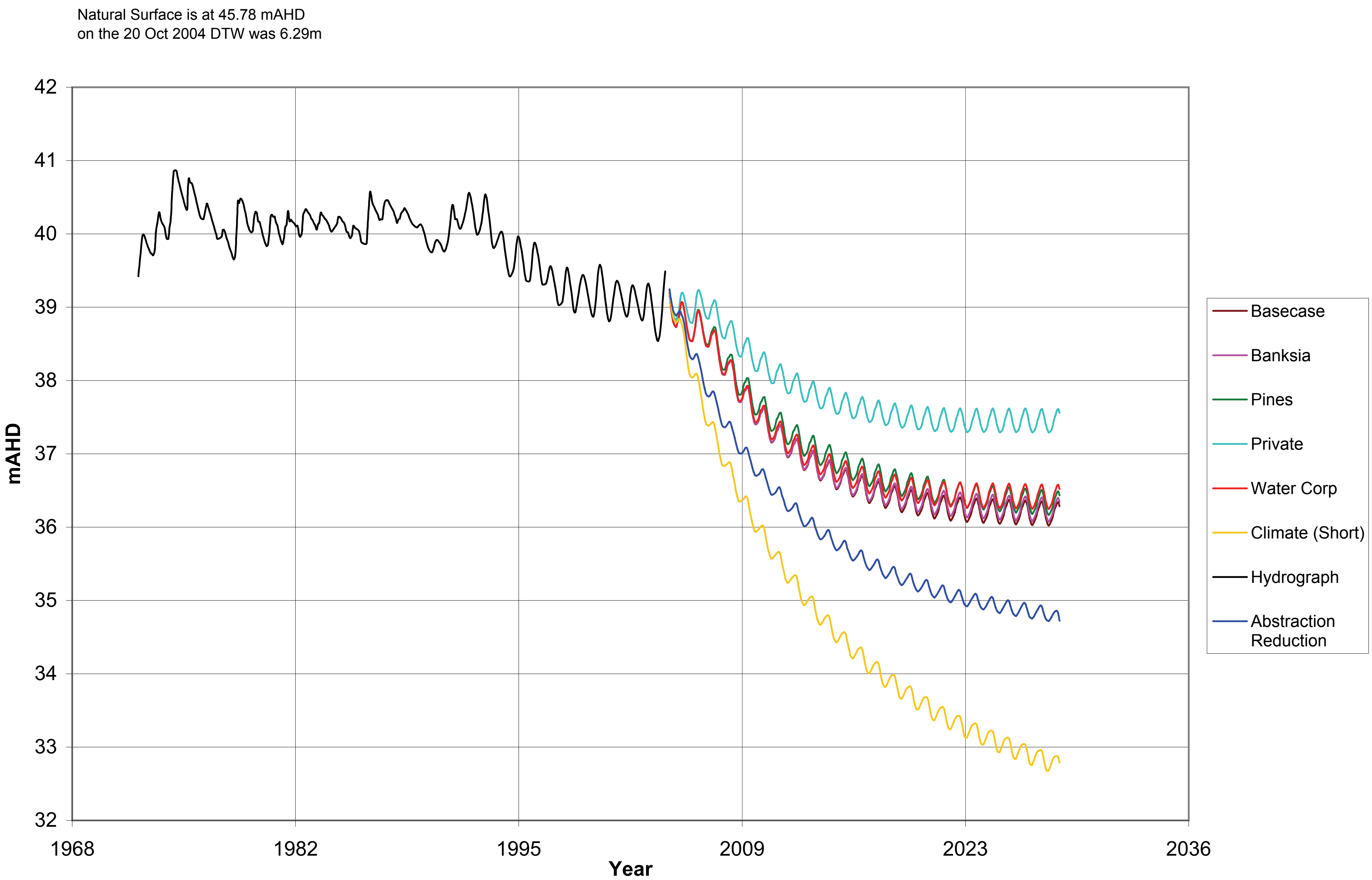


Figure 13: Observed and Predictive Hydrograph JP9

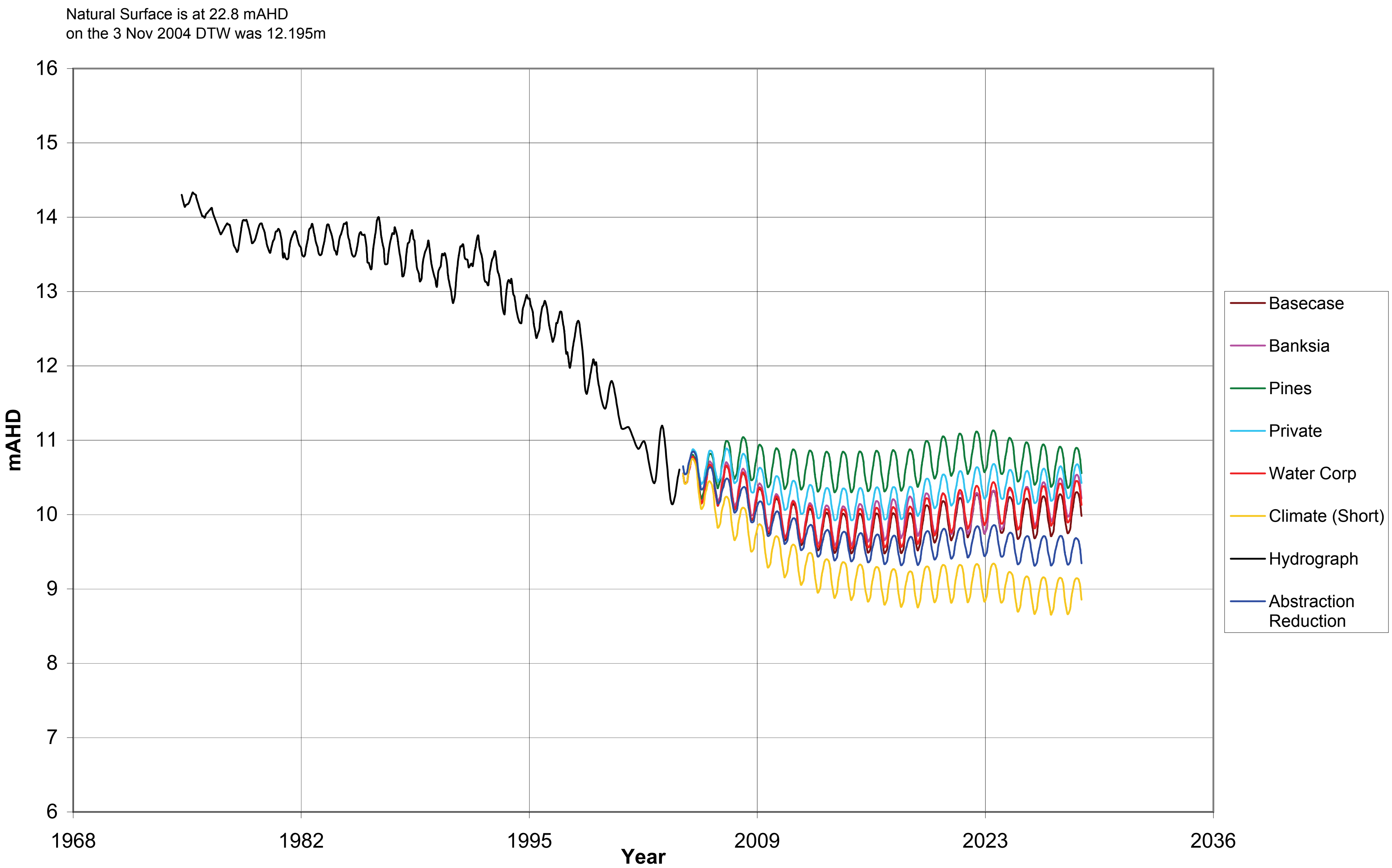


Figure 14: Observed and Predictive Hydrograph JP19

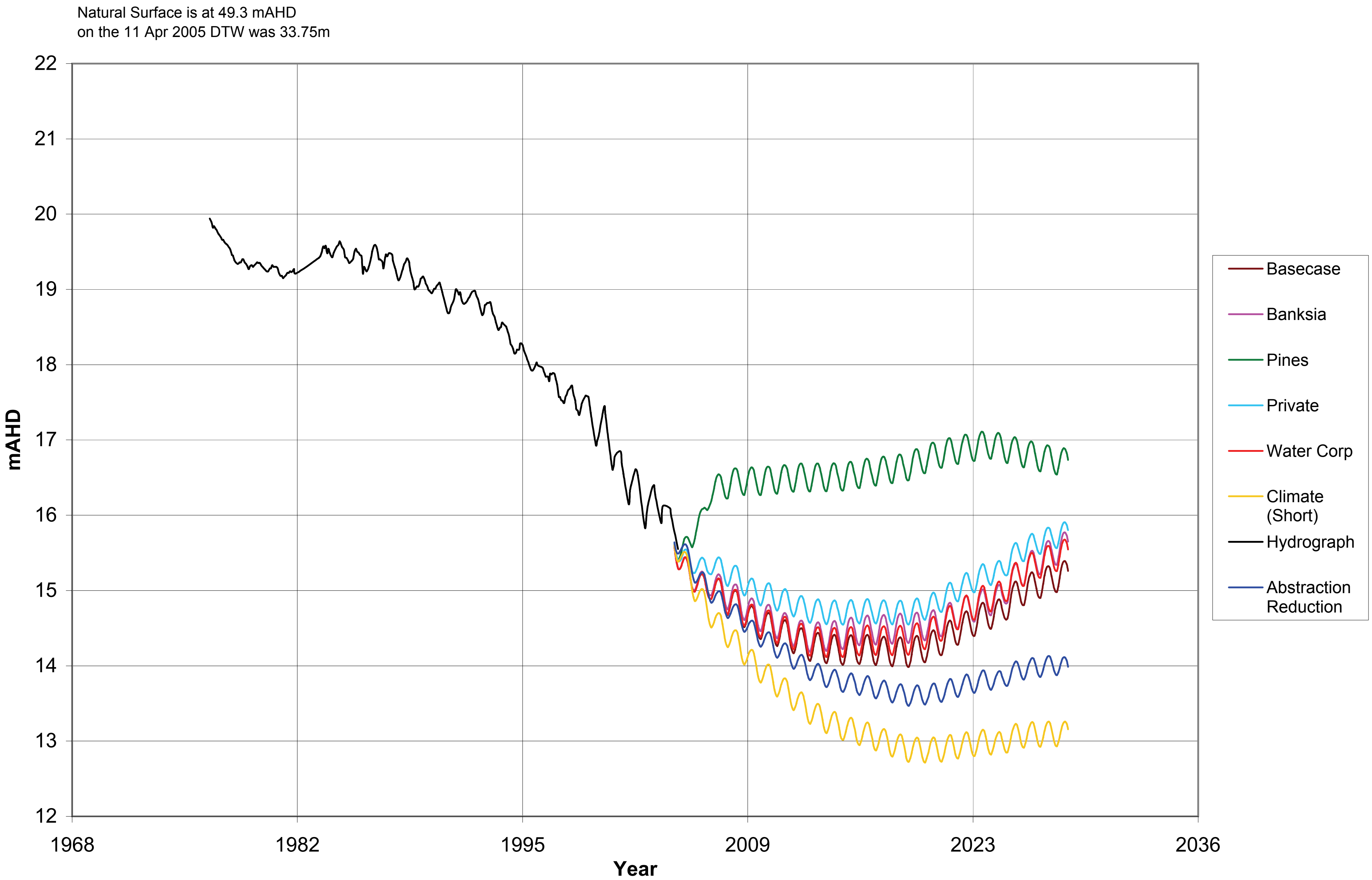


Figure 15: Observed and Predictive Hydrograph PM29

Natural Surface is at 68.20 mAHD
on the 22 Apr 2005 DTW was 11.88m

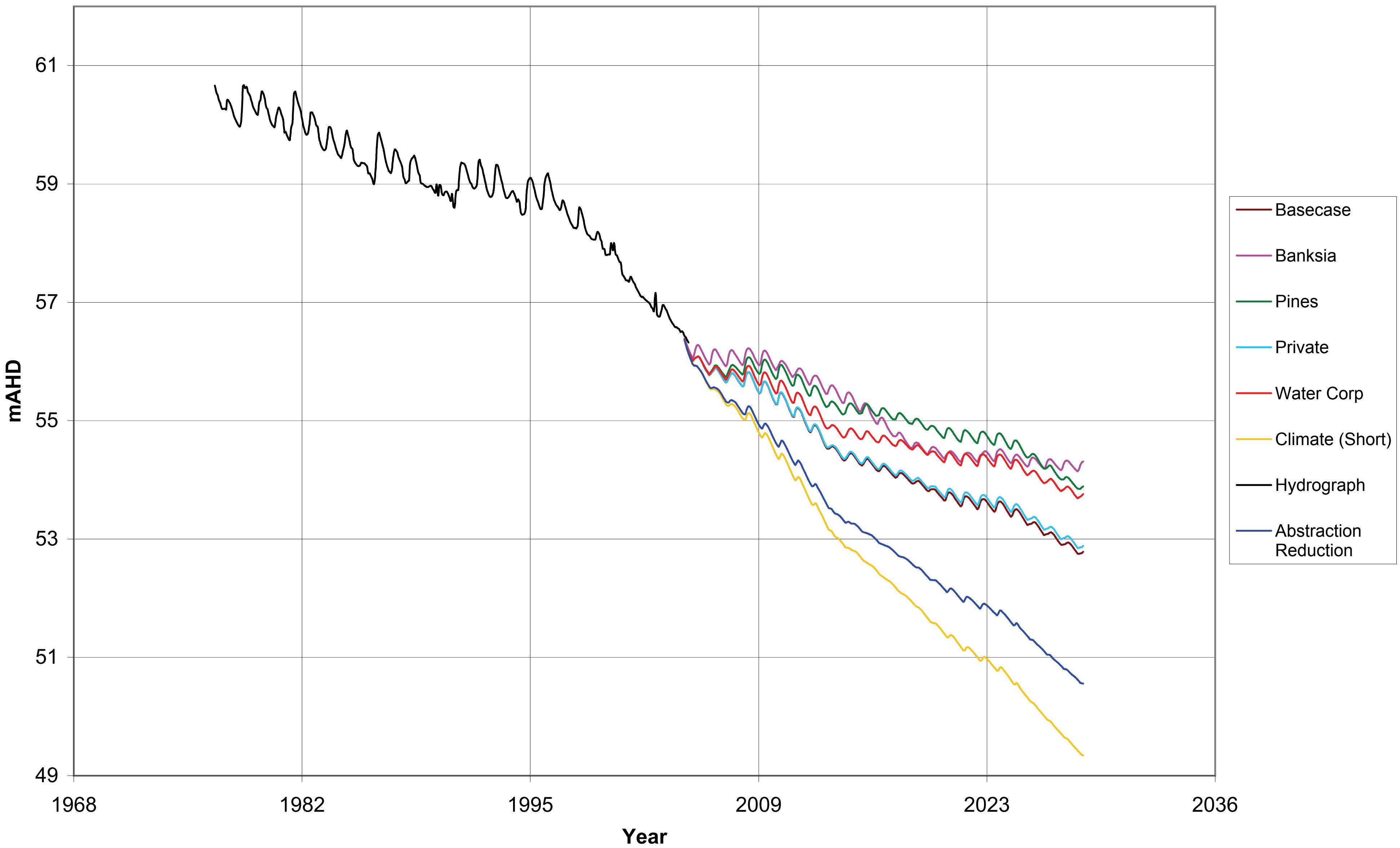


Figure 16: Observed and Predictive Hydrograph PM4

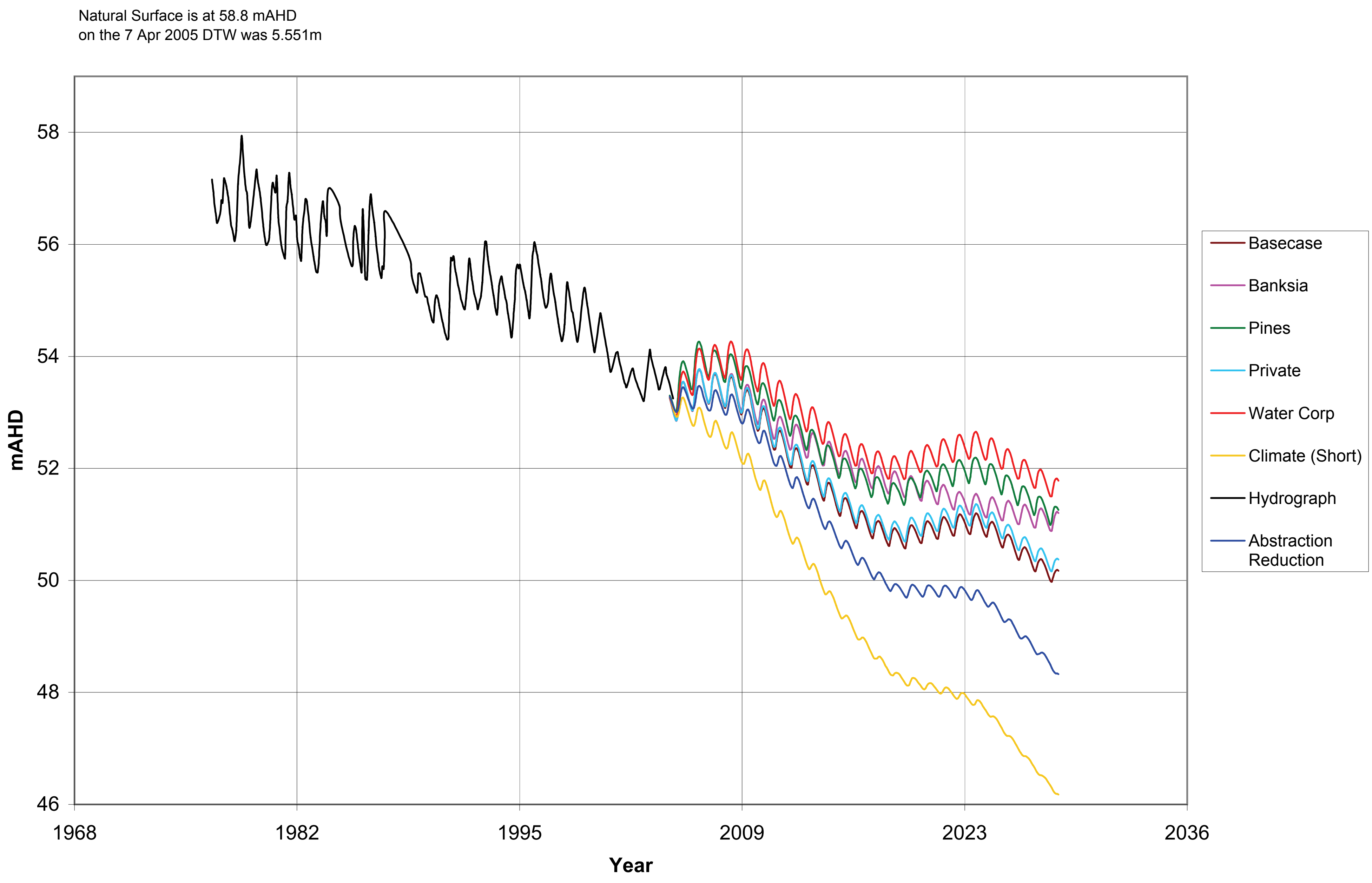


Figure 17: Observed and Predictive Hydrograph PM12

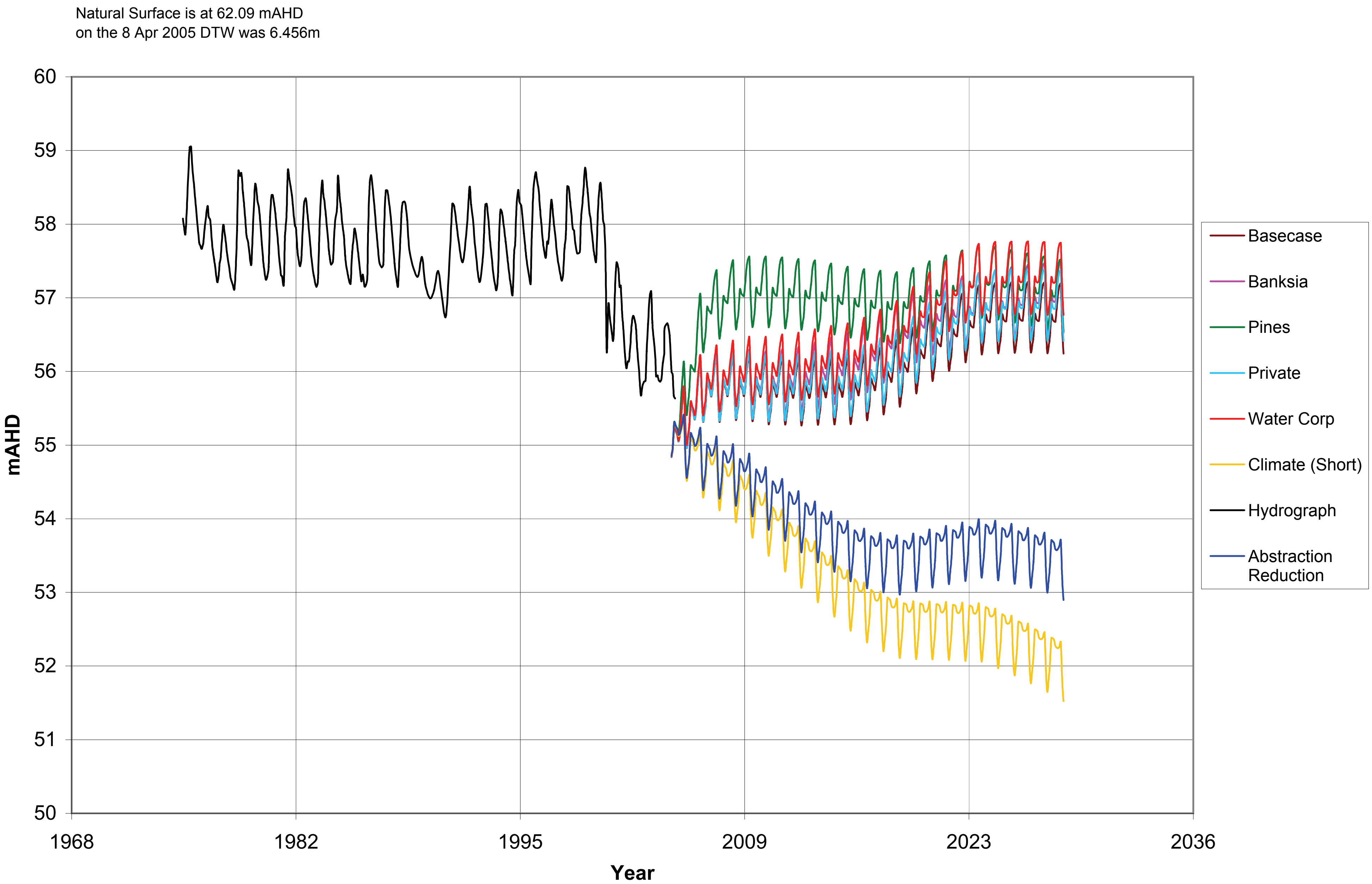


Figure 18: Observed and Predictive Hydrograph WM32

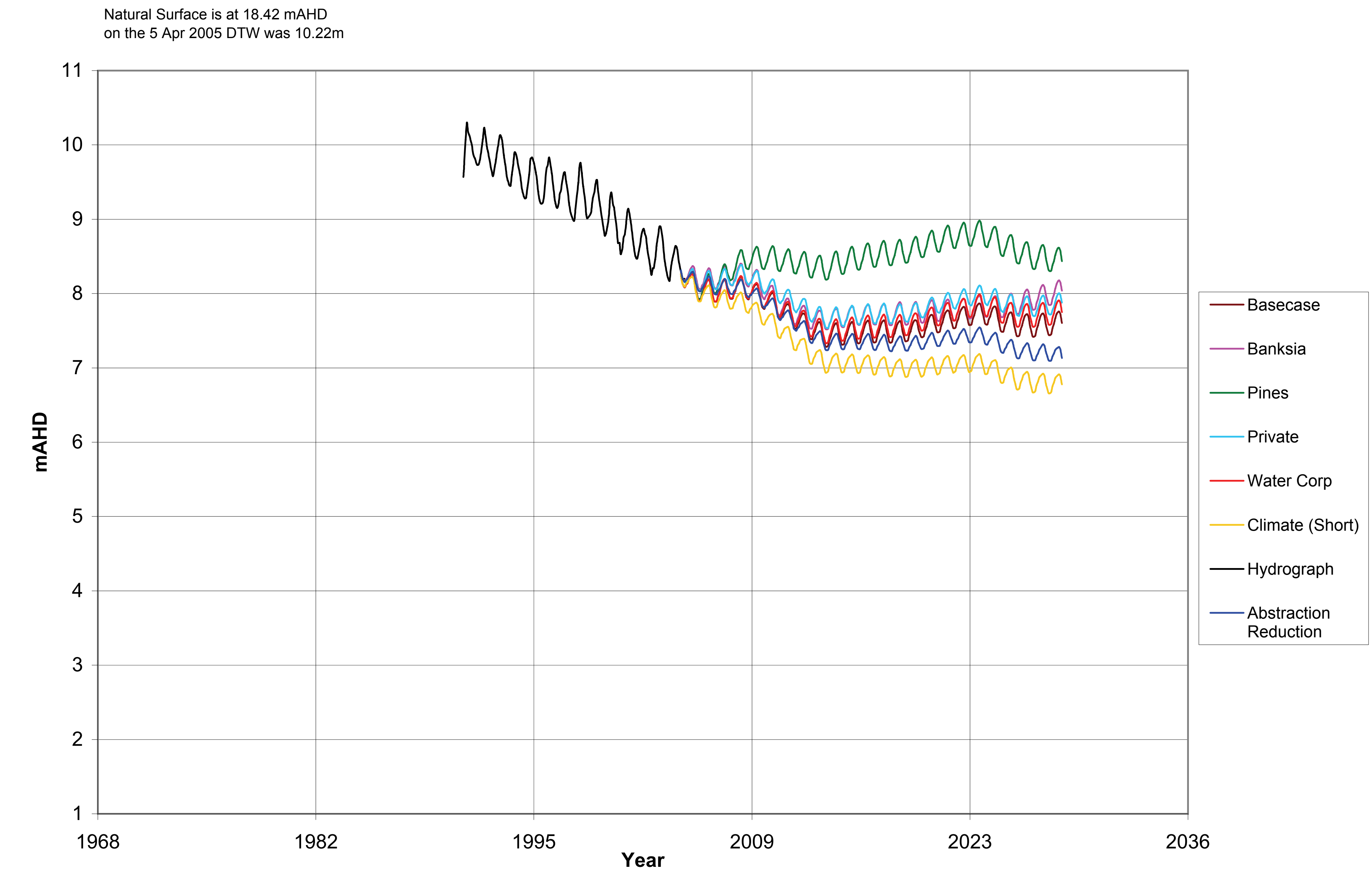


Figure 19: Observed and Predictive Hydrograph YN8

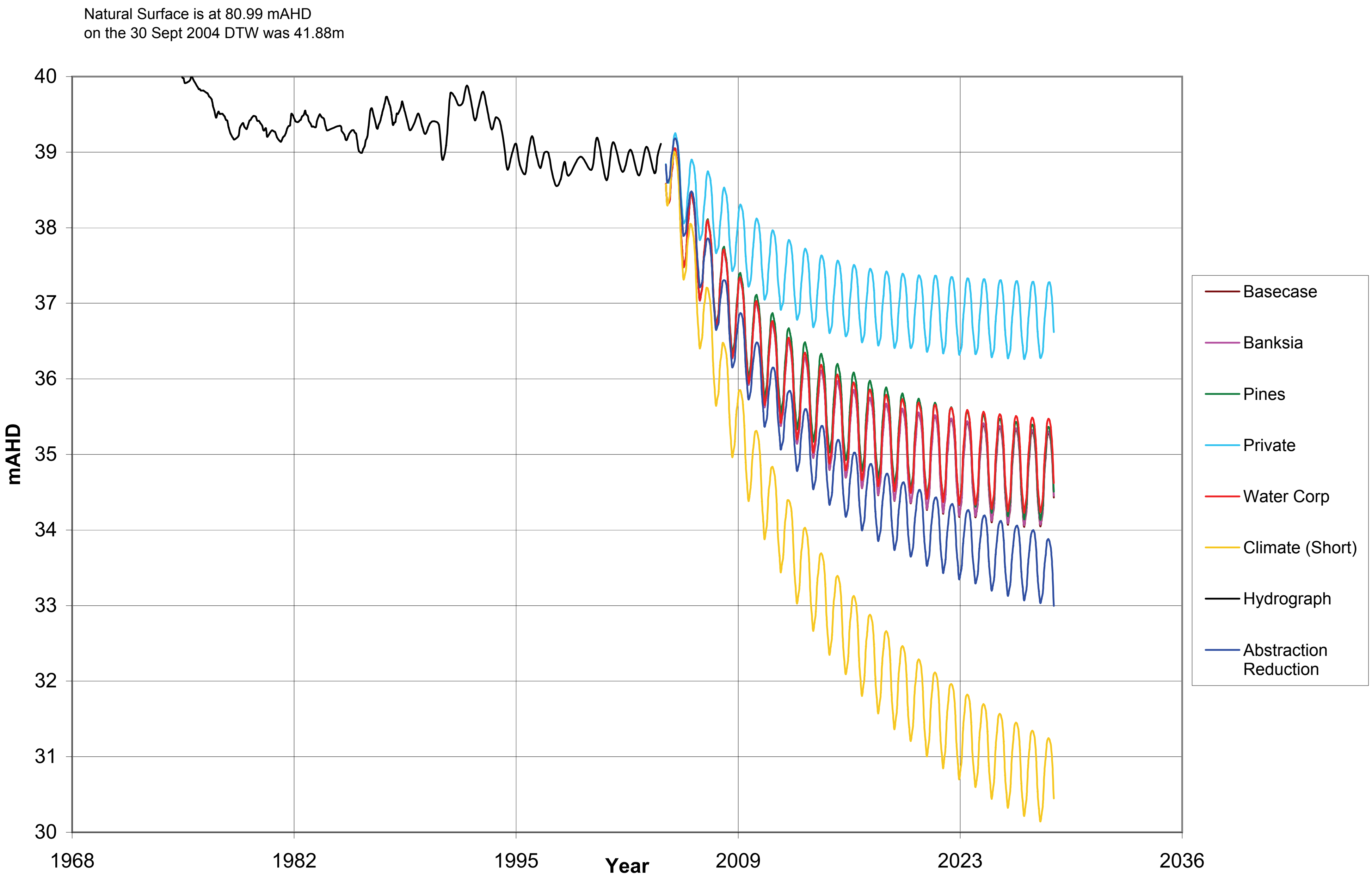


Figure 20: Observed and Predicitive Hydrograph WM28

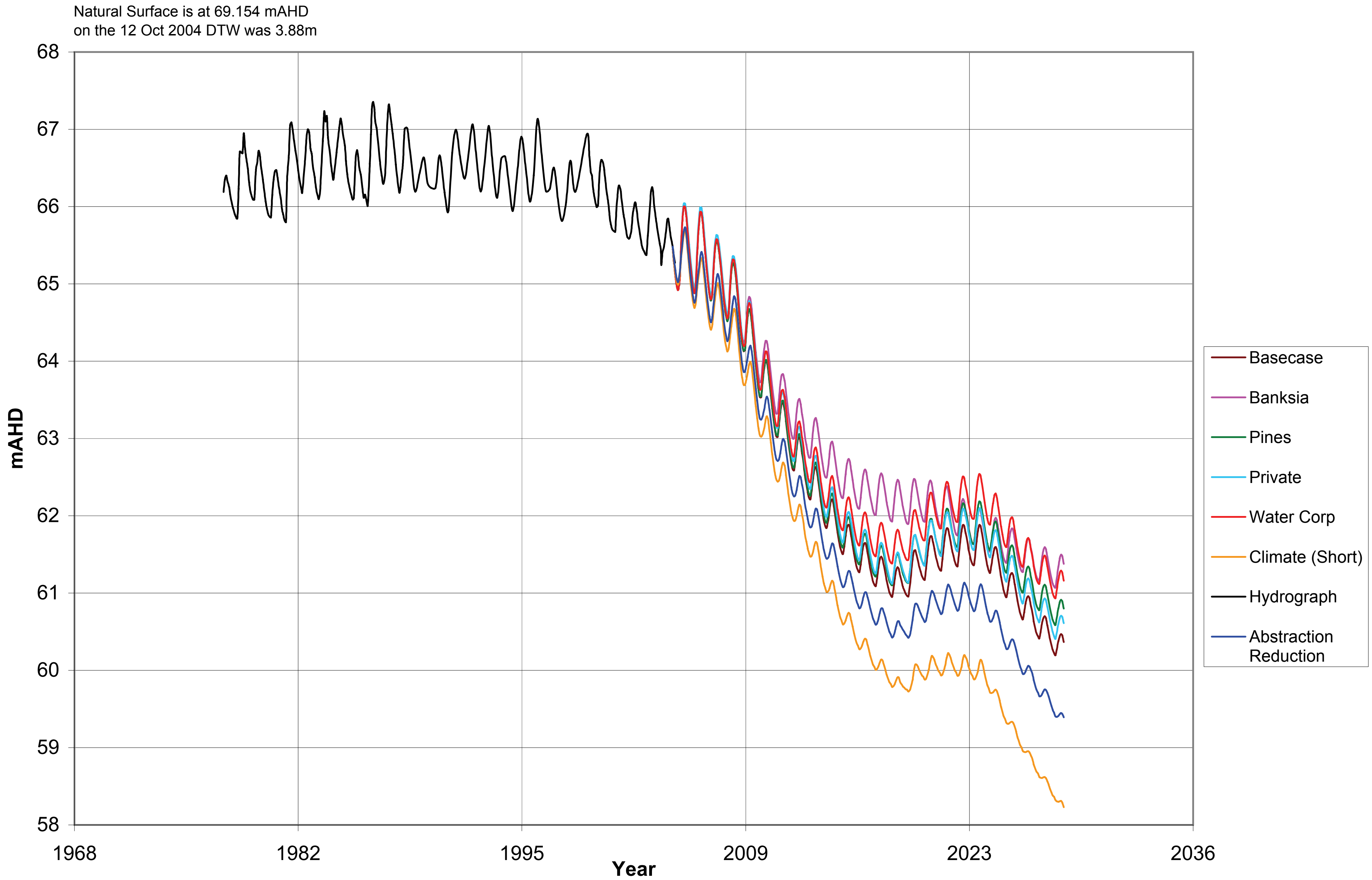


Figure 21: Observed and Predictive Hydrograph GC9

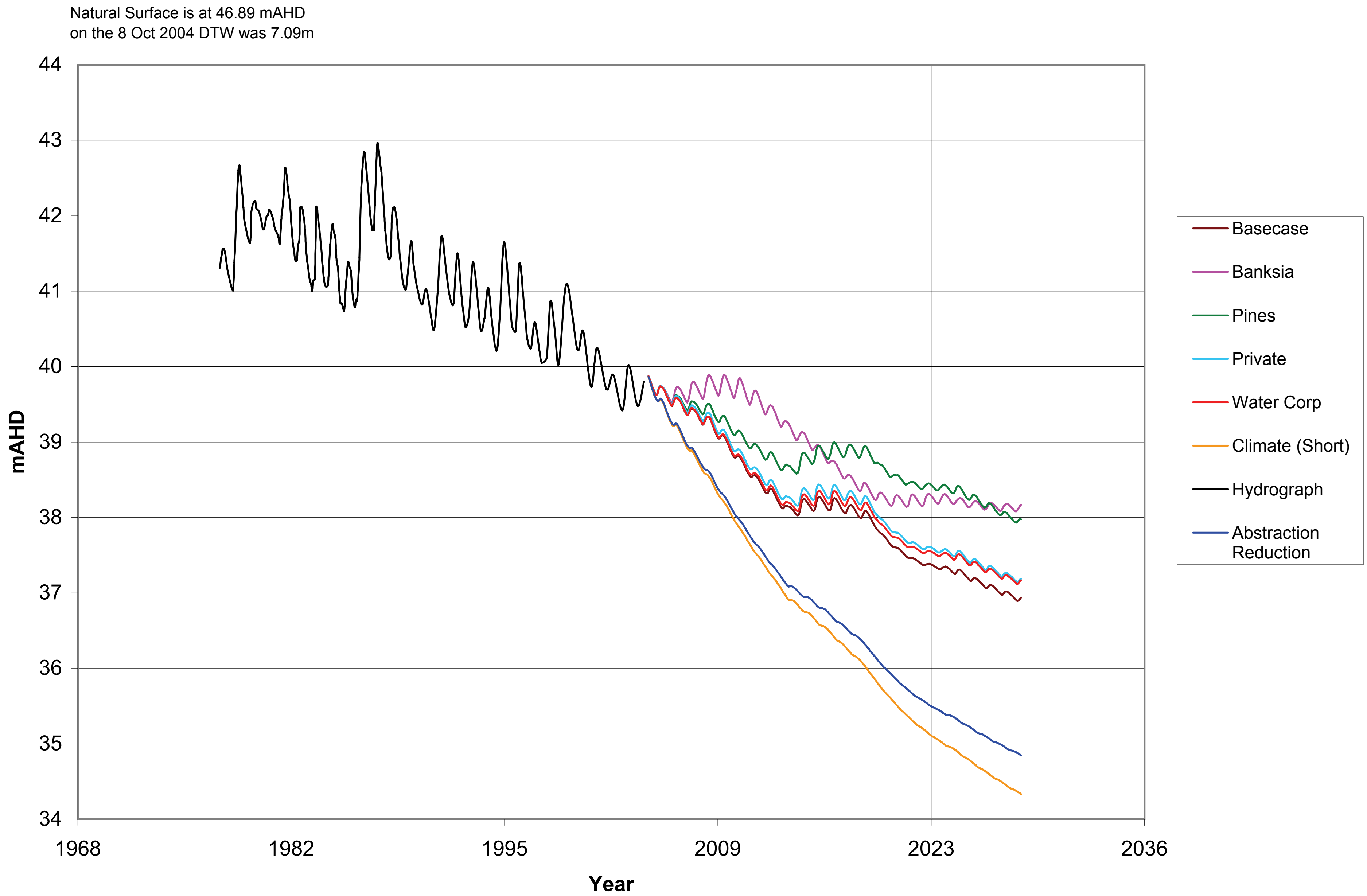


Figure 22: Observed and Predictive Hydrograph GB15

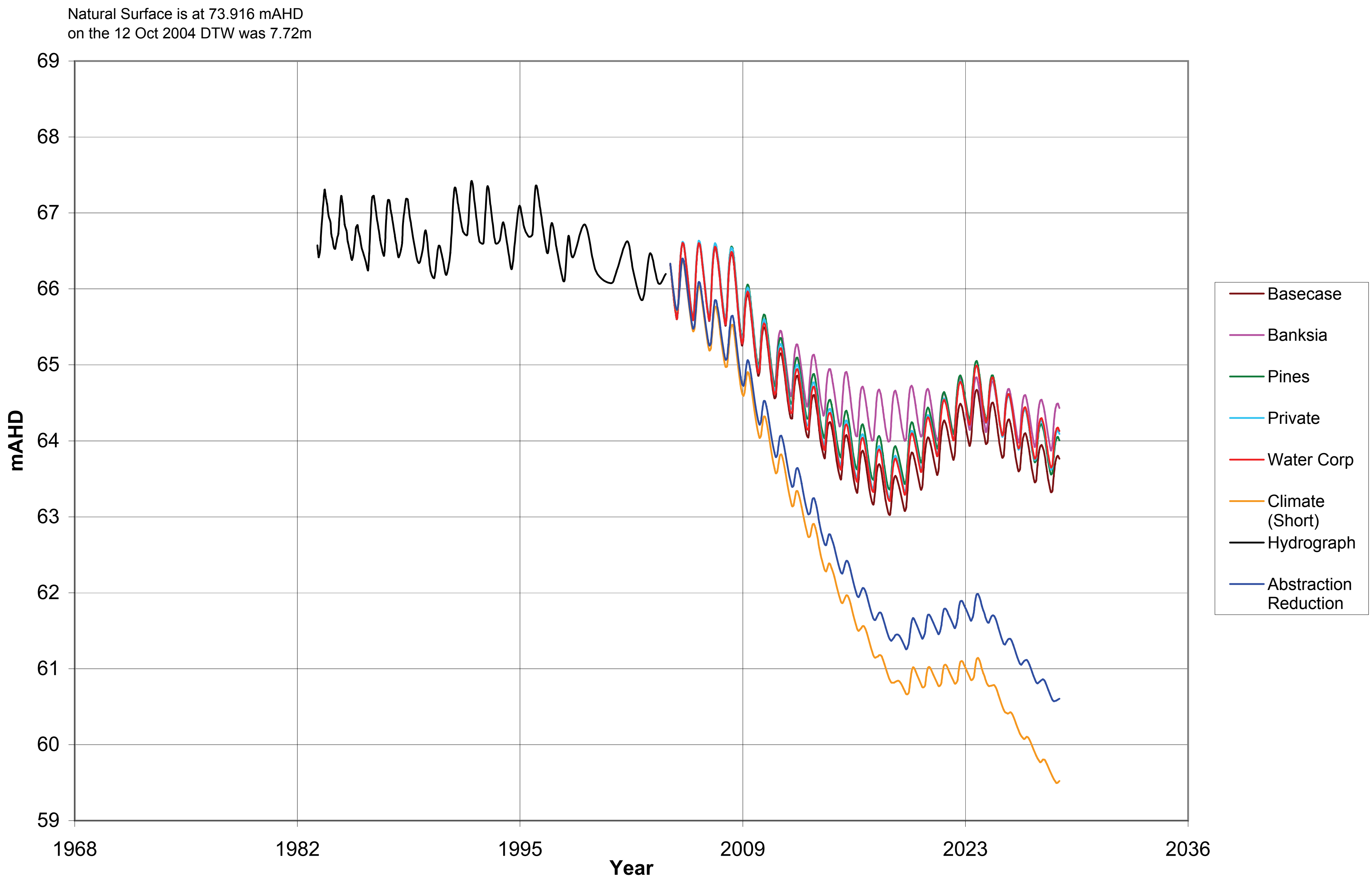


Figure 23: Observed and Predictive Hydrograph NR10c

4.3 Other Possible Management Actions

The Department of Environment, via the Gnangara Co-ordinating Committee, will pursue the development of an integrated strategy with other government agencies to better manage the impacts of pine plantations, native vegetation and land use planning decisions on groundwater levels. Through this work, the Department aims to foster whole of Government action for the more effective management of the Gnangara and Jandakot Mounds.

The following initiatives will be investigated:

- Managed aquifer recharge (MAR) with recycled water;
- Increased burning frequency of native vegetation; and
- Accelerated and/or concentrated pine felling to reduce impacts on certain groundwater dependent ecosystems or to provide for continued abstraction from public water supply bores.

4.4 Conclusions

It is widely acknowledged that around the mid 1970s, there was a shift to consistently drier winter conditions in South West Western Australia, which have continued to this day. Impacts on surface and groundwater resources, on natural ecosystems and agriculture have been observed. The ongoing significant decrease in rainfall experienced since 1998 has had a major impact on recharge and water levels on the Gnangara Mound over that period. This has been reflected in the significant increase in the number of sites breaching minimum water level conditions (up from 2 in 1996 to 16 in 2005).

However, it should be noted that these non-compliances have not been manifested in wholesale collapses in the groundwater dependent vegetation communities they are representing. Rather, what has been observed is a *terrestrialisation* or shift to a drier climate vegetation complex (ie. Moving from a phreatophytic to xerophytic vegetation community; an example is the Lexia wetland adjacent to monitoring bore GNM16 which is shown on the cover of this report). Therefore, the original environmental values may have changed or even been lost, but they have been replaced by another set of values reflecting the changed environmental conditions.

5 Future DoE Work

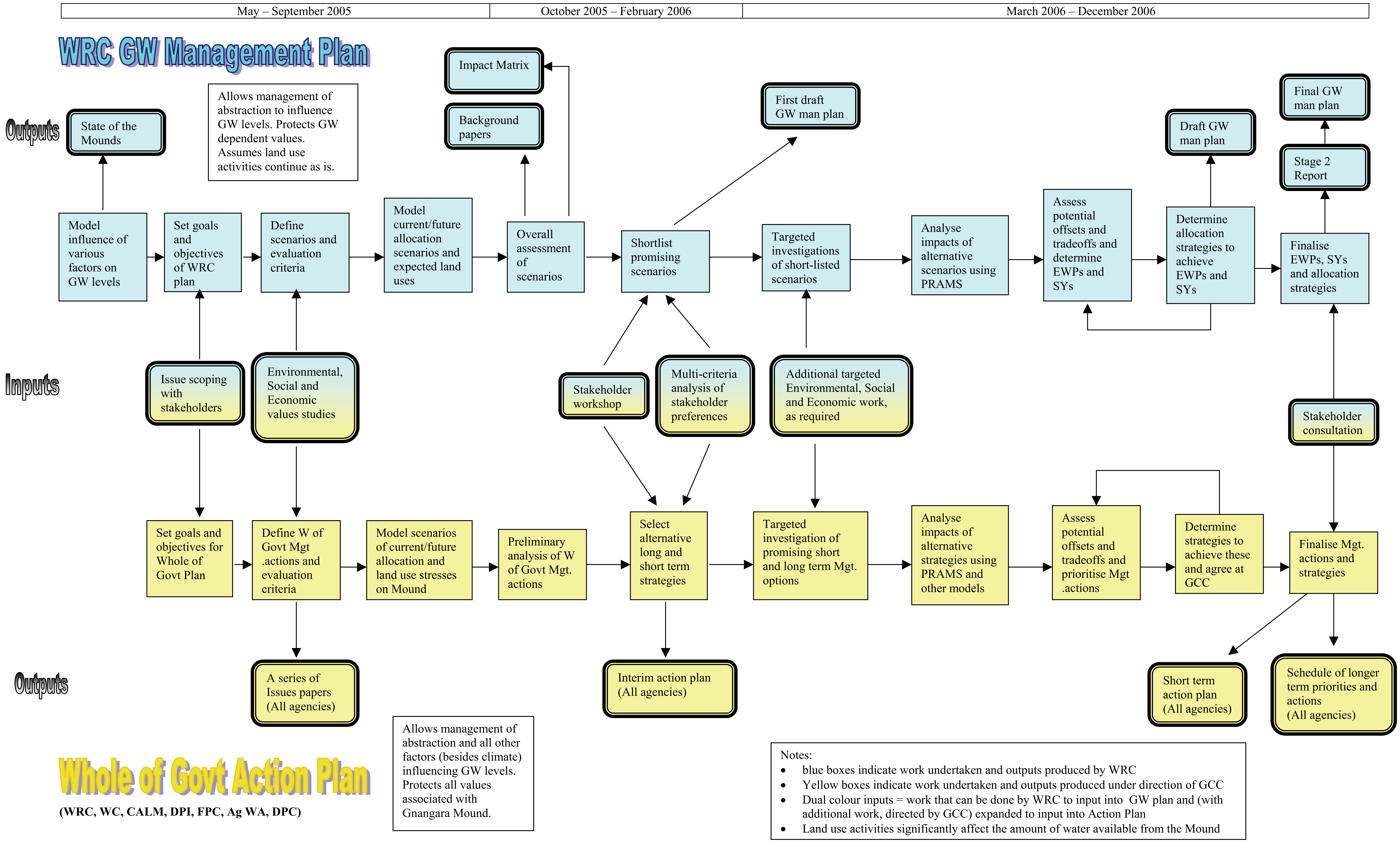
5.1 DoE Management Plan

There is a pressing need for a groundwater management plan for the Gnangara Mound and the DoE, as the resource manager, is progressing with preparation a draft plan for early 2006 (Figure 24). However, the complexity of stresses on the Mound (eg. climate change) and the interrelationship of land and water issues make a single agency approach less than ideal. Therefore it is proposed that while the DoE will continue with the development of the plan, other land and water agencies will become partners in the planning process. By utilising the expertise of multiple state agencies as well as the CSIRO, a true sustainability framework can be applied to managing the groundwater resources of the Gnangara Mound.

The need for an integrated multi-agency approach is well recognised by key private and public sector stakeholders with ties to the Mound (Section 2.9). The DoE sponsored study of 70+ of these stakeholders indicated strong support for the endorsement by the executive level of government for an integrated multi-agency planning effort for the Mound. Without this integration the potential for conflicts between land and water planning increases.

Integrated planning will allow the state government to present a single 'all of government' face to the community and should result in better public involvement outcomes. Integration will improve the sharing of information, the collaborative development of land and water use options, the evaluation of the options and the selection of preferred solutions so that trade-offs and outcomes are supported across the agencies. This will include a whole of government evaluation of technological, socio-economic, ecological and human-health considerations. A defining characteristic will be the integration of the land- and water-related aspects of the planning problem. Integration of this planning will also include the implications of climate change for all sectors, an issue which has not been adequately addressed to date.

GNANGARA MOUND: WRC Groundwater Management Plan Process vs Whole of Government Action Plan Process



References and recommended reading

Department of Environment, 2004a, *Environmental Management of Groundwater Abstraction from the Gnangara Mound July 2003 – June 2004*, Annual Compliance Report to the Environmental Protection Authority, Perth.

Department of Environment, 2004b, *Environmental Management of Groundwater Abstraction from the Jandakot Mound July 2003 – June 2004*, Annual Compliance Report to the Environmental Protection Authority, Perth.

Department of Environment, 2004c, *Section 46 Review of Environmental Conditions on Management of the Gnangara and Jandakot Mounds – Stage 1 Proposal for Changes to Conditions,* report prepared for the Department of Environment by Strategen, Perth.

Environmental Protection Authority (EPA), 2004, *Environmental Management of Groundwater Abstraction from the Gnangara Mound July 2000 – June 2003 - Triennial Report. Water and Rivers Commission* - Report by the Environmental Protection Authority under section 48(1a) of the *Environmental Protection Act 1986*, Environmental Protection Authority Bulletin 1139, Perth, Western Australia, 8 June 2004.

Froend, R., Loomes, R., Horwitz, P., Rogan, R., Lavery, J., How, A., Storey, A., Bamford, M. and Metcalf, B. (2004a). *Study of the Ecological Water Requirements of the Gnangara and Jandakot Mounds under Section 46 of the Environmental Protection Act. Task 1: Identification and Re-evaluation of Ecological Values*. Report to the Department of Environment. Centre for Ecosystem Management, Edith Cowan University, Joondalup.

Froend, R., Loomes, R., Horwitz, P., Bertuch, M., Storey, A. and Bamford, M. (2004b). *Study of the Ecological Water Requirements of the Gnangara and Jandakot Mounds under Section 46 of the Environmental Protection Act. Task 2: Determination of Ecological Water Requirements.* Report to the Department of Environment. Centre for Ecosystem Management, Edith Cowan University, Joondalup.

Froend, R., Rogan, R., Loomes, R., Horwitz, P., Bamford, M. and Storey, A. (2004c). *Study of the Ecological Water Requirements of the Gnangara and Jandakot Mounds under Section 46 of the Environmental Protection Act. Tasks 3 and 5: Parameter Identification and Monitoring Program Review.* Report to the Department of Environment. Centre for Ecosystem Management, Edith Cowan University, Joondalup.

Froend, R., Loomes, R. and Rogan, R (2005). *Study of the Ecological Water Requirements of the Gnangara and Jandakot Mounds under Section 46 of the Environmental Protection Act. Task 4: Management Framework (DRAFT).* Report to the Department of Environment. Centre for Ecosystem Management, Edith Cowan University, Joondalup.

IOCI, 2002, *Climate Variability and Change in South West Western Australia*, Indian Ocean Climate Initiative Panel.

Vogwill, R.I.J., 2005, *Section 46—Groundwater Modelling Scenarios Stage 2,* HR 235, Department of Environment internal publication—in preparation.

Water and Rivers Commission, 2003, *Section 46 Review of Environmental Conditions on Management of Gnangara and Jandakot Mounds, Progress Report 2003*, report prepared for the Water and Rivers Commission by Strategen, Perth.

Welker Environmental Consultancy, 2002, *Section 46 Review of Environmental Conditions on Management of Gnangara and Jandakot Mounds, Progress Report 2002*, report prepared for the Water and Rivers Commission.

Yesertener, C., 2002, Declining water levels in the Gnangara and Jandakot Mounds (Stage 1), Hydrogeology Report HR199, Department of Environment.

Appendix 1 – Ecological Water Requirements Study Summary

This ecological water requirements study is one of several specific studies being undertaken as input into the Stage II review. This study is aimed at reviewing the groundwater dependent ecosystem values in the study area to be protected through water and land planning and management decision making. Within this, there are several detailed aspects to be considered:

- Ecological water requirements and environmental water provisions.
- Environmental criteria and the form of future environmental conditions.
- Biological monitoring techniques and programs.

The objectives of the ecological water requirements study were:

- To identify, and where appropriate, re-evaluate the environmental values associated with the groundwater dependent ecosystems (GDEs) within the study area.
- To consider how current (re-evaluated) values may change further under a declining water level (drying climate) scenario.
- To propose the EWRs necessary to support current values and values that may exist under a drying climate.
- To propose environmental and biological condition indicators that reflect environmental values and have a defined relationship with groundwater levels and could be used together with water level criteria within a management framework as management criteria for Gnangara and Jandakot groundwater resources.
- To provide advice to the WRC in its development of a management framework within which water level criteria and environmental criteria can be applied in management of groundwater resource.
- To review the ecological monitoring programs associated with management of the GDEs in the study area and recommend a revised program to provide information on the achievement or otherwise of the finally determined management criteria.

Current approach

A number of approaches have been developed to determine the water requirements of water dependent ecosystems. The majority of these, however, focus on the requirements of systems dominated by surface water flows with fewer approaches directed entirely towards groundwater dependent ecosystems. The approaches that do exist for GDEs generally focus on one type of ecosystem (eg. wetlands) or on one component of that ecosystem (eg. wetland vegetation). Surface water system approaches are more holistic in nature, considering the requirements of the many interacting components of river systems. Further differences exist in terms of the spatial scale of approaches, for example the water requirements of an individual wetland or an entire catchment. The greatest variation however relates to available time and resources. These factors in turn influence the extent of fieldwork, intensity of data analysis and the level of involvement by experts.

In this section, the existing WA approach for GDEs will be summarised and general strengths and limitations assessed. For a full review and comparison of other approaches used for groundwater and surface water systems, refer to Froend and Loomes (2004). Particular emphasis will be placed on identifying the recognised weaknesses of past WA approaches and improvements in a revised approach to determining EWRs for GDEs.

The current WA approach is defined here by the *Review of Proposed Changes to Environmental Conditions, Gnangara Mound Groundwater Resource (Section 46)* – Western Australian Water Authority (1995).

In response to further proposed increases in groundwater abstraction, changes in private groundwater usage and an improved understanding of groundwater dependent ecosystems, a section 46 review of environmental conditions of the Gnangara Mound was undertaken (Water Authority of Western Australia, 1995). The requirements of three types of GDEs were determined: wetland ecosystems, terrestrial vegetation and cave streams.

The specific approach to defining EWR was:

- Identification of GDE components (wetlands, terrestrial vegetation, cave streams and pools).
- Selection of representative parts for which EWRs were set to ensure appropriate protection for the region.
- Identification of values of those parts, including social and environmental aspects.
- Determination of management objectives based on the values.
- Establishing water levels for each ecosystem component that satisfy the identified management objectives and which define the EWR.

Determination of EWRs for wetland ecosystems involved the following steps:

- Identifying characteristics of the wetland.
- Identifying values of the wetland, both environmental and social.
- Determining management objectives that reflect wetland values, in particular those achievable through management of water levels.
- Developing a water regime consistent with the management objectives, with water levels to describe that regime.

Wetlands were identified as groundwater dependent ecosystems and wetland vegetation was selected as the representative component for protection due to the interdependent nature of wetland biota. Management objectives included conserving the existing distribution and composition of fringing and emergent vegetation. EWRs were set as minimum and maximum water levels. Absolute minimum water levels for each wetland were set to ensure populations of the sedge *Baumea artic*ulata were sufficiently inundated and that surface water was present long enough for aquatic invertebrates to complete their life-cycles. The water requirements of *B. articulata* were considered, as this species is known to be the most susceptible to declining water levels. Maximum water levels were based on ensuring wetland trees were dry for a minimum period per year.

The approach to setting EWRs for terrestrial vegetation was identified separately, to that for wetlands, with the aim of determining water levels required for survival and a level of draw down that could be tolerated by the vegetation.

The approach involved:

- Identification of areas of susceptible native vegetation.
- Selection of monitoring bores within the areas that best represent water table levels and which can be used to monitor compliance with water levels.
- Defining rates of change and minimum groundwater levels to minimise the potential for vegetation deaths due to water stress.

This involved the setting of absolute and preferred minimum groundwater levels that did not represent a static volumetric amount. Instead, these were expressed as dynamic water level regimes that could be changed in response to differing needs and situations. In areas where extraction had already been occurring and had resulted in a stabilised drop in the watertable, the philosophy of no further impact on groundwater levels was adopted.

Minimum water level requirements were selected for susceptible terrestrial vegetation, those existing at shallow depths to groundwater (0-8 m), on the basis of previously observed water levels and resulting impacts on the vegetation. Minimum groundwater level requirements were determined using historical monitoring records from groundwater monitoring wells located within areas of susceptible vegetation. The hydrographs from the monitoring well data were analysed to ascertain a 'normal' minimum groundwater level defined as the average minimum groundwater level occurring at the end of summer periods in the early 1970s prior to abstraction and the continuing drought period. The absolute minimum groundwater level was determined by subtracting 1.5 m from what was considered to be the 'normal' groundwater level.

In areas where abstraction had not been occurring for long enough to result in a stabilised watertable, a vegetation water stress study was used to derive the maximum rate of watertable drop that could still support the extant vegetation. The study indicated that the overstorey component of the vegetation could tolerate a water table draw down of 1.5 m in total (this is where the figure of 1.5 m was derived to arrive at absolute groundwater levels), and that this draw down could be tolerated at no more than an average rate of 0.2 m per year.

Due to the limited information on groundwater levels in cave streams and pools at the time of the Section 46 review, EWRs were not set. However management objectives were developed to maintain the existing hydrological regimes and permanent water in streams supporting fauna.

EWPs were established following comparisons of groundwater modelling of preferred abstraction and land use scenarios and EWRs. Finally, management and monitoring programs were implemented to minimise the impact of land use activities on groundwater resources and GDEs.

Strengths and limitations

The setting of EWRs for a wetland based on the pre-determined requirements of a single vegetation species (*Baumea articulata*) represents a relatively quick and inexpensive approach. The use of a species identified as most susceptible to water levels changes also ensures that the requirements of other, less susceptible species are met. However, this species generally occurs only in wetlands that hold surface water for some part of the year, making the approach inapplicable to many systems.

The use of pre-determined requirements in the approach for terrestrial vegetation is also quick and inexpensive. However, setting the same water levels for susceptible vegetation (0-8m groundwater depth) does not recognise the variation in dependence of vegetation at different depths to groundwater. For example, vegetation at 0-3m is more susceptible to draw down than that at 6-8m. Setting a maximum allowable draw down of 1.5m also does not consider the greater susceptibility of vegetation at shallower depths to groundwater.

However, this approach was the first attempt at setting preferred and absolute minimum groundwater levels that did not represent a static volumetric amount and reflected the dynamic nature of water level regimes.

Since 1995 there have been numerous interim assessments and research conducted on GDEs on the SCP and elsewhere [refer to (Froend & Loomes, 2004) for review] that has led to an improved understanding of the ecology of these systems and the identification of their EWRs. Incremental changes to the approach described above have been made in recognition of observed limitations and increased knowledge. A summary of these limitations is presented below.

- Limitations relevant to identification of EWRs:
- Insufficient consideration of all recognised groundwater dependent ecosystems. The original approach assessed wetlands, terrestrial vegetation and cave streams only with little acknowledgment in the variability within each type of GDE.
- Consideration of the water requirements of only one component of a GDE; eg. Determining EWRs of a whole wetland based on wetland vegetation water requirements alone.
- No acknowledgment of the variability in groundwater dependency within a GDE and/or an ecological component; eg. Variability in groundwater dependency of phreatophytic vegetation relative to depth the water table and hydrological ranges (tolerances) of wetland vegetation. Leads to insufficient awareness of biological/ecological variability and incorrect interpretation of EWRs as absolute 'thresholds' of tolerance.
- Simplification of water requirements into minimum water table depths without recognition of other hydrological variables important to the ecology of the system; eg. duration, timing and rate of seasonal flooding/drying and the episodicity of extreme flooding/drying events.
- No consideration of cumulative effects of reduced groundwater availability or a lag-response in the ecology.
- No consideration of the resilience of GDEs to draw down impacts.
- Consideration of GDEs as single units only without a system/catchment approach towards identifying water requirements and possible impacts.
- These limitations have often led to the identification of EWRs that do not accurately reflect the requirements of the ecology, often resulting in technical breaches of environmental conditions (without obvious ecological impact) or understated water requirements leading to unexpected environmental impacts.
- Other limitations reflect how EWRs are used in the determination of environmental water provisions (EWPs) or determining likely impacts. Limitations relevant to identification of EWPs:
- Absence of a risk (of impact) assessment incorporating variability in current vulnerabilities (water requirements and drought stress) and potential degree of change/impact.
- Management (environmental compliance) criteria based on simplified minimum 'threshold' water table levels without consideration of acceptable changes to ecological values.

- Direct translation of EWRs to EWPs or management criteria without sufficient consideration of social and economic water requirements.
- Inaccurate assessment of groundwater levels/wetland surface water level relative to GDE ecology; eg. No groundwater monitoring at vegetation monitoring sites.

Revised approach

Revision of the current WA approach to identification of GDEs and EWRs should involve the adoption of frameworks described in SKM (2001) and Froend and Loomes (2004). Specifically, a revised approach should:

- Recognise all identifiable GDEs within the study region and set about collecting sufficient information to identify their EWRs. In the case of the SCP, this would see the expansion of wetlands assessed to include damplands, assessment of phreatophytic vegetation over a variety of depths to groundwater, assessment of baseflow-dominated systems, the inclusion of near-shore marine and estuarine systems and increased assessment of cave and mound spring systems.
- Consider the EWRs of as many components of the GDE ecology for which necessary data are available. For example, this would require the determination of wetland EWRs to be an integration of vegetation, vertebrate, macroinvertebrate and physicochemical water requirements. Single components may dominate the EWR assessment of particular GDEs if insufficient data exist to incorporate the other components of the ecology, or if the requirements of one component (eg. 'Umbrella' species) can be demonstrated to cater for all other key components.
- Acknowledge variability in EWRs within ecological components (eg. vegetation) of a GDE. Not all phreatophytic vegetation has the same degree of dependency on groundwater and therefore the same response to draw down. This variability in dependency has a significant effect on the risk of impact from groundwater draw down. The expression of EWRs should therefore incorporate the range in water requirements (not absolute 'threshold' values only) and or categories of differing requirements/dependency.
- Recognise other hydrological variables important to the ecology of the system; eg. duration, timing and rate of seasonal flooding/drying and the episodicity of extreme flooding/drying events.
- Consider the cumulative effects of reduced groundwater availability by assessing historical changes in water tables/surface water levels and determine the net change in groundwater availability over key periods of time. This historical change should then be considered in addition to any impacts from proposed developments. A lag-response in a GDE may occur after EWRs have been compromised for some time without obvious ecological response. Identification of EWRs should consider the rate at which GDEs are likely to response to changes in groundwater availability.
- Acknowledge the resilience of GDEs to altered groundwater availability. Ecological values are able to be restored/maintained if remedial/mitigation practices are put in place. Therefore a longer-term perspective in water requirements necessary to maintain ecological values should be adopted.
- Consider system/catchment level water requirements as well as single GDE requirements. Important landscape level ecological processes should be considered, eg. Acid Sulphate Soils.

EWR determination

The assessment of values related to macroinvertebrates, waterbirds, other vertebrates and water quality were beyond the scope of these assessments, as were assessments of 'new' cave pool and near-shore marine systems. EWRs therefore could not be described for a vast number of GDEs while the EWRs for many others remain qualitative and based on what little information is available. However, where the required level of information is available detailed/quantitative EWRs were described.

Vegetation

Where the dominant vegetation species of 'new' and 'previously identified' wetlands have been determined, basic water requirements were described (Table 4). These were based on a previous study of minimum and maximum water depths and duration of inundation experienced by common tree, shrub and emergent macrophyte species of monitored Gnangara and Jandakot wetlands (Loomes, 2000). Comments on the likely magnitude (m) and rate (m/year) of water level decline at a wetland were also noted.

Due to the vast number of 'new' wetlands, dominant species are merely listed. The following represents the water depth ranges of the most common/dominant species at 'new' wetlands;

M. rhaphiophylla – mean 0.006 to -2.14 m, absolute 1.03 to -4.49 m.

M. preissiana – mean -0.54 to -2.62 m; absolute 1.03 to -5.04 m.

E. rudis – mean -0.7 to -3.26 m, absolute 1.03 to -6.44 m.

B. littoralis – mean -0.39 to -1.92 m, absolute 0.43 to -3.09 m.

B. articulata – mean 0.28 to -1.22 m, absolute 0.81 to -2.59 m.

T. orientalis – mean 0.74 to -0.95 m, absolute 1.49 to -1.9 m.

A. fascicularis – mean -0.35 to -2.26 m, absolute 1.03 to -4.6 m.

Duration of inundation (mean months/year) for the same set of species is as follows;

M. rhaphiophylla – mean 2.15, absolute 9.4 (months/year).

M. preissiana– mean 0.6, absolute 4.4 (months/year).

E. rudis – mean 1.55, absolute 12 (months/year).

B. littoralis – mean 0.3, absolute 2.8 (months/year).

B. articulata – mean 3.26, absolute 12 (months/year).

T. orientalis – mean 7.7, absolute 12 (months/year).

A. fascicularis – mean 0.66, absolute 2.6 (months/year).

EWRs for terrestrial vegetation were based on previous investigations into the tolerance and dependence of selected *Banksia sp*. to various groundwater regimes (Froend, Loomes, & Zencich, 2002; Froend & Zencich, 2001). In these studies the potential risk of groundwater declines to phreatophytic vegetation were qualitatively assessed. The risk assessment involved categorising areas according to the depth to groundwater as follows:

0-3m

3-6m

6-10m

and >10m.

Within each of these depth categories, an individual plant is thought to respond to the magnitude of draw down according to a species response curve (Tables 2 and 3). The threshold curve has so far only been developed for two Banksia species on the Swan Coastal Plain, *B. ilicifolia* and *B. attenuata*. For these species it is suggested that for each depth category, increasing the magnitude of groundwater decline will lead to a differing level of response. Those populations in areas of highest water tables (0-3m) are most highly dependent on groundwater and are therefore at greater risk of impact from the same degree of draw down than populations at 3-6m and 6-10m. Where *M. preissiana*, *E. rudis* and/or *B. littoralis* occurred within an area of 0-3m, the site was regarded as a wetland.

For each terrestrial vegetation site (or 0-3m site with wetland species) EWRs are described as the risk of impact (low, moderate or high) that phreatophytic vegetation of the appropriate depth to groundwater category is at for a range of groundwater level declines. Groundwater level declines are expressed as magnitude (m) and rate (m/year). For example, phreatophytic vegetation in the 0-3m category is at low risk of impact from a decline of 0.75m at a rate of 0.1m/year.

Table 1: Risk of impact level and magnitude of permissible change (m) for phreatophytic vegetation.

Phreatophytic category	Low	Moderate	High	Severe
0-3m (wetland)	0-0.25	0.25-0.5	0.5-0.75	>0.75
0-3m (terrestrial)	0-0.75	0.75-1.25	1.25-1.75	>1.75
3-6m	0-1.0	1.0-1.5	1.5-2.25	>2.25
6-10m	0-1.25	1.25-2.0	2.0-2.75	>2.75

Table 2: Risk of impact level and rate of permissible change (m/year) for phreatophytic vegetation.

Phreatophytic category	Low	Moderate	High	Severe
0-3m (wetland)	0-0.1	0.1-0.2	0.2-0.3	>0.3
0-3m (terrestrial)	0-0.1	0.1-0.25	0.25-0.5	>0.5
3-6m	0-0.1	0.1-0.25	0.25-0.5	>0.5
6-10m	0-0.1	0.1-0.25	0.25-0.5	>0.5

Vertebrates

The water requirements needed to maintain the fauna could only be discussed in a general sense. For some species of fauna, such as frogs, the species present may be determined by the lowest water levels experienced in the recent past. These would have acted as a bottleneck through which only the more tolerant species could pass. For other faunal groups, however, water levels over successive years will have influenced the abundance and presence of species. All that can be confidently stated is that the faunal assemblage present now has been influenced by the recent history of water levels and the current levels in the area. This faunal assemblage is also dynamic, with rapid changes in some groups but gradual changes in others. This means that maintaining current water levels could still lead to changes in the faunal assemblage, as it is very likely that the assemblage is still influenced by high water levels probably experienced in the 1950s and 1960s.

Macroinvertebrates

Although many of the wetlands of the Gnangara and Jandakot mounds support significant macroinvertebrate assemblages the water requirements needed to maintain macroinvertebrates can only be discussed in a general sense.

Where macroinvertebrate richness is significant for a wetland the known temporal and spatial habitat heterogeneity needs to be maintained by ensuring the mix of vegetation assemblages can persist. Vegetation assemblages may include the following:

- Metaphyton - where known to occur it must remain permanently inundated, all year, every year.
- Submergent - requires inundation according to the specifications of the dominant taxa.
- Emergent - requires inundation according to the specifications of the dominant taxa.
- Littoral assemblages - requires inundation according to the specifications of the dominant taxa.

Rationale: habitat heterogeneity in SCP wetlands is dictated by water regimes as they interact with

- Depression/ landscape geomorphology.
- Vegetation assemblages.
- Sediment processes.
- Water quality.
- Other biotic/abiotic interactions.

These factors are all inter-related and the degree to which any or all of these interact or influence habitat heterogeneity is wetland dependent. Assigning water requirements to one of these as a surrogate for all may, if comprehensively achieved, be adequate to maintain macroinvertebrate richness. Choosing vegetation assemblages as the surrogate has the advantages of contributing to structural heterogeneity, being likely to reflect and contribute to all other influences anyway, and being more likely to be mapped than sediments and water quality.

Where macroinvertebrate proportional endemism is significant for a wetland then the endemic features need to be identified. This is beyond the scope of this work and no EWRs can be set, as it requires specific understanding of EWRs of endemic species or assemblages. This type of analysis is begging to be done for plants, invertebrates and microbes. To what degree will endemism be important in wetlands of the SCP? Probably relatively low for macroinvertebrates (>0.5 mm), higher for micro-invertebrates (<0.5 mm).

Where macroinvertebrate proportional rarity is significant for a wetland then the rare features need to be identified. This is usually beyond the scope of this work and no EWRs can be set. However, wetland/landscape geomorphology may be a sufficient surrogate for this significant feature, particularly since most proportional rarity is encountered in geomorphologically distinct wetlands like springs, caves, etc. EWRs can therefore be deferred to those set for these wetlands. This type of analysis gives an indication of relative uniqueness and representativeness of any wetland on the SCP.

Waterbirds/waders

Although many of the wetlands of the Gnangara and Jandakot mounds support significant waterbird assemblages. Water requirements can only be discussed in a general sense. Comments are made on requirements in terms of surface water permeance and depth where possible.

Water quality/sediments

Although wetland water quality is often impacted by inflow of nutrients and pollutants from external sources, in-situ sediment processes also have a major influence. Drying and wetting of sediments containing significant amounts of nutrients can result in the remobilisation of nutrients into the water column. Drying of sediments can also reduce habitat and expose peats and other types of organic matter to fire. The sediment type is generally the determining factor in these processes and may require different water regimes.

Where wetlands have peat or sandy peat, water regime contributions to sedimentary processes leading to the formation of peat need to be maintained. To achieve this, sediments must remain saturated/moist throughout summer, each year. This means that the water table must not drop below the stratigraphic level/layer that is capable of providing water to surface organics through capillary rise during summer.

Where *Baumea articulata* dominates the system this species needs to be inundated each year. The rationale behind this is that sediments that receive predominantly allochthonous organic matter, usually faster than it can be broken down or metabolised or washed away will accrue layers of peat. This process requires a moisture regime to keep sediments anaerobic (to slow the metabolism) and prevent them from burning (since burning is very rapid metabolism). EWRs for this objective will need to ensure that sediments remain saturated/moist throughout summer, each year, and that vegetation communities that contribute the bulk of this material continue to do so. *Baumea articulata* dominated assemblages are identified as such here, but there are others. Sediments need to be mapped across the SCP.

Where wetlands are known to have, or are likely to have potentially acid sulphate soils (PASS) in their sediments, anaerobic sediments need to be prevented from drying, cracking and aerating. Exposure of anaerobic sediments by lowering water table during periods of high temperatures, exacerbated if associated with removing covering vegetation, will produce the undesired effect. To prevent this, sediments must remain saturated during late summer and early autumn every year.

Sediments need to be mapped across the SCP to identify where PASS occurs and where local vulnerabilities may exist. Management becomes awkward because two management paradigms currently operating contradict the water regimes required to prevent PASS. One of the management options for eutrophic systems is to dry the sediments out so that phosphorus can be more effectively bound in the sediment the other is that most wetlands on the SCP need to dry out seasonally.

Cave fauna

Root mat communities of the Yanchep Caves persist in permanent pools or streams. As excessive declines in levels are known to expose the suspended root mats and cause them to die-off, stable water levels are required. Water quality is also an important issue for cave fauna that require stable pH, dissolved oxygen and temperature, with minimal daily, seasonal or annual variation.

Summary

In summary the following outcomes of Task 1 included:

- Potential GDEs not previously considered based on depth to groundwater mapping of Gnangara and Jandakot Mounds were identified.
- Gnangara
- >400 wetlands
- 33 Bush Forever Sites supporting areas of phreatophytic terrestrial vegetation
- Six mound springs
- Four caves
- Near shore marine systems.
- Identified ecological values of new GDEs (where previously assessed)
- Outlined changes in ecological condition (where assessed)
- Recommended ecological management objectives developed to represent the ecological values identified.

Stage II was structured into three parts:

- Summary of existing information on GDEs and their EWRs, review of current EWR methods and description of approach used in report
- General (qualitative) EWRs for all GDEs listed in Task 1 (identification of environmental values), quantitative EWRs for sub-set of GDEs with sufficient information
- GDE susceptibility to groundwater level changes and likely response to predicted changes in groundwater level.

The scope of the study is described in the following tasks that identified and re-evaluated ecological values:

Task 1a

This task involved:

- A desktop review of ecological values identified in the 1995 *Section 46 Review (Gnangara)*, 1997 *East Gnangara Environmental Water Provisions Plan*, and 1991 *Public Environmental Review* and 1992 *Environmental Management Program (Jandakot)*.
- A restatement of the 1995, 1997 and 1991–92 values where applicable and a reassessment and redefinition of these values where they changed.

- Identification of the ecological values of GDEs in the wider study area that were not considered in 1995, 1997 and 1991–92, but were now appropriate to define (desktop identification and site inspection).

Task 1b

This task involved consideration of how values may change under a dry climate scenario or other land use changes. Outcomes were:

- A prediction of how the values as defined in task 1a may alter with a declining water level scenario. This utilised predictions based on probable continuation of current water level trends, as well as likely climate scenarios.
- An identification of significance of altered values and areas where there is a high level of degradation risk. Consideration was given to interim management approaches to managing this risk until the progression of the hierarchical management framework proposed.
- A definition of how the values identified in 1a may alter under a rising water level scenario. Influencing factors were noted, for example, that longer term increases in water levels are likely in areas proposed for urban development under the MRS, or where other land use changes.

Task 1c

- Proposed management objectives for the values identified in tasks 1a and 1b. Proposed objectives utilised information on biological and ecological parameters collected.

Proposed ecological water requirements

- Establish water regimes (EWRs) considered necessary to support the values identified in Tasks 1a and 1b.
- In addition to longer term climate scenarios/water level trends (already considered in tasks 1a and 1b), in proposing EWRs, the rate of change of water availability was considered, as well as the effect of short-term (inter-annual) variations in rainfall, along with the effect of high temperatures and other climate parameters were factored into the EWRs.
- The EWRs were proposed within a consistent framework that can be reiterated as EWPs for management purposes.

Parameter identification

- This task involved the identification of parameters that can be used to reflect the ecological values, environmental condition and health of the GDEs.
- The parameters provided for better measures of environmental condition/health than the surrogate approach currently provided through groundwater/wetland water levels.
- The parameters considered the 'lag' effects between depressed groundwater levels and environmental conditions/health.
- The parameters have a defined relationship with groundwater levels.
- The variability of climate was considered, particularly in terms of long term cyclic variation, extended wet or dry periods, temperature effects, or other factors that may affect those parameters.
- The importance of each parameter in characterising the risk to the environment was evaluated, with a focus on parameters that are particularly important in characterising risk. The parameters were designed to be able to identify whether impacts to environmental values

are short/long term, reversible/irreversible, minor/catastrophic (in terms of being able to meet the management objectives developed in Task 1c).

- The ease of measurement of the parameters in terms of the cost-effectiveness and practicalities of monitoring was considered.
- Advice on the early warning capability of the parameters in terms of available time for implementing management responses was given i.e. the lead time that will be available from the time the parameter indicates that there is potential change of value(s), to the time of occurrence of that change.

Adoption into a management framework

This task involved:

- Providing advice in the development of a hierarchical response based management framework.
- Developing model Ministerial environmental conditions that reflect the ecological values, EWRs and parameters.
- NOTE: the task proposed model conditions based on the ecological values identified within this study. It should be recognised that the final environmental criteria to be proposed for approval might involve acceptance of some change to the values in balancing the economic and social aspects of use of the groundwater resource. However, the model conditions suggested quantified parameters in accordance with the ecological values identified within Task 1 for demonstration purposes and to allow testing of the approach.

Monitoring program

- This task involved reviewing existing ecological monitoring programs associated with groundwater dependent ecosystems within the study areas and providing advice on a revised program, based on at least monitoring environmental condition and other factors considered appropriate to achieve good management. It also considered the frequency of ground or surface water level monitoring necessary to assist in the monitoring of ecological health at each site. A specific review of groundwater level monitoring is being carried out as a separate project. That project focuses on the adequacy of the monitoring bore network in monitoring the effects of groundwater abstractions, climate, land use and management measures, on the groundwater resource and not on how it relates to the monitoring of ecological health.
- The monitoring review clarified the monitoring objectives, and included the monitoring requirements needed to ensure compliance with the (likely) environmental conditions. A revised monitoring program was recommended. The revised monitoring program should be able to demonstrate the achievement or otherwise of the management objectives in set in Task 1c. The cost of implementation in recommending a revised monitoring program was considered.

Appendix 2 – Groundwater–Wetland Water Level Relationship Study

Introduction

The Department of Environment (DoE) is undertaking a review into environmental management on the Gnangara and Jandakot Mounds in the Perth region. As part of this study, Rockwater was commissioned to investigate the relationship between monitored wetland and groundwater levels for 28 wetland sites comprising 18 on the Gnangara Mound and 10 on the Jandakot Mound.

Hydrogeological background

In the Perth region the Swan Coastal Plain is formed by a complex sequence of Pliocene to Quaternary sedimentary rocks referred to as the superficial aquifer. They occur in three sub-parallel belts of about 10km wide, which from west to east are referred to as the Spearwood and Bassendean Dunes and the Pinjarra Plain.

The Pinjarra Plain comprises mainly clayey sediments, which interfinger and grade into a variable, predominantly sandy sequence of sand and basal limestone which underlie the Bassendean Dunes. Overlying and abutting against the sediments forming the Bassendean Dunes is a predominantly carbonate sequence consisting of fixed and decalcified carbonate cemented dunes underlain by shallow water marine limestone. The limestone is usually very permeable and is locally karstic with cave systems. They rest on Mesozoic sediments of the Perth (sedimentary) Basin.

The Gnangara and Jandakot mounds in the Superficial aquifer, originate from rainfall recharge and occur in large areas of relatively high topography on poorly defined topographic divides on the Bassendean Dune system. Radial groundwater flow occurs from the groundwater mounds and some groundwater locally leaks downward into underlying Mesozoic formations.

The various wetlands are located where the water table permanently or seasonally outbreaks at the surface. They are usually located in interdunal swales in Spearwood and Bassendean Dunes, at the margins between the Spearwood Dunes and Pinjarra Plain with the Bassendean Dunes. Other wetlands occur on groundwater divides and sites of uncertain origin. The wetlands are generally local, small basins where biogenic deposits (principally peat and diatomite) are deposited.

Water levels in the various wetlands are maintained by local flow systems within the regional flow systems of the groundwater mounds. Wetlands on the Bassendean Dunes and Pinjarra Plains are generally flow-through wetlands with capture and release zones of various sizes. However, in the Spearwood Dunes inflow and outflow may be localised by cave-systems.

Before settlement, the groundwater system was in a dynamic balance with wetlands, climatic conditions, vegetation and sea levels. Since settlement, clearing of bushland, urban drainage, and groundwater pumpage from both the Superficial and Leederville aquifers has altered the dynamic balance. Superimposed on these changes has been a period of below average rainfall, which has been experienced since the mid-1970s when most of the changes have been occurring.

The changes to the dynamic balance that have occurred have affected the size and persistence of most wetlands. Presently many wetlands are now more extensive and persistent than formerly and there is a public perception that this is their natural condition. However, various wetlands are being affected by the climatic conditions, pumpage and agro-forestry, and DOE is seeking to manage various wetlands to meet environmental and community requirements.

Results of review

Monitoring results from the wetlands and all monitoring bores within a 500m radius were reviewed.

The relationship between wetland and groundwater hydrographs and topographic data were compared and assessed. The results of this were described in a progress report (Rockwater, 2003). In the present report only surface water data and data from a criteria bore (or suitable bore) are described, and conclusions provided. These data and results are summarised in Tables 1, 2 and 3.

Groundwater–wetland water level relationships

The groundwater–wetland relationships for the various wetlands are briefly discussed, and results summarised in the text. The principal results referenced to the Gnangara Mound and Jandakot Mound are given in Tables 4 and 5.

Table 1 – Summary of data review for wetlands located on the Pinjarra Plain

AWRC Ref No	Bore Name	Orientation to Staff Gauge (or Permanent Marker)	Orientation to Lake	Total Depth of Shallow Bore (m)	Approx. Water Level RL (m AHD)[1]	Approx. Difference Between Lake and Groundwater Levels (m)[1/2]	Approx. Hydraulic Gradient From/To Lake[1]	Upward/ Downward Aquifer Head[3]	Correlation of Water Levels and Trends	Comments
Muchea (B/P.3)										
6162630	**Lexia 86 Swamp**	Staff	East of swamp	-	<48.3	-	-		-	
61613215	GNM16	20 m W	Up-gradient	2	47.9				High	Swamp levels appear to be an expression of groundwater rising above ground level.
	Lexia 94 Swamp	No staff								
61613216	GNM17A	-	In swamp	1.2	46.2					
61613217	GNM17B	-	In swamp	5.5	46.2			Slight downward		Slightly lower groundwater levels during low periods in some years; possibly some perching and/or recharge to the groundwater.
	Lexia 186 Swamp	No staff								
61613214	GMN15	-	North of swamp	3	47.4				Unknown	Groundwater levels are unlikely to have risen above ground level at this site since monitoring commenced in 1995.
	Egerton Seepage	No staff								
61618607	B23	-	Top of catchment						Unknown	Groundwater levels are unlikely to have risen above ground level at this site since monitoring commenced in 2000.
	Edgecombe Seepage	No staff								
61618606	B10	-	Top of catchment						Unknown	Groundwater levels are unlikely to have risen above ground level at this site since monitoring commenced in 1999.
Bennet Brook (B/P.4)										
6162557	**Forrestdale Lake**	Staff	Northern edge	-	<21.6	-	-		-	
61410714	Bore 602	170 m E	North-east edge	6	22	1	0.04		Poor	Groundwater level rise precedes lake water level rise, and groundwater levels remain higher for longer, suggesting groundwater flow to the lake is restricted.

1. Refers to recent years only, and therefore may differ slightly from the text.
2. Negative values indicate groundwater levels are lower than lake levels.
3. From detailed data review presented in the progress report (Rockwater 2003)

Table 2 – Summary of data review for wetlands located on the Bassendean Dunes

AWRC Ref No	Bore Name	Orientation to Staff Gauge (or Permanent Marker)	Orientation to Lake	Total Depth of Shallow Bore	Approx. Water Level RL (m AHD)[1]	Approx. Difference Between Lake and Groundwater Levels (m)[1/2]	Approx. Hydraulic Gradient From/To Lake[1]	Upward/ Downward Aquifer Head[3]	Correlation of Water Levels and Trends	Comments
Gnangara Grouping										
6162591	**Lake Gnangara**	Staff	20 m W	-	41.9	-	-	-	-	
61618440	Bore 8386	1,010 m E	80 m up-gradient	6	41.9	0	0	-	High	
61610843	MM9	1,250 m NE	200 m up-gradient	26	42.4	0.5	0.003	-	Moderate	
6162577	**Lake Mariginiup**	Staff	40 m W	-	41.5	-	-	-		Staff location to be checked.
61610685	MS10	40 m E	Immediately down-gradient	9	41.1	-0.4		-	Moderate	Historically groundwater levels were very similar to lake levels. With declining groundwater levels, however, groundwater levels have dropped below lake levels, suggesting some perching in the lake.
61610687	MS11	330 m SW	500 m down-gradient	20	38	-3.5	0.007	-	Moderate	
61610688	MS7	580 m NNW	Down-gradient	9	40.8	-0.7		Strong downward	Moderate	
61610694	MS4	1,050 m NNE	Immediately down-gradient	9	41.1	-0.5		-	Moderate	Magnitude of seasonal fluctuations is lower.
61610733	MS13	1,025 m SE	100 m up-gradient	9	42.1	0.6	0.006	-	Moderate	Magnitude of seasonal fluctuations is lower.
61610736	MT1S	1,225 m ENE	80 m up-gradient	9	42.4	0.9	0.011	Slight upward	Moderate	Magnitude of seasonal fluctuations is lower.
61610742	MS1	1,325 m NE	Immediately up-gradient	9	42.3	0.8	0.008	-	Moderate	
6162578	**Jandabup Lake**	Staff	SE Corner	-	44.4	-	-	-	-	
61610728	JB15A	1,700 m NW	Immediately down-gradient	10	43.8	-0.6		Nil	Moderate	Greater declining trend in groundwater levels has lead to an increase in the difference between lake and groundwater levels, particularly during periods of low levels.

Table 2 – Summary of data review for wetlands located on the Bassendean Dunes

AWRC Ref No	Bore Name	Orientation to Staff Gauge (or Permanent Marker)	Orientation to Lake	Total Depth of Shallow Bore	Approx. Water Level RL (m AHD)[1]	Approx. Difference Between Lake and Groundwater Levels (m)[1/2]	Approx. Hydraulic Gradient From/To Lake[1]	Upward/ Downward Aquifer Head[3]	Correlation of Water Levels and Trends	Comments
61610739	MT2S	2,730 m NW	500 m NW	18	43.2	-1.2	0.002	Nil	Moderate	Greater declining trend in groundwater levels has lead to an increase in the difference between lake and groundwater levels.
61610745	MT3S	2,630 m NW	250 m NW	13	44.6	0.2		Downward	Moderate	Greater declining trend in groundwater levels has lead to a decrease in the difference between lake and groundwater levels.
61610761	JB4	1,350 m SW	500 m SSW	30	42.4	-2	0.004	-	Moderate to poor	Greater declining trend in groundwater levels has lead to an increase in the difference between lake and groundwater levels.
61610762	JB5	780 m SE	500 m SSE	11	44.9	0.5	0.001	-	Moderate to poor	Greater declining trend in groundwater levels has lead to a decrease in the difference between lake and groundwater levels.
61610763	JB12A	430 m SE	150 m SE	7	44.8	0.4	0.002	Slight downward	Moderate	Greater declining trend in groundwater levels has lead to a decrease in the difference between lake and groundwater levels.
61610773	JB13C	1,660 m NNE	300 m up-gradient	8	45.8	1.4	0.005	Slight downward	Moderate to poor	
61610776	JB14C	1,660 m N	50 m up-gradient	9	45.2	0.8	0.016	-	Moderate to poor	Difference in water levels tends to be greatest during periods of low water levels.
61610777	JB17A	1,840 m NE	500 m up-gradient	-	46.9	2.5	0.005	-	Moderate to poor	Difference in water levels tends to be greatest during periods of low water levels.
61610817	WM23	600 m E	300 m up-gradient	18	45.7	1.3	0.004	-	Moderate	Greater declining trend in groundwater levels has lead to a decrease in the difference between lake and groundwater levels.
61610821	JB9B	1,130 m NE	500 m up-gradient	7	45.8	1.4	0.003	Slight downward	Moderate	
Jandakot Grouping										
6142544	**Twin Bartram Swamp**	Staff	South-west corner	-	23.5	-	-	-	-	
61410715	Twin Bartram Swamp Bore	55 m S	South-west corner	5.5	23.5	0	0	-	High	Groundwater levels above 23.0 m AHD correlate very well with lake levels, suggesting inundation at the lake is a direct result of the rise of groundwater levels to above ground. More distant observation bores (>500 m) indicate a hydraulic gradient of 0.005 to the west and south of the swamp.

Table 2 – Summary of data review for wetlands located on the Bassendean Dunes

AWRC Ref No	Bore Name	Orientation to Staff Gauge (or Permanent Marker)	Orientation to Lake	Total Depth of Shallow Bore	Approx. Water Level RL (m AHD)[1]	Approx. Difference Between Lake and Groundwater Levels (m)[1/2]	Approx. Hydraulic Gradient From/To Lake[1]	Upward/ Downward Aquifer Head[3]	Correlation of Water Levels and Trends	Comments
6142576	**Shirley Balla Swamp**	Staff	Northern edge	-	<25.0	-	-	-	-	
61410713	Shirley Balla Swamp Bore	200 m SE	Immediately up-gradient	4.5	24.6	0.1	-		Moderate	Groundwater level rise follows the water level rise in the wetland, although peak groundwater levels can be up to 0.2 m higher than wetland levels. Possibly some perching and recharge from the lake.
6142547	**Beenyup Road Swamp**	Staff	NW corner	-	<24.6					
61410711	Beenyup Road Swamp Bore	70 m SW	Immediately down-gradient	5	24	-0.1	-	-	Moderate	Groundwater level rises follow rises in swamp levels, suggesting some perching and recharge from the swamp.
Riverdale Grouping										
6162628	**Melaleuca Park - EPP 173**	Staff	Northern edge swamp		50.6	-	-	-		
61613213	GNM14	20 m NE	Down-gradient of swamp	8	49.8	-0.8			Poor	Evidence of significant perching in the wetland.
	Melaleuca Park - Dampland 78	No staff								
61613231	GNM31	-	South of swamp	10	65.9	-	-	-	Unknown	Groundwater levels are unlikely to have risen above ground level at this site since monitoring commenced in 1995.
Bibra Grouping										
6142521	**North Lake**	Staff	Northern edge	-	13	-	-	-	-	
61410726	North Lake Bore	170 m W	50 m down-gradient	3	12.5	-0.5			Moderate to high	Groundwater levels tend to decline faster than lake levels, suggesting perching in the lake.
6142520	**Bibra Lake**	Staff	East side	-	14.4	-	-	-	-	
61410177	BM7C	975 m SW	South-west corner	10	-	0.5		downward	High	Groundwater levels have not been measured since 1999. Prior to this groundwater levels were about 0.5 m lower than lake levels with a high correlation to lake level trends.

Table 2 – Summary of data review for wetlands located on the Bassendean Dunes

AWRC Ref No	**Bore Name**	**Orientation to Staff Gauge (or Permanent Marker)**	**Orientation to Lake**	**Total Depth of Shallow Bore**	**Approx. Water Level RL (m AHD)[1]**	**Approx. Difference Between Lake and Groundwater Levels (m)[1/2]**	**Approx. Hydraulic Gradient From/To Lake[1]**	**Upward/ Downward Aquifer Head[3]**	**Correlation of Water Levels and Trends**	**Comments**
61410186	BM2C	790 m W	200 m down-gradient	19	12.5	2	0.01	downward	Moderate	
										Groundwater levels monitored in additional bores between 1983 and 1986 suggest a moderate hydraulic gradient into the lake (0.007) and a high hydraulic gradient for groundwater flowing from the lake (0.01).
6142517	**Lake Thomson**	N edge	-	-	<11.9	-	-	-	-	
61410367	TM14A	1,100 m SW	Immediately down-gradient	35	11.6			downward in summer - upward in winter	High	Peak groundwater levels are up to 0.4 m lower than peak lake levels. Note, bore TM14C (below) is more relevant to lake levels because of its shallower depth.
61411110	TM14C	1,100 m SW	Immediately down-gradient	6	11.7			downward in summer - upward in winter	High to moderate	Groundwater level peaks are sharper, with groundwater levels falling before lake levels, suggesting perching in the lake.
61410365	TM7A	1,545 m SW	500 m down-gradient	19	8.5	3	0.006	downward	Poor	Minimal seasonal fluctuations suggest bore is completed in a more highly transmissive part of the aquifer.
61611106	TM12C	1,975 m SW	300 m south-east	21	10	1.5	0.005		Moderate	Lower seasonal fluctuations suggest bore is completed in a more transmissive part of the aquifer.
61611108	TM10C	1630 m S	Southern edge	5					High	Monitoring in this bore stopped in 1999. Prior to this however, groundwater levels were very similar to those measured in the lake.
61611111	TM4C	650 m WSW	Immediately down-gradient	6	11.9				High	Possibly some evidence of perching.
										Monitoring of groundwater levels in bores up-gradient of the lake between 1985 and 1993 suggest a high hydraulic gradient (about 0.016) exists into the lake.
6142523	**Lake Yangebup**	Staff	Southern edge	-	16	-	-	-	-	
61419707	JE21C	1,030m NW	100 m NW	6	15.7	-0.3	0.003		High	

Table 2 – Summary of data review for wetlands located on the Bassendean Dunes

AWRC Ref No	Bore Name	Orientation to Staff Gauge (or Permanent Marker)	Orientation to Lake	Total Depth of Shallow Bore	Approx. Water Level RL (m AHD)[1]	Approx. Difference Between Lake and Groundwater Levels (m)[1/2]	Approx. Hydraulic Gradient From/To Lake[1]	Upward/ Downward Aquifer Head[3]	Correlation of Water Levels and Trends	Comments
61410411	TD29	180 m SE	100 m south	5	15.9	-0.1			High	Probably a better bore than JE21C for monitoring groundwater levels when the lake dries.
6142516	**Banganup Lake**	Staff	North-west corner	-	<12.7	-	-	-	-	
61419614	LB14	60 m NW	North-west corner	4	12	-0.05	0.0008		High	Peak groundwater levels above 12.7 m AHD correlate very well with lake levels, suggesting inundation at the lake is a direct result of the rise of groundwater levels to above ground.
61419602	LB2	465 m SW	Immediately down-gradient	5.5	10.9	-1.1			Moderate	
61419605	LB5	725 m SE	50 m up-gradient	6	12.6	0.6			Moderate	
										Data obtained in other monitoring bores around the lake between 1992 and 1994 indicate groundwater flows beneath the swamp from east to west with a hydraulic gradient of about 0.003 to 0.005, with the steeper gradient occurring down-gradient of the swamp.
6142522	**Kogolup Lake South**	Staff	South-east corner	-	14	-	-	-	-	
61410727	Kogolup Lake Bore	At surface monitoring site	South-east corner	1.5	14.2					Groundwater levels monitored after surface monitoring ceased.
61611112	TM2C	570 m W	400 m down-gradient	22	13	-1	0.003		Moderate	
61611114	TM5C	520 m S	500 m South	5			0.003		Moderate	Data to 1993 only.

1. Refers to recent years only, and therefore may differ slightly from the text.
2. Negative values indicate groundwater levels are lower than lake levels.
3. From detailed data review presented in the progress report (Rockwater 2003)

Table 3 – Summary of data review for wetlands located on the Spearwood Dunes

AWRC Ref No	Bore Name	Orientation to Staff Gauge (or Permanent Marker)	Orientation to Lake	Total Depth of Shallow Bore	Approx. Water Level RL (m AHD)[1]	Approx. Difference Between Lake and Groundwater Levels (m)[1/2]	Approx. Hydraulic Gradient From/To Lake[1]	Upward/ Down-ward Aquifer Head[3]	Correlation of Water Levels and Trends	Comments
Yanchep Grouping										
6162517	**Lake Goollelal**	Staff	South-western edge	-	27	-				
61610112	Bore 459	90 m SE	Immediately down-gradient	-	26.8	-0.2	0.005	-	High	
6162564	**Loch McNess**	Staff	Southern tip	-	7	-				
61710028	BD9 (LMN1A)	600 m NW	Immediately down-gradient	-	7	<-0.1			High from 1986	Data are erratic prior to 1986 with no correlation to lake levels.
61710029	BD10 (LMN1C)	600 m NW	Immediately down-gradient	-	6.5	-0.5			Moderate to poor	Water levels have declined since 1998; prior to then they were about 0.5 m higher than lake levels.
6162565	**Lake Yonderup**	Staff	North-eastern corner	-	6	-	-			
61612106	YN7	90 m NE	100 m up-gradient	-	7.8	1.8	0.018		Poor	
6162566	**Coogee Spring**	Staff	60 m east of south-eastern corner	-	11	-	-	-		Lake levels artificially maintained with groundwater from the Leederville aquifer
61611303	CG4/90	At staff site	60 m east of south-eastern corner	7.2	9.8	-1.2	-	-	Poor	Water perching in lake
							0.006	-		Groundwater levels monitored in nine other monitoring bores between 1990 and 1992. In a number of bores a significant rise in minimum water level was noted between the summer of 1991 and 1992; the trend was not as pronounced in the lake water levels.
6162567	**Lake Nowergup**	Staff	Northern edge	-	16.3	-	-	-		

Table 3 – Summary of data review for wetlands located on the Spearwood Dunes

AWRC Ref No	Bore Name	Orientation to Staff Gauge (or Permanent Marker)	Orientation to Lake	Total Depth of Shallow Bore	Approx. Water Level RL (m AHD)[1]	Approx. Difference Between Lake and Groundwater Levels (m)[1/2]	Approx. Hydraulic Gradient From/To Lake[1]	Upward/ Down-ward Aquifer Head[3]	Correlation of Water Levels and Trends	Comments
61611247	LN2/89	450 m SW	25 m down-gradient	7	15.3	-1	0.04	-	Moderate	Peak groundwater levels are possibly higher than natural, due to recharge from the lake during artificial augmentation of lake levels.
61611220	LN19/89	230 m SE	Immediately up-gradient	5	16.3	0		Slight downward	Moderate	Historically, groundwater levels were 0.5 to 1 m higher than lake levels, but they have declined more rapidly and are currently at similar levels.
61611223	LN12/89	235 m NW	North	14	15.8	-0.5		Strong downward	Moderate	Historically, groundwater levels were about 0.25 m higher than lake levels, but they have declined more rapidly and are currently at about 0.5 m lower than lake levels.
61611225	LN4/89	400 m NW	40 m down-gradient	8	13 to 14	- 1 to 3	0.04	-	Moderate	Values measured in 2003 may be in error, or else there has been a strong groundwater level decline at this site.
61611228	LN8/89	600 m SSE	30 m up-gradient	8	16.3	0	0	Nil	Moderate	Historically, groundwater levels were up to 0.5 m higher than lake levels, but they have declined more rapidly and are currently at similar levels.
61611231	LN11/89	960 m SSE	Immediately up-gradient	8	16.5	0.2		-	Moderate	Groundwater levels are generally very similar to lake levels, but can be up to 0.3 m lower during summer, suggesting some perching in the lake.
61611233	LN6/89	1,015 m S	Immediately down-gradient	8	15	-1.3		Strong downward?	Moderate	Magnitude of seasonal fluctuations is up to two times higher than that for lake levels.
61611234	LN5/89	765 m SSW	Immediately down-gradient	13	12	-4		Strong downward	Moderate to high	Magnitude of seasonal fluctuations is up to one and a half times higher than that for lake levels.
61611235	LN3/89	715 m SW	350 m down-gradient	30	6.3	-10	0.029	Strong upward	Moderate to poor	Magnitude of seasonal fluctuations is less than half of that for lake levels.
61611237	LN25/89	900 m SW	350 m down-gradient	38	9	-7	0.020	-	Moderate to poor	Magnitude of seasonal fluctuations is less than half of that for lake levels.
61611238	LN27/89	1,165 m SSW	300 m down-gradient	41	8.8	-7.5	0.025	-	Moderate to poor	Magnitude of seasonal fluctuations is less than half of that for lake levels.

Table 3 – Summary of data review for wetlands located on the Spearwood Dunes

AWRC Ref No	Bore Name	Orientation to Staff Gauge (or Permanent Marker)	Orientation to Lake	Total Depth of Shallow Bore	Approx. Water Level RL (m AHD)[1]	Approx. Difference Between Lake and Groundwater Levels (m)[1/2]	Approx. Hydraulic Gradient From/To Lake[1]	Upward/ Down-ward Aquifer Head[3]	Correlation of Water Levels and Trends	Comments
61611245	LN15/89	300 m E	200 m up-gradient	8	17.3	1	0.005	Nil	Poor	Historically, groundwater levels were up to 2 m higher than lake levels, but they have declined more rapidly and are currently about 0.5 to 1 m higher.
6162572	**Lake Joondalup**	Staff	150 m W	-	16.5	-	-	-	-	Staff gauge location needs to be checked.
61610661	Bore 8281	1,700 m E	150 up-gradient	4	18.3	1.8	0.012	-	High	Steep hydraulic gradient between the bore and the lake.
61610628	JP20C	2,025 m NNE	30 m up-gradient	5	16.8			Nil	High	Only two data points per year.
6162623	**Lake Wilgarup**	Staff	SW corner		<6.0					
61618500	Wilgarup lake bore	0	SW corner	7	4.9	>0.5			Moderate	Groundwater levels are up to 0.5 m lower than sump levels during periods of inundation, suggesting perching and possible recharge.
61612107	YN8	755 m NE	340 m NE	18	8.9	4	0.012			
6162624	**Pipidinny Swamp**	Staff	SW corner	-	2.2	-	-	-	Unknown	

1. Refers to recent years only, and therefore may differ slightly from the text.
2. Negative values indicate groundwater levels are lower than lake levels.
3. From detailed data review presented in the progress report (Rockwater 2003)

Table 4 – Summary of predominant groundwater-wetland relationships on the Gnangara Mound

Lake or Wetland	**Predominant Groundwater/Surface Water Relationships and Criteria Bore Status**
	No anomalous relationship
Lake Goollelal	High correlation – no anomalous relationship. No criteria bore.
Loch McNess	High correlation – no anomalous relationship; bore depths need to be checked. No criteria bore.
Lake Gnangara	High correlation – no anomalous relationship. Criteria bore probably representative of conditions.
	High groundwater gradients – monitoring bore location important
Lake Yonderup	Poor correlation – high groundwater gradient into lake. No criteria bore; one bore up gradient, construction unknown.
Lake Joondalup	High correlation – high groundwater gradient into and out of lake. Criteria bore located 100 m up-gradient with 2 m difference between groundwater levels and lake levels. Alternative monitoring bore (JP20C) identified.
Lake Nowergup	Moderate correlation – high hydraulic gradient out of the lake. Criteria bore located 25 m down-gradient with 1 m difference between groundwater and lake levels. Alternative monitoring bore (existing or new) may be required.
	Evidence of perching
Coogee Spring	Poor correlation – water perching in the lake (artificially augmented). Criteria bore located 60 m up-gradient; monitoring bore closer to lake recommended.
Lake Wilgarup	Moderate correlation – evidence of perching and possible recharge from the lake. Criteria bore probably representative.
Melaleuca Park EPP 173	Poor correlation – evidence of significant perching. No criteria bore.
	Groundwater decline greater than lake level decline
Lake Nowergup	Moderate correlation – Groundwater levels declining more rapidly than lake levels (artificially augmented). A high groundwater gradient exists between the lake and the criteria bore, alternative may be required.
Lake Mariginiup	Moderate correlation – Groundwater levels declining more rapidly than lake levels, with evidence of water perching in the lake. Criteria bore probably representative.
Lake Jandabup	Moderate correlation – Groundwater levels declining more rapidly than lake levels, with evidence of water perching in the lake (occasional artificial augmentation). No criteria bore.
	Surface water an expression of groundwater level rise to above ground level
Lexia 86 Swamp	High correlation – Swamp levels an expression of the rise of groundwater above ground level. Criteria bore representative.
	Insufficient data for assessment
Lexia 94 Swamp	No surface water data
Lexia 186 Swamp	No surface water data
Melaleuca Park Dampland 78	No surface water data
Pipidinny Swamp	No groundwater data
Egerton Seepage	No surface water data
Edgecombe Seepage	No surface water data

Table 5 – Summary of predominant groundwater-wetland relationships on the Jandakot Mound

Lake or Wetland	**Predominant Groundwater/Surface Water Relationships and Criteria Bore Status**
	No anomalous relationships
Lake Yangebup	High correlation – no anomalous relationships. Criteria bore located in release zone, alternative monitoring bore recommended (TD29)
	High groundwater gradients – monitoring bore location important
Lake Thompson	Moderate correlation – high gradient into lake. Criteria bore in release zone and completed at 35m depth; an alternative monitoring bore is recommended.
Forrestdale Lake	Poor correlation – high groundwater gradient into lake. Criteria bore may not be representative, alternatives should be considered.
Bibra Lake	High correlation – high groundwater gradient into and out of the lake. Water levels not measured in criteria bore since 1999
	Evidence of perching
Shirley Balla Swamp	Moderate correlation – evidence of perching and possible recharge from the lake. Criteria bore probably representative, although a monitoring bore closer to the staff gauge could be considered.
Beenyup Road Bore	Moderate correlation – evidence of perching and possible recharge from the lake. Criteria bore probably representative.
Lake Thompson	Moderate correlation – evidence of perching. Criteria bore in release zone and completed at 35 m depth; an alternative monitoring bore is recommended.
North Lake	Moderate correlation – evidence of perching. Criteria bore located in release zone, where groundwater levels are lower than lake levels.
	Surface water an expression of groundwater level rise to above ground level
Banganup Lake	High correlation – swamp levels an expression of the rise of groundwater above ground level. Criteria bore probably representative.
Twin Bartram Swamp	High correlation – swamp levels an expression of the rise of groundwater above ground level. Criteria bore probably representative.
	Insufficient data for assessment
Kogolup Lake South	Surface water monitoring ceased before groundwater monitoring commenced. No criteria bore.
Bibra Lake	No groundwater data from 1999. Criteria bore not monitored.

Setting future criteria

The present study indicates that the setting of water level criteria is rather arbitrary. Changes to the water balances of most wetlands on the coastal plain have occurred. Water levels have risen in some areas since first settlement as a result of urbanisation, and in others have fallen in response to drainage, pumpage and changes in land use. There is a difficulty in choosing representative bore sites that will reflect water levels in wetlands, because positioning bores in capture and release zones or in karstic limestone, as well as bore depths, will affect head measurements.

Based on the outcomes of this study, the following matters should be considered when setting and monitoring water-level criteria for the wetlands:

1. Are the criteria bore and surface monitoring staff appropriately located, and giving representative monitoring data?

2. Is the wetland perched, or partially perched?

3. Are there sufficient monitoring data to show seasonal and long-term trends?

4. Is the wetland in an area of high hydraulic gradients, which could result in groundwater flows to the wetland on the up-gradient side, and flows out of the wetland on the down-gradient side?

5. Is the wetland level controlled by a particular discharge mechanism, such as a karstic release zone?

6. Is there stormwater drainage to the wetland, or pumping of water to or from the wetland?

7. Is the wetland in an area where there is inter-aquifer flow (eg. from a confined aquifer to the superficial aquifer)?

Consideration needs to be given to reducing the amount of monitoring, and obtaining as many direct measurements as possible before setting criteria. This will require evaluation of each site, and possibly establishing paired staffs and monitoring bores. This needs more detailed discussion in the report that is to be prepared by DoE.

Proposals for investigations

The present network of monitoring staffs and monitoring bores has been gradually put in place over the last 35 years. This has been in response to:

- Drainage programs, management of bore fields on the Gnangara and Jandakot mounds.
- Threatened wetland habitats.
- Environmental concerns about possible unexpected effects of pumpage from existing and proposed bore fields on wetlands, vegetation, and cave systems.

As a result, the monitoring bores and measuring staffs are not of a uniform standard, and are inappropriately located and constructed in some instances.

Table 6 summarises the situation with respect to criteria bores or suitable monitoring data for the wetlands. Of the 28 wetlands, 23 (82 percent) either have no criteria bores, the criteria bores are unsuitable, or there are no (or insufficient) monitoring data available.

Table 6: Wetlands, and the Number of Suitable Criteria Bores

Area	Number of Wetlands	Number Without Criteria Bores	Number With Unsuitable Criteria Bores	Number With No or Insufficient Ground- or Surface-Water-Data
Gnangara Mound	18	5	4	6
Jandakot Mound	10	0	6	2

Conclusions

The present review has investigated the groundwater-wetland water level relationships of 28 wetlands comprising 18 on the Gnangara Mound and 10 on the Jandakot Mound (six on the Pinjarra Plain, 14 on the Bassendean Dunes and eight on the Spearwood Dunes). Hydrographs of surface water and groundwater levels in criteria bores and other bores have been manually compared to determine the degree of correlation between the hydrographs. Where anomalous relationships have been found, possible reasons have been discussed.

From the review it is concluded:

1. The relationship between surface water levels and groundwater levels is complex and no general relationship can be applied to all wetlands in the Perth region.

2. Water levels in wetlands are controlled by a variety of factors such as size, depth, physiographical location, nature and thickness of the sedimentary deposits in the wetlands, nature of the superficial aquifer, groundwater flow to or from underlying Mesozoic aquifers, land-use in capture zones, groundwater pumpage, urbanisation, and drainage to and from wetlands.

3. Each wetland has a specific water balance controlled by the relative size of components making up the balance, and the size and depth of the wetland.

4. The wetlands on the Bassendean Dunes and Pinjarra Plain are mainly flow-through systems with an upstream capture zone, and a downstream release zone, which maintains a plume of higher salinity groundwater.

5. The wetlands in karstic areas of the Spearwood Dunes vary from partly to completely dominated by groundwater flow in cave systems.

6. Relatively impermeable biogenic sediments are deposited in wetland basins. The thickness and nature of the sediments may affect the location of inflow and outflow from a wetland.

7. All wetlands on the coastal plain are permanently or seasonally in some degree of hydraulic connection with the regional water table. Perching of groundwater in wetlands probably only occurs for a short period after the onset of heavy rainfall.

8. The situation where water levels in a wetland were apparently identical in level and character was only found at two sites.

9. At many locations there were regular differences between surface and groundwater levels.

10. Without a detailed investigation it is very difficult to locate groundwater monitoring bores which accurately reflect surface water levels in wetlands.

11. The effects of groundwater inflow and outflow from the Superficial formations to the Leederville aquifer is inferred to be contributing to decline in some water levels on the western side of the Gnangara Mound.

12. A team should be assembled to ensure a suitable and reliable monitoring network is established and maintained.

Appendix 3 – Gnangara Land Use Zones Summary

Land and water use in Yeal Zone

Groundwater Level influences		'Business as usual' Current practice and committed developments		What can be done to protect the Mound?	
		Current / planned practice	**Relative impact on Mound***	**Actions**	**Barriers and drivers**
Land use and Water use	Pine plantation management	Pine impacts important in the west.	-1		Very young pines in the area are uneconomic to remove
	Urban development		0		
	Public abstraction	Confined aquifer abstraction may be impacting.	-1	Improve understanding of interaction between Yarragadee and superficial aquifer	Additional bores required across area for monitoring inputs to Yarragadee. Resources needed to monitor the area better, and in particular recharge areas. Needs use of wide range of expertise (botany, hydrogeology in designing research programs and interpreting data
	Private abstraction	Confined aquifer abstraction may be impacting.	-0.5	Water rights options for negotiating with landholders for water rights (transferring rights from private to public use)	
	Native vegetation management	Native vegetation impacts occur mostly in the north and east. Some areas are very dense.	-2	Bring burning regime to less than 10 yrs within the next 3 years Priority for burning – pristine areas with low risk of weed invasion	Need more efficient MoU with the Commonwealth to ensure that appropriate action can be taken (ie. burning regimes) Appropriate resourcing (DCLM) – fire management, biodiversity research Address Commonwealth's low priority for burning on its land
	Agricultural development		0		
	Supplementation of GDEs		0		
	Recharge using recycled water		0	Uncertainty about its applicability in this area	
Climate change		2 to 3m (some bores show up to 4m) decline by CDFM, although some bush fire impacts have partially mitigated these declines.	-3		
PRAMS Combined Scenario 2 prediction		2 to 3 m of additional decline anticipated in the next ten years.	N/A		General barrier – need for integration of skills, capacity building, retention of knowledge

* Relative impact on Mound. 3 (large change) to 1 (small change). Sign (+/-) indicates direction of change, ie. +ve rising, -ve falling, 0 is no impact.

Land and water use in Pinjar Zone

Groundwater Level influences		'Business as usual' Current practice and committed developments		What can be done to protect the Mound?	
		Current / planned practice	**Relative impact on Mound***	**Actions**	**Barriers and drivers**
Land use and Water use	Pine plantation management	Pine impacts important in the west.	-1	Thinning 100 per cent of pines to west of Pinjar borefield (near future)	Currently monitoring impact of thinning
	Urban development		0		
	Public abstraction	Major impacts near the Water Corp. borefields. Confined aquifer abstraction may also be impacting.	-2 (confined aquifer abstraction *is* also impacting)	P5O project – researching current impacts of drawdown on Banksia woodlands. Determine sub crop of Leederville aquifers	
	Private abstraction		0		
	Native vegetation management	Native vegetation impacts occur mostly in the east.	-1.5	Biodiversity and fire impacts research	Vegetation is already separated from the groundwater table. Commonwealth land to the east of the zone – the state has no control over burning regimes.
	Agricultural development		0		
	Supplementation of GDEs		0		
	Recharge using recycled water		0		
Climate change		3m decline by CDFM	-3		
PRAMS Combined Scenario 2 prediction		3 m of additional decline anticipated in the next ten years.	N/A		

* Relative impact on Mound. 3 (large change) to 1 (small change). Sign (+/-) indicates direction of change, ie. +ve rising, -ve falling, 0 is no impact.

Land and water use in Yanchep Caves Zone

Groundwater Level influences		'Business as usual' Current practice and committed developments		What can be done to protect the Mound?	
		Current / planned practice	**Relative impact on Mound***	**Actions**	**Barriers and drivers**
Land use and Water use	Pine plantation management	Pine impacts important in the east.	-2	Thinning and harvesting of pines Monitoring of pine removal to measure impacts	Large depth to groundwater – recharge issue (there will be a slow response. Negotiate compensation with Wesbeam
	Urban development		0		
	Public abstraction	Minor impacts near the pine plantations in the east.	-0.5	Review effect of Leederville drawdown on water levels in the superficial aquifer	
	Private abstraction	Some impacts close to the caves in the west.	-1	Undertake a survey on water use Implement metering (already happening) Restricting water trading to 10,000 m3 assuming water available (possible sustainable limit reduction)	Impacts on southern caves from Carabooda (horticulture)
	Native vegetation management	Native vegetation impacts occur mostly in the west.	-1	TEC research required (other than caves TECs) to inform burning responses. Maintain the Tuart woodlands so we have tuart roots for the caves (bore, long-term viability) Burn bushland to the east of the caves and wetlands regularly	Native vegetation quite dense Biodiversity issues Presence of TECs
	Agricultural development		0		
	Supplementation of GDEs	Caves supplementation could be a long-term solution.	+1		
	Recharge using recycled water		0		
Climate change		2-3 m decline by CDFM	-3		
PRAMS Combined Scenario 2 prediction		2 to 3 m in the east and 1 to 2 m in the west of additional decline anticipated in the next ten years	N/A		

* Relative impact on Mound. 3 (large change) to 1 (small change). Sign (+/-) indicates direction of change, ie. +ve rising, -ve falling, 0 is no impact.

Land and water use in North Wanneroo Zone

Groundwater Level influences		**'Business as usual' Current practice and committed developments**		**What can be done to protect the Mound?**	
		Current / planned practice	**Relative impact on Mound***	**Actions**	**Barriers and drivers**
Land use and Water use	Pine plantation management	Impacts occur in the east.	-2 (may only be –1)	Accelerate harvest/ total clear fell Define after harvest land use (change to what?)	Economics LVL agreement (State Agreement Act) Desired water outcomes
	Urban development		0	Change from no urban development to increased urbanisation	Cost of infrastructure Increased costs of food because of displaced horticulture Social values
	Public abstraction	Minor impacts, no more abstraction planned.	-0.1 (possibly –1)	Artificial recharge	Social issues
	Private abstraction	Major impacts, allocation limit reached.	-3	Implement a percentage reduction in abstraction Increase water use efficiency through education means Introduce a charge for water abstracted Relocation of Abstraction for horticulture	Economics Need for compensation for relocation Deciding what to replace relocated uses with?
	Native vegetation management	Very little native vegetation left in the north of this area, but some large areas remain in the south.	-0.5	Increase frequency and extent of burning of native vegetation Removal of native vegetation	Political issues Public perception Air pollution (from burning) Loss of ecological values Research needed to support case for increased frequency of burning
	Agricultural development	Possible horticultural precinct.	-1	Development in alternate locations Analyses of crop suitability (aim for low water using crops)	Economics Infrastructure needs Impact on water table
	Supplementation of GDEs	Coogee Springs and Lake Nowergup	+1	Supplementation where (environmental) values are identified	Unsustainable, could create a deficiency elsewhere
	Recharge using recycled water	Could be used to mitigate declines or facilitate additional horticulture.	+1?	Recharge for horticulture and environment	Aquifer clogging Public perception of actions Water quality issues
Climate change		~1.5-2.0 m decline by CDFM	-1.5		
PRAMS Combined Scenario 2 prediction		Additional 2 to 3m over next 10 years	N/A		

* Relative impact on Mound. 3 (large change) to 1 (small change). Sign (+/-) indicates direction of change, ie. +ve rising, -ve falling, 0 is no impact.

Land and water use in South Wanneroo Zone

Groundwater Level influences		'Business as usual' Current practice and committed developments		What can be done to protect the Mound?	
		Current / planned practice	Relative impact on Mound*	Actions	Barriers and drivers
Land use and Water use	Pine plantation management	Some impact occurs along the eastern boundary.	-1	Accelerated clear felling followed by replacement with suitable vegetation (as for North Wanneroo)	Economics LVL agreement (as for North Wanneroo)
	Urban development	Still in planning stage, large range from none to total urbanisation.	+1	Discourage garden bores Maximise urban run-off/ recharge Impose a charge ($) for garden bores Grey water use 'Xeriscaping' with native vegetation to reduce garden water use Manipulating bore size, bore sharing, optimise location of householder bores	Unequal treatment of people according to their location in the zone
	Public abstraction	Wanneroo bore field has a major impact when used.	-1	Further reduction of abstraction Development of alternate sources More public bores located in limestone	Cost of changing abstraction arrangements Timeframe may not allow timely adjustment High transmissivity in limestone may facilitate salt water incursion into the aquifer
	Private abstraction	Major impacts, allocation limits reached.	-3	Accelerate urbanisation across the zone Restrict allocations Implement water trading	Timeframe may not allow timely adjustment
	Native vegetation management	Very little dense native vegetation left in this area.	-0.5	Protection of wetlands Line wetlands Fill wetlands Address acid sulphate soil issues Hobby farms	Aesthetics Legislation
	Agricultural development	Minor amounts of additional horticulture occurring due to trading	0	Accelerate development	
	Supplementation of GDEs	Lake Jandabup	+1	Fill in damaged GDEs with soils Top up (remaining) wetlands	Public perception More urban land
	Recharge using recycled water	Could be used to mitigate declines or facilitate additional horticulture.	0	Recharge for horticulture and environment	Aquifer clogging Public perception of actions Water quality issues
Climate change		~0.5 m decline by CDFM, but in a discharge zone with frequent surface water bodies	-1.5		
PRAMS Combined Scenario 2 prediction		Additional declines anticipated, but model is not well calibrated here	N/A		

* Relative impact on Mound. 3 (large change) to 1 (small change). Sign (+/-) indicates direction of change, ie. +ve rising, -ve falling, 0 is no impact.

Land and water use in Perth Metro Coastal Zone

Groundwater Level influences		'Business as usual' Current practice and committed developments		What can be done to protect the Mound?	
		Current / planned practice	**Relative impact on Mound***	**Actions**	**Barriers and drivers**
Land use and Water use	Pine plantation management		0	N/A	
	Urban development	Very large areas of urbanisation have often created watertable rises.	+2	Protection of wetlands Maximise groundwater recharge up gradient	Potential groundwater contamination
	Public abstraction		0	Increase abstraction in this Zone	
	Private abstraction	A minor impact, mostly in southern areas, saline water incursion is a potential issue.	-1	Encourage sharing of garden bores	
	Native vegetation management		0	N/A	
	Agricultural development		0	N/A	
	Supplementation of GDEs		0	Maintenance of marine ecology	
	Recharge using recycled water		0	N/A	
Climate change		0 to 0.5 m decline by CDFM, but area is near discharge zone	-0.5		
PRAMS Combined Scenario 2 prediction		Very minor additional declines anticipated.	N/A		

* Relative impact on Mound. 3 (large change) to 1 (small change). Sign (+/-) indicates direction of change, ie. +ve rising, -ve falling, 0 is no impact.

Land and water use in Lexia Zone

Groundwater Level influences		'Business as usual' Current practice and committed developments		What can be done to protect the Mound?	
		Current / planned practice	Relative impact on Mound*	Actions	Barriers and drivers
Land use and Water use	Pine plantation management	Pine impacts important in the west.	-1 (believed to be an underestimate – DCLM)	Clear or thin	Legislation, the LVL MoU
	Urban development		0 (suggested to be +0.5)	Wastewater recharge Stormwater management/ infiltration Water for POS and urban lakes (education issue?) WSUD/ redesign of urban vegetation Licensing garden bores	Water quality protection/ public health protection
	Public abstraction	Major impacts near the Water Corp. borefields. Confined aquifer abstraction may also be impacting.	-2 (localised impact, may be –1.5 overall - need > 8 GL/a to impact GDEs)	1. Alternative sources 2. Turn-off bores near GDEs 3. Import water for local irrigation (second class water) 4. Wastewater reuse in urban areas 5. Manage local demand through application of restrictions	1. Costs of development and transfer of impacts to other catchments 2. Other externalities 2. Loss of water
	Private abstraction	Some impact in the west.	-0.5	Review allocations Review Mirrabooka abstraction Metering of use	
	Native vegetation management	Native vegetation impacts occur mostly in the east.	-1	Vegetation management (burning regime)/ planning/ location is important Burn the native vegetation to less than 10 years frequency across area	Public resistance to burning and smoke haze Area has high conservation value (mound springs, wetlands on east side of Swan Coastal Plain) Resourcing of DCLM for managing altered fire regime
	Agricultural development		0 (may be having some negative impact)		There is some agricultural development in the east of the zone, plus POS and corridors. Grazing controlling density
	Supplementation of GDEs		0		
	Recharge using recycled water		0		
Climate change		0-3 m decline by CDFM	-2		
PRAMS Combined Scenario 2 prediction		3 m of additional decline anticipated in the next ten years. Some areas greater near abstraction.	N/A		

* Relative impact on Mound. 3 (large change) to 1 (small change). Sign (+/-) indicates direction of change, ie. +ve rising, -ve falling, 0 is no impact.

Land and water use in Mirrabooka Zone

Groundwater Level influences		**'Business as usual' Current practice and committed developments**		**What can be done to protect the Mound?**	
		Current / planned practice	**Relative impact on Mound***	**Actions**	**Barriers and drivers**
Land use and Water use	Pine plantation management	Pine impacts important in the north.	-0.5		
	Urban development	Urbanisation has increased recharge and storage by a small amount.	+0.5		
	Public abstraction	Major impacts near the pine plantations and Water Corp borefields.	-3 (impacts restricted to western side)	Manage demand and restrictions Identify alternate sources vv business as usual	Difficulty in meeting demand Infrastructure isolation ('stranded asset') if abstraction reduced Cost
	Private abstraction	Some minor impacts in the north.	-0.5		
	Native vegetation management	Native vegetation is present but at low density.	-0.5		
	Agricultural development		0		
	Supplementation of GDEs		0		
	Recharge using recycled water		0		
Climate change		1 m decline by CDFM.	-2		
PRAMS Combined Scenario 2 prediction		Most of the area is predicted to be stable, with up to 1 m declines in the north and west.	N/A		

* Relative impact on Mound. 3 (large change) to 1 (small change). Sign (+/-) indicates direction of change, ie. +ve rising, -ve falling, 0 is no impact.

Land and water use in Gwelup Zone

Groundwater Level influences		'Business as usual' Current practice and committed developments		What can be done to protect the Mound?	
		Current / planned practice	**Relative impact on Mound***	**Actions**	**Barriers and drivers**
Land use and Water use	Pine plantation management		0		
	Urban development	Urbanisation has increased recharge.	+1	Increase local recharge of stormwater by modifications to the drainage systems Manage potentially acid sulphate soils (PASS)	Population growth in the zone Occurrence of acid sulphate soils
	Public abstraction	Major impacts near the Water Corp borefields, mostly in the last 10 years	-2 (could be –3)	Abstraction from coastal limestone (high conductivity, resulting in small draw down) Develop other sources Water re-use within the Zone Manage demand/ restrictions Supplementation of GDEs at risk	Water quality (EC levels)
	Private abstraction	Private abstraction impacts dominate in the early, pre-1990 years	-3 (could be –3)	Move horticultural businesses to the planned new precinct Promote water use efficiency	Data on private abstraction are unreliable Development of golf courses in the early 1990s
	Native vegetation management		0		
	Agricultural development	Decreasing	0		
	Supplementation of GDEs	Lake Gwelup	+1		
	Recharge using recycled water		0		
Climate change		1.5 m decline by CDFM in the last 10-12 years. Rising trend prior to that.	-1	Population management (at state scale) Development of alternative energy sources	
PRAMS Combined Scenario 2 prediction		Unrealistically high due to poor calibration significant additional declines are anticipated.	N/A		

* Relative impact on Mound. 3 (large change) to 1 (small change). Sign (+/-) indicates direction of change, ie. +ve rising, -ve falling, 0 is no impact.

Appendix 4 – Workshop Report – The Gnangara Groundwater Mound – understanding and planning change

WORKSHOP REPORT

The Gnangara Groundwater Mound - understanding and planning change

Prepared for

Department of Environment

Second Floor, Hyatt Building
3 Plain Street
EAST PERTH WA 6004

18 March 2005

42443938/ 1817

URS

Sustainable Development

Project Manager	…………………………………..	URS Australia Pty Ltd
	Don Burnside	Level 3, The Hyatt Centre
	Principal Natural Resource Scientist	20 Terrace Road
		East Perth, WA 6004 Australia
		Tel: 61 8 9221 1630
Project Director	…………………………………..	Fax: 61 8 9221 1639
	Don Burnside	
	Principal Natural Resource Scientist	

Checked by:	…………………………………..	Date:	**18 March 2005**
	Bruce Howard	Reference:	42443938/ 1817
	Principal Environmental Economist	Status:	Workshop Report

Contents

Tables

Figures

Executive summary

The workshop 'The Gnangara Mound – understanding and planning change' was held over one day on 16 November 2004 at the Royal Freshwater Bay Yacht Club.

Objectives

There were three main objectives for the workshop:

- For participants to gain a common understanding of what we know about the current state of the Mound, and projected trends in groundwater levels under current patterns of land and water use.
- To hear from the key decision-making agencies about what they see as the key issues in land and water use and management, and the constraints and opportunities for improving the Mound.
- To initiate the development of a range of scenarios for improving the Mound that can be tested, refined and serve as a major input to the planning processes.

Issues

The Gnangara Groundwater Mound is a vital contributor to the water supply in the Perth Region. The main issues are summarised below:

- Groundwater levels are generally falling across the Gnangara Mound.
- The cause of the falling water levels is understood to be significantly reduced rainfall, land use changes and increased groundwater abstraction.
- Some wetlands and groundwater dependent ecosystems (eg. Yanchep Caves) are severely impacted.
- Emerging issues, such as oxidation of Acid Sulphate Soils in the Superficial Aquifer, in response to decreases in groundwater levels, require further investigation understanding.
- Various management practices constrain and/or compromise competing management objectives.
- The Water Corporation has altered and restricted abstraction from its superficial production bores in an attempt to reduce impacts.
- In some areas the groundwater allocation limit has been reached and water trading is occurring within the constraints of acceptable impacts on the environment and other users. There is potential for this to create problems when land use change is occurring to mitigate environmental impacts.
- Increasing reliance is being placed on domestic bores to meet water needs.

The workshop was held to begin, but certainly not complete, the task of planning for improvement in the management of the Gnangara Groundwater Mound.

Workshop Content

The DoE made presentations on the development of an integrated management strategy, groundwater level history and assessment of groundwater level fluctuations due to climate, abstraction and land use changes using Cumulative Deviation From the Mean (CDFM) hydrograph analysis and the Perth Regional Aquifer Modelling System (PRAMS).

Five State agencies (DPI, CALM, FPC, WC, and DoE) have direct responsibilities in managing land and water use in the area delineated as the Gnangara Groundwater Mound (GGM). These five agencies were invited to make presentations to the workshop, addressing the following issues.

- Role and responsibilities in GGM management.
- Current and planned activities in the GGM
- Opportunities and constraints for further intervention

The Mound was divided into nine zones and actions, barriers and drivers were workshopped for each of the zones. The zones were Yeal, Pinjar, Yanchep, North Wanneroo, South Wanneroo, Perth Metro Coastal, Lexia, Mirrabooka, and Gwelup. Hydrograph analysis (CDFM) and PRAMS were used to provide guidance on the relative impact of climate, abstraction and land use changes on each of the zones.

Key Findings and Conclusions

Plenary discussions throughout the workshop identified the following key findings, observations and conclusions. These considered the state of the GGM, the pressures on it, and the required management responses. Additional commentary considered the outstanding uncertainties that need to be addressed through further research and development. Policy and institutional needs were also itemised.

The presentations at the workshop confirmed that groundwater levels are dropping at nearly all locations across the GGM. The context for this decline is the drying climate, which is also affecting wetlands, other GDEs and the distribution of some biodiversity. The physical environment's response to climate change is a series of step-wise processes and it is unlikely to collapse in functionality. However, the community and Government need to understand that change in the bio-physical state of the Mound is inevitable. Further, stakeholders need to be aware that the predictions from the modelling are probabilities not certainties.

At the end of the workshop, discussion about the required management responses focused on four themes.

- Deciding what 'we' want for the Mound. This will need engagement of the community in considering options and ultimately decisions to be taken at a whole-of-government level.
- The need for 'informed adaption' in a dynamic environment. Decisions need to be made now, given existing technical information and understanding of system behaviour, with a capacity to adjust those decisions, as new information becomes available.

- The imperative of changing land and water use. Participants at the workshop recognised that the responsible agencies may need to 'give some ground' in making whole of government decisions that address the overall health of the Mound.

- Implications for resources. Workshop participants also recognised that decisions required will have significant resource implications.

The presentations and discussions at the workshop highlighted the need for a broader, more long-term strategy that coordinates management in deciding the actions that all relevant agencies can take. This strategy also needs to confirm the overall responsibility for managing the Mound, which is an issue that should be discussed by the GCC.

Finally, the presentations and discussions at the workshop have highlighted the urgency of the issues, and the need to take action now, based on current knowledge - we cannot afford to wait for results from more research. The documentation of the issues, the possible scenarios, potential outcomes and needs for change identified in this Report need to promote action.

This Report presents the outputs from a Workshop addressing the use and management of the Gnangara Groundwater Mound (GGM). The workshop was hosted by the Department of Environment (DoE), which is the agency with overall responsible for water resources in Western Australia.

1.1 Background

1.1.1 Issues for the Gnangara Groundwater Mound

The Gnangara Groundwater Mound is a vital contributor to the water supply in the Perth Region. The issues that need to be addressed are summarised in the following points.

- Groundwater levels are generally falling across the Gnangara Mound.
- The cause of the falling water levels is understood to be significantly reduced rainfall, land use changes and increased groundwater abstraction.
- Some wetlands and groundwater dependent ecosystems (e.g. Yanchep Caves) are severely impacted.
- Emerging issues, such as oxidation of Acid Sulphate Soils in the Superficial Aquifer, in response to decreases in groundwater levels, require further investigation understanding.
- Various management practices constrain and/or compromise competing management objectives.
- The Water Corporation has altered and restricted abstraction from its superficial production bores in an attempt to reduce impacts.
- In some areas the groundwater allocation limit has been reached and water trading is occurring within the constraints of acceptable impacts on the environment and other users. There is potential for this to create problems when land use change is occurring to mitigate environmental impacts.
- Increasing reliance is being placed on domestic bores to meet water needs.

The workshop was held to begin, but certainly not complete, the task of planning for improvement in the management of the Gnangara Groundwater Mound.

1.1.2 An integrated management strategy for the Gnangara Groundwater Mound

Under the current management framework of Ministerial conditions, the Department of Environment (DoE) is responsible for managing groundwater levels to protect environmental values. Work undertaken to date highlights the loss of environmental values of groundwater dependent ecosystems that has occurred through a variety of factors. Management of land uses (such as the burning of native vegetation and pine plantation management) is of similar importance to management of water use in influencing groundwater levels. Overshadowing all of these factors is the influence of a drying climate.

Controlling water use is not enough, as in many parts of the mound abstraction is having very little or no impact. To manage the wide range of factors contributing to groundwater level declines, an Integrated Management Strategy needs to be developed between government agencies to better manage the impact of water and land use decisions on groundwater levels. Through this Strategy, whole of Government action for more effective management of the Gnangara Mound can be delivered.

The Integrated Management Strategy should:

- define management objectives for the Groundwater Mound taking into consideration environmental, economic and social goals (these could be very different to current ones);
- propose a set of actions each agency can take to help achieve sustainable use of the Mound;
- identify the probable outcomes of actions in terms of meeting the objectives; and
- define the costs and benefits of actions for triple bottom line (environmental, social and economic water requirements) accounting.

Responsibility for managing water use rests with the DoE. A key component of this is the determination of abstraction limits for groundwater resources. This process involves the following steps:

1. defining sustainable management objectives for groundwater use are defined via the DoE's water allocation processes;
2. determining environmental water provisions (EWPs) - water regimes required to maintain ecological, social and economic values;
3. identifying abstraction regimes that best allow EWPs to be met; and
4. determining sustainable yields and allocation limits.

The approach is holistic involving offsets within and trade offs between accounts to determine the optimal balance between Environmental Water Requirements (EWRs), EWPs and water allocations. It also includes significant public participation and consultation.

Identifying management objectives enables a future, preferred state of the Mound to be defined. Expanding the scope of Step 1 allows a range of non-groundwater values to be used to shape that vision. Expanding Step 3 from abstraction regimes to other actions such as pine thinning, land use change etc. allows a wide range of management actions, well beyond the remit of the DoE, to be considered. Widening the scope of the process in this way allows assessment of a wide range of management options to determine those which best produce the future desired state of the Mound. These actions can then be brought together into an Integrated Management Strategy.

A key component of this process is the modelling of management action scenarios to predict the extent to which groundwater levels in the various aquifers on Gnangara Mound might be drawn down. Each of the scenario outcomes is assessed against criteria that are considered to best reflect the range of social, environmental and economic objectives for the future use of the Gnangara Mound. This provides valuable information about those management actions most likely to produce the desired objectives.

The various scenarios and their outcomes will be assessed through a multi-criteria analysis. This allows results to be assessed in a more complete sense, where the objectives of the social, economic and environmental needs are considered jointly. This technique is important particularly where there are conflicting objectives. For example, an economic objective might rate water for public water supply higher than water for agriculture and a social objective might rate local use higher. In this instance, a trade-off may be deemed acceptable that allows a detrimental impact on one criterion to be counter-balanced by increased opportunities against another. This process will be used to help determine Environmental Water Provisions. The management actions that best meet the management objectives after first allowing for EWPs, then form the basis for an Integrated Management Strategy.

Undertaking such an analysis will not be a simple process and requires close cooperation between agencies, both to decide on a future desired state for the Mound and to produce a co-ordinated set of management actions. However, one thing is clear; a co-operative approach to management of the Mound is the best way to ensure its values are protected. The process for developing an integrated management strategy is presented in Figure 1.

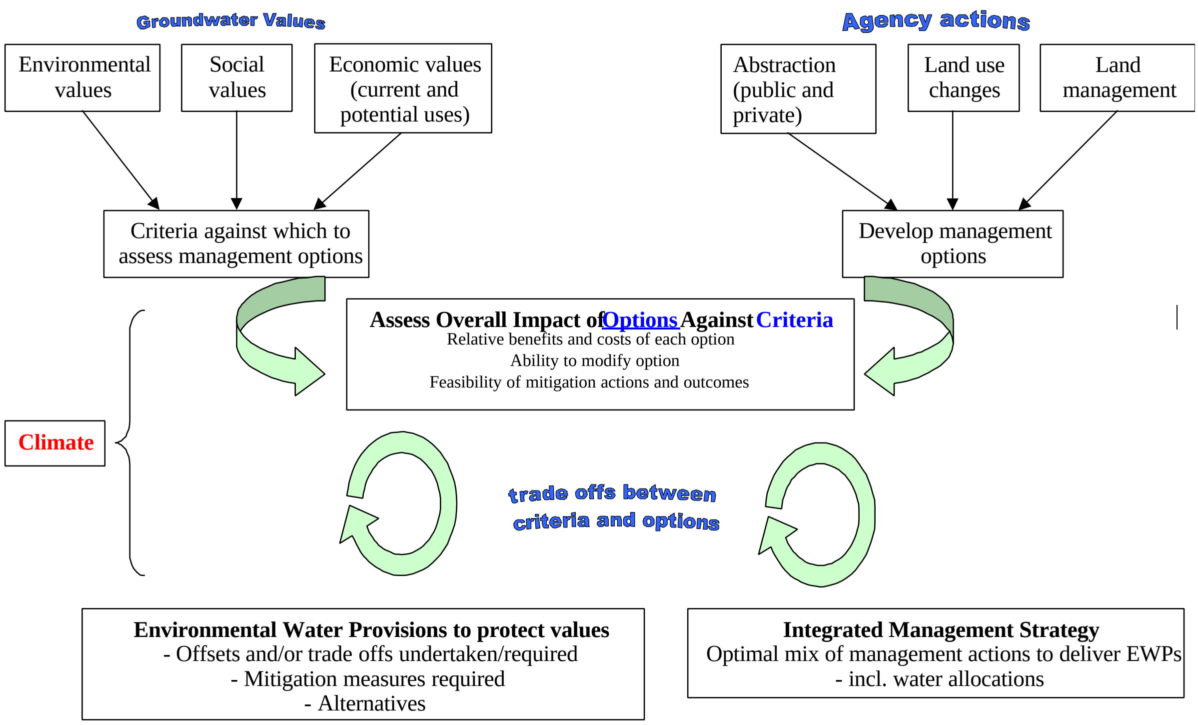


Figure 1: An integrated management strategy for the Gnangara Groundwater Mound

1.2 Objectives for the workshop

- For participants to gain a common understanding of what we know about the current state of the Mound, and projected trends in groundwater levels under current patterns of land and water use.
- To hear from the key decision-making agencies about what they see as the key issues in land and water use and management, and the constraints and opportunities for improving the Mound.
- To initiate the development of a range of scenarios for improving the Mound that can be tested, refined and serve as a major input to the planning processes.

1.3 Workshop methodology

The Agenda for the workshop is presented in the **Annex 1** in Section 6.1.

Participants in the workshop represented the Gnangara Coordinating Committee; the Departments of Agriculture, Conservation and Land Management, Environment, Health, and Planning and Infrastructure, the Environmental Protection Authority Service Unit, the Forest Products Commission, the Water Corporation, CSIRO Land and Water, Edith Cowan University, and a number of consulting firms who have provided services in respect of the GGM. The participants are listed in **Annex 2** in Section 6.2.

The workshop commenced with a presentation of current and predicted groundwater behaviour across the Mound, as derived from the PRAMS Model. The presentation showed the changes in groundwater levels across the Mound, with ‘what if’ scenarios used to show predicted trends under these scenarios. This information is presented in Vogwill (2004).

This was followed by presentations from the state agencies (DPI, DCLM, FPC, Watercorp, DoE) with direct responsibility for managing land and water assets in GGM. These presentations, which are summarised in Section 2 outlined current and planned activities in the Mound, and opportunities and constraints faced in contributing to improvement of the Mound.

Participants at the workshop then used this information to capture ideas, suggested actions, and research and policy needs for each of the nine zones. This information has been presented without interpretation in the matrices in Section 3. The research and policy information was aggregated and is shown in Section 4.2. Finally, the participants reviewed the outputs from the workshop in developing summary conclusions.

1.4 Groundwater level history – climate impacts and major factors affecting change

The Gnangara groundwater mound, referred to as the Mound, is comprise of the unconfined sediments in the superficial aquifer in the area outlined in Figure 2.

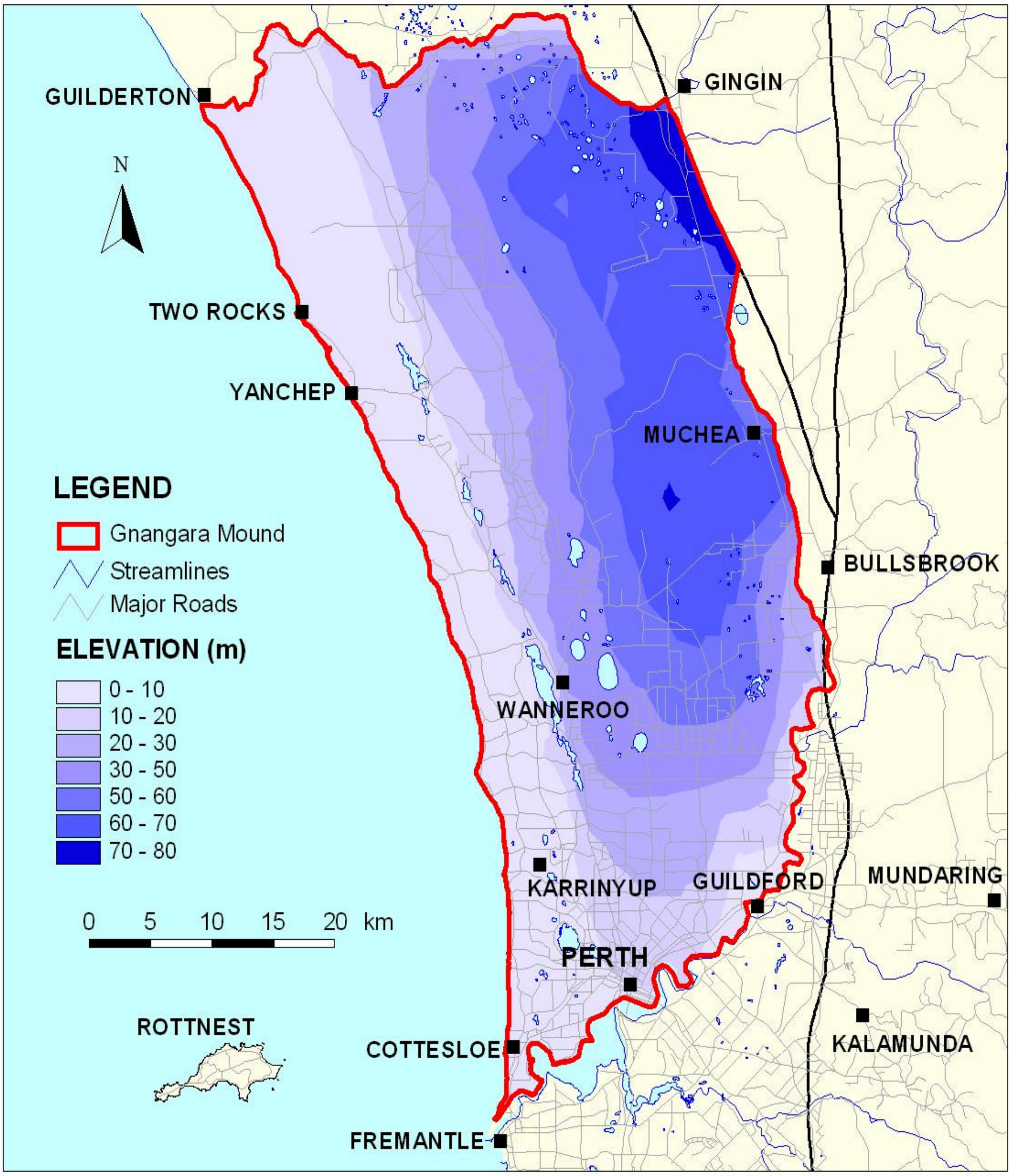


Figure 2: Location plan

Average rainfall over the Mound for the period 1914 to 2003 is 782 mm. However, depending on the period selected, rainfall and subsequent recharge to the Mound has varied significantly as shown in Table 1. The shift to a drier climate state since the mid-1970s represents a decline of 11.0 per cent when compared to the wetter period between 1914 to 1975. When comparing recent years between 1997 and 2003 with the 1976 to 2003 period a 4.1 per cent decline is observed while the rainfall for the 2000 to 2003 period is 5.3 per cent less. This recent decline poses a significant challenge for water planners. Declines in rainfall isohyets for different periods as derived using weighted Silo patch point rainfall data for the area are outlined in Figure 3.

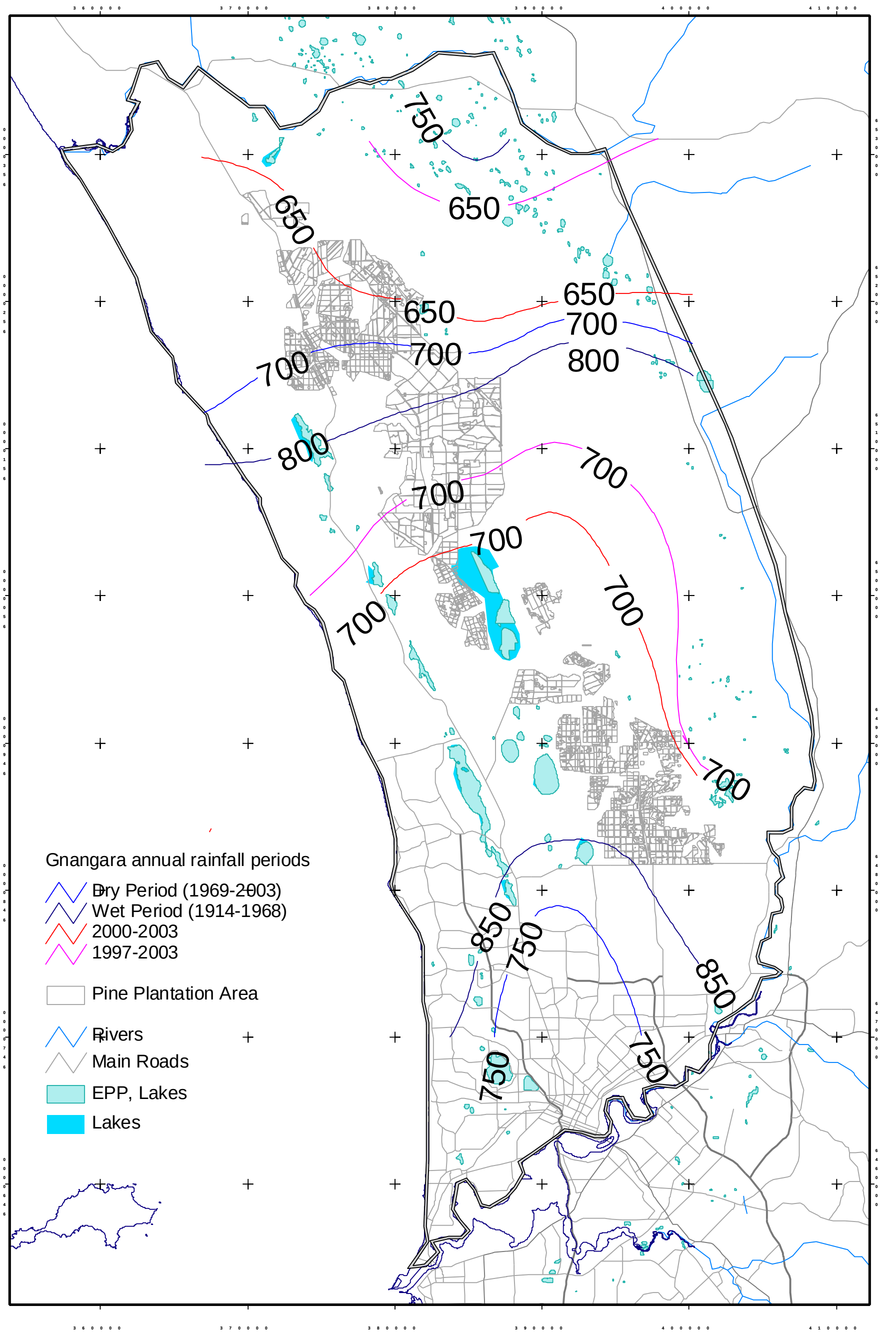


Figure 3: Gnangara rainfall isohyte variation for different periods

Table 1: Average annual rainfall for selected periods

Period	Average annual rainfall (mm) *	Percentage of period 1914 to 1968
1889 – 2003	781.4	95.3
1914 – 2003	781.9	95.3
1914 – 1968	820.4	100
1914 – 1975	809.5	98.7
1969 – 2003	721.4	87.9
1969 – 1996	725.7	88.5
1976 – 1996	728.2	88.8
1976 – 2003	720.7	87.9
1997 – 2003	698.4	85.1
2000 – 2003	689.7	84.1

* Annual rainfall derived using weighted averages from the SILO database.

Recent research on synoptic climate features for the south west characterise the decline in rainfall as follows (Hope, 2004):

- ‘Wet’ synoptic types have decreased
- ‘Dry’ types have increased, to a lesser extent
- Rain linked with northerly flow types has decreased
- Increase in rainfall is linked to southerly flow types
- Average south west rainfall links well with ‘wet’ synoptic types.

Mound groundwater levels have declined progressively since the early 1970s as shown in Figure 4 and Figure 5 with the decline most notable over the last six years. The decline reflects a decreased amount of recharge to the Mound and also shows the additive impacts of land management and both public and private water use. Lack of sufficient groundwater level monitoring data prior to the late 70’s limits the selection of a representative baseline year. The choice of 1979 as the baseline year was carefully selected as being the most representative, considering the limitations of the data (Yesertener, 2002). Although the 1979 groundwater levels reflect the climate in preceding years along with abstraction and land use changes, the relative stability of groundwater levels across the Mound at this time provide a useful reference for subsequent observed groundwater level declines.

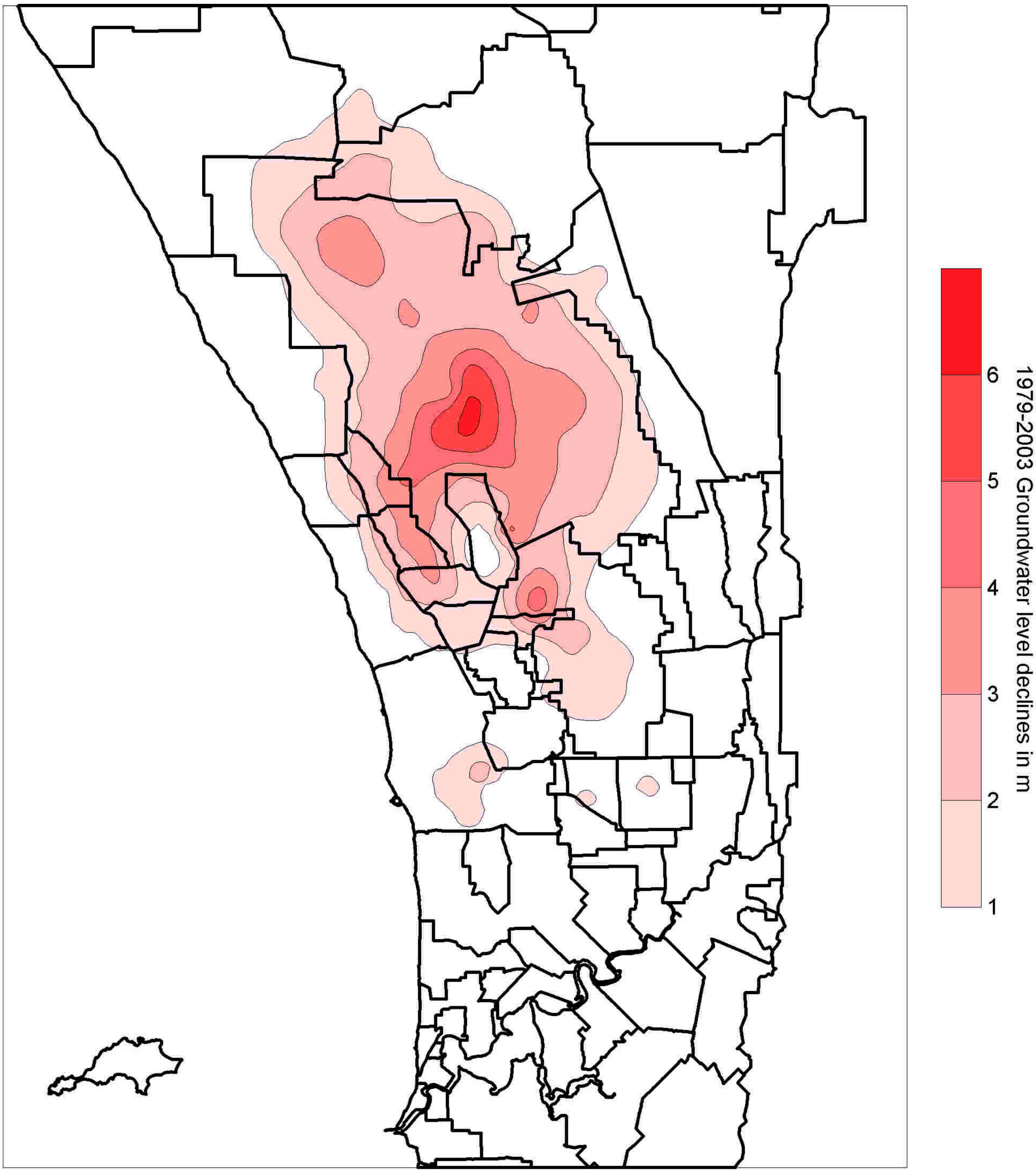


Figure 4: Groundwater level declines from 1979 to 2003

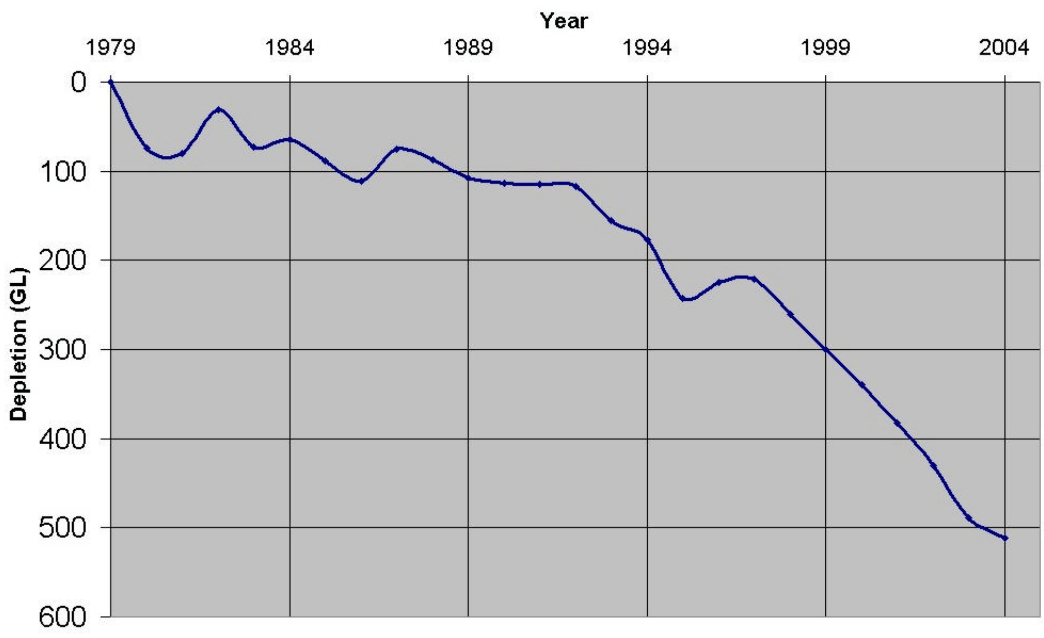


Figure 5: Gnangara Groundwater Mound superficial aquifer depletion

1.5 Modelling scenarios on Gnangara groundwater mound

Change in Gnangara Mound groundwater levels is an attenuated response to variations in the climate regime, upon which abstraction and land use impacts are superimposed. Climate change in the southwest of Western Australia has caused a significant decrease in rainfall, which is predicted to continue (IOCI, 2002), (Yesertener, 2002). Within this background of declining groundwater levels, factors contributing to breaches of environmental conditions set under Section 46 of the *Environmental Protection Act 1986* reflect the combined impact of site specific factors. To better understand the implications of regional climate variability and change, it is desirable to model the range of recorded and likely future water level changes, based on the extent of known and possible future climate regimes. This will enable us to better understand and manage groundwater abstraction and land use from an overall systems perspective.

Currently, the Perth Regional Aquifer Modelling System (PRAMS) model is sufficiently calibrated for assessing the relative benefit of permutations of individual parameters. The model has accurate, reliable water balances and is a powerful tool for looking at the area of influence of an individual parameter, with the result being the water table difference maps. The scenarios used to produce the water table difference maps are being refined and will contribute to the development of future management plans. These scenarios and modelling work are also being used to identify where the present calibration is inadequate and identify where model parameters and relationships need to be refined to improve calibration.

The relative impact of abstraction reduction has been modelled and shows the nature and magnitude of expected recoveries from reduction in licensed self-supply and Water Corporation abstraction. Impacts from Water Corporation abstraction appear to be smaller in aerial extent but much larger in magnitude than licensed self-supply impacts. It is critical that the allocation database contain accurate water use information to improve the calibration of groundwater models and the representation of likely impacts from different management or climate regimes.

Land use changes can be beneficial by increasing recharge, and detrimental by decreasing recharge. Urbanisation is a good local scale outcome for increasing groundwater recharge and thus mitigating water table decline impacts, while increases in pine and native vegetation density can reduce recharge to almost zero. Appropriate management of pine plantations in terms of thinning and clear-felling, will provide additional recharge to the Gnangara Mound. The Forestry Products Commission (FPC) could attempt to maximize recharge under their pine plantations, while meeting the requirements of the Lumber Veneer Laminate (LVL) State agreement. This analysis may change however, as the model parameters are refined, but that is unlikely.

The burning regime of native vegetation by Department of Conservation and Land Management (DCLM) over the last 25 years has reduced recharge, leading to additional water table declines. Unlike pine plantations, which actually have a positive impact on groundwater recharge levels for the first 5-10 years following clearing, native vegetation (banksia woodland) density has increased and hence recharge has dropped substantially.

Conclusions and recommendations.

Groundwater flow modelling indicates the following points.

- Climate is the dominant influence on the superficial aquifer groundwater levels, which are likely to continue to fall, in many parts of the mound, unless annual rainfall increases by 100-200 mm/yr.
- Groundwater flow modelling, using reduced rainfall scenarios is not ideal because at this stage the model input data needs to be generated from the re-working of actual data. The natural variability of rainfall in the Perth Metropolitan Region means that it is unlikely that lower than average rainfall is recorded in all areas of the PRAMS domain in the same year.
- The impact of varied groundwater abstraction can be modelled with a fair degree of certainty. The impact of public water supply abstraction is shown to have a significant impact on groundwater levels but the drawdown is very localised, whereas private abstraction is shown to have the potential to have less drawdown but over a much wider area.
- The available records of private abstraction are not adequate, leading to poor calibration and intractable errors in some parts of the PRAMS domain. There is a need to record actual abstraction as opposed to allocation to improve the present calibration of the model for future predictive modelling.
- The impact of pine plantations on groundwater levels is somewhat localised to the areas directly overlain by pine plantations. Of similar significance to groundwater levels are the far larger areas of native vegetation. Burning frequency in the native vegetation areas may possibly be a major factor affecting groundwater recharge and hence groundwater levels.

- Urbanisation and 'special ruralisation' of exiting rural zones can be a useful way to increase groundwater recharge, reduce abstraction and hence increase groundwater levels. Care must be taken to ensure that the environmental benefits of this land use change are not compromised by the amount of abstraction that occurs in newly created urban but more particularly, special rural zones.

The approximate impact areas for various model parameters are shown in Figure 6 with climate influencing water levels across the whole mound.

Further studies are required to understand the influence of each model input and component. This work should be undertaken in close co-operation with individual stakeholders to ensure that the scenarios are realistic, relevant and will provide a diverse range able to be utilized in the process to sustainably manage groundwater resources now underway. It is recommended that individual model inputs, such as banksia density, be assessed by the DoE in co-operation with the relevant agencies, to optimise recharge and minimize groundwater level decline impacts.

PRAMS calibration has improved significantly since the model was run for the scenarios in this report. The average error in the superficial aquifer has been reduced by approximately 50 per cent. Further advances in the model to improve calibration are possible but this is dependent on making improvements that include the following actions.

- Allocation database improvements by more accurately determining the relationship between what is allocated and how much is actually abstracted. This is required for the present, with the use of meters, and if possible for the past.
- Specifically designed climate scenarios need to be created. New methodologies for improving the climate scenario inputs are presently being investigated.
- Studies to better determine pine plantation absolute water use and the ability of the pine trees on Gnangara Mound to directly access groundwater.
- Studies to better estimate native vegetation absolute water use.
- Improved calibration of satellite imagery to reduce the error and LAI 'drift' between satellite images. More ground measurements (under story verses canopy and ground base LAI determinations) are required to improve the modelling of LAI based PRAMS land uses.
- The impact of bush wild fires, controlled burns, and native vegetation thinning on groundwater recharge needs to be better understood.
- The impact of an increased native vegetation-burning regime needs to be studied and evaluated from both a groundwater recharge and biological perspective.

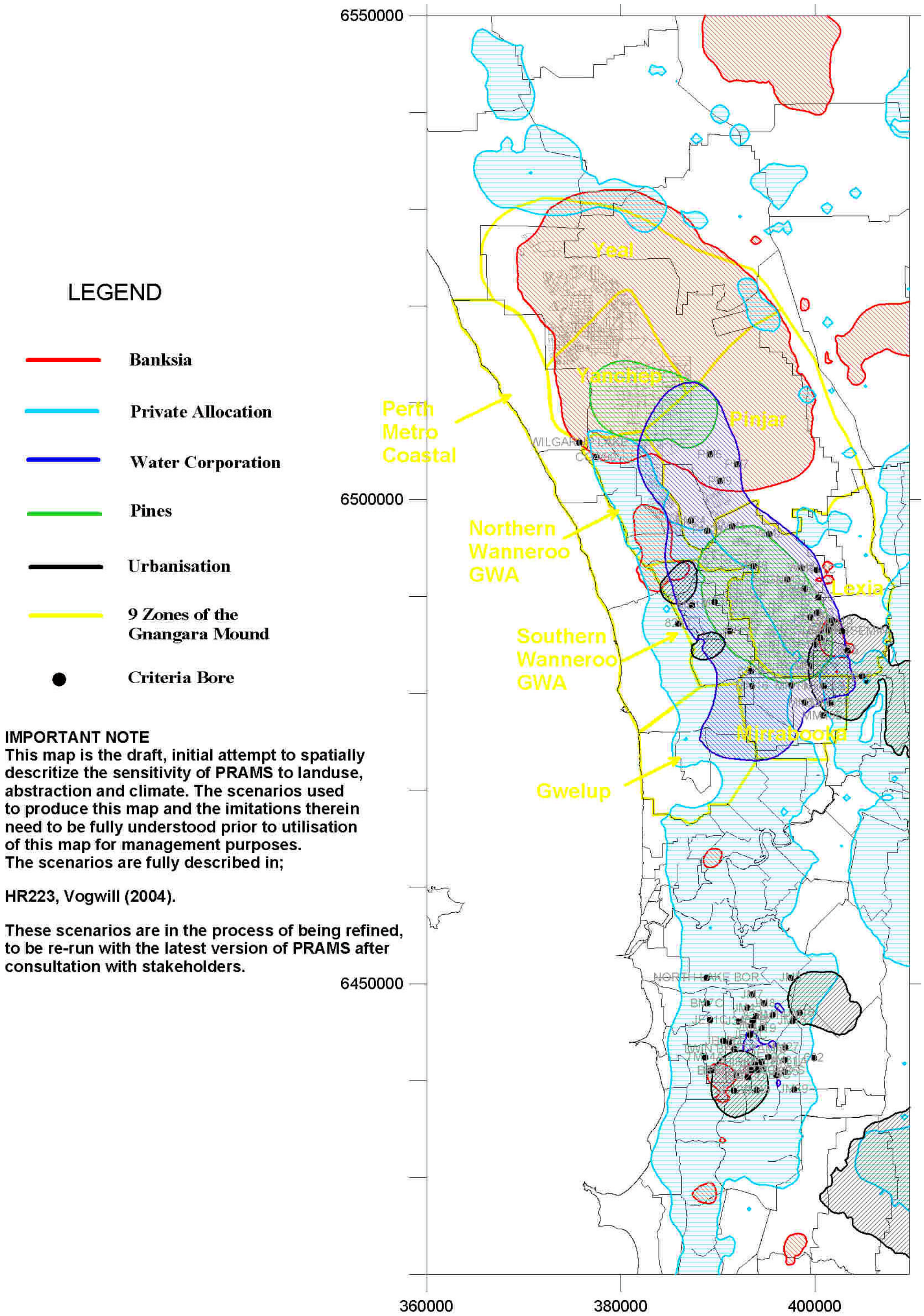


Figure 6: Areas of influence for the major system parameters, criteria bores shown, climate impacts across the entire mound.

Five State agencies have direct responsibilities in managing land and water use in the area delineated as the Gnangara Groundwater Mound. These five agencies were invited to make presentations to the workshop, addressing the following issues.

- Role and responsibilities in GGM management.
- Current and planned activities in the GGM
- Opportunities and constraints for further intervention

Summaries of the individual presentations follow.

2.1 Department of Planning and Infrastructure

2.1.1 Overview of land use planning on the Gnangara Mound

Land use planning, subdivision and development in the Perth metropolitan area is guided by statutory and strategic planning mechanisms. Strategic planning focuses on the big picture and aims to integrate social, environmental, economic and infrastructure issues and is guided by the preparation of structure plans, policies and planning best practice guidelines.

Statutory planning deals with the legal aspects (for example, legislation, development regulations, town planning schemes). The primary statutory mechanisms are town planning schemes that are prepared by local government for a local government area and, at the regional level, by the West Australian Planning Commission (WAPC).

The Perth Metropolitan Region Scheme (MRS) is the regional town planning scheme that identifies the broad pattern of land use zones and reserves to guide spatial location of land uses, infrastructure and subdivision in the Perth Metropolitan area. The MRS can be reviewed and amended.

Land use planning and development of land outside of the MRS boundary is controlled by the local government town planning schemes but is still be guided by WAPC strategic plans and policies prepared for specific areas.

The Gnangara Groundwater Mound is the largest and most important source of fresh groundwater in the State. It supplies public drinking water and also supports a variety of significant environmental features such as wetlands, shallow cave streams, springs and seepages, and native vegetation and fauna dependent on groundwater.

The Mound covers approximately 2,200 square kilometres extending from Gingin Brook and Moore River in the north, to the Gingin Scarp in the east, the Swan River in the south, and the Indian Ocean to the west.

Inappropriate land use on the Mound has the potential to have a significant effect on the quantity and quality of groundwater resources.

In 1994 the Western Australian Legislative Assembly established a Select Committee to examine a range of issues relating to groundwater protection and prepare a report on Metropolitan Development and Groundwater Supplies. This report made many recommendations relating to the protection of public drinking water supply areas. Those recommendations relating to the land use planning system have been the basis for the WAPC's approach to integrating land use planning and the protection of public drinking water resources.

On the Mound there are the Gnangara, Wanneroo and Mirrabooka Underground Water Pollution Control Areas (UWPCA) and the Perth Coastal and Gwelup UWPCA's.

Specifically, the WAPC has prepared land use and water management strategies for the Jandakot and Gnangara UWPCAs resulting in statutory MRS Amendments to reserve land for Water Catchments and zone land for Rural Water Protection in these UWPCAs.

On the Gnangara Mound large areas of land are within the Gnangara, Wanneroo and Mirrabooka UWPCA's and reserved for State Forest. The Gnangara Land Use and Water Management Strategy (2001 recommended that all Priority 1 areas in the remodelled UWPCA boundary be reserved for Water Catchments and all land in Priority 2 area be zoned as Rural Water Protection. The *Gnangara Groundwater Protection MRS Amendment 1036/33* proposes the reservation and zoning of these areas and is in its final stages and due for gazettal in 2005. This will protect the P1 and P2 areas from inappropriate development. The WAPC is also progressively purchasing all private land within the P1/Water Catchments reservation

In the Priority 3 areas of the UWPCAs, and outside of UWPCAs, land use is guided by structure plans, town planning schemes and planning policies. The Department of Environment under the Metropolitan Water Supply, Sewerage and Drainage Act, 1909 (as amended) By-Laws and the Water Quality Protection Note – Land Use Compatibility in Public Drinking Water Source Areas also provide guidance for land uses.

Over the Gnangara Mound the North West Corridor Structure Plan (currently under review) and the NE Corridor Structure Plan are the strategic plans that identify broad land uses, assess environmental, social and economic issues that need to be considered for the sustainable development of land and provide guidelines for future zones and reserves that will be implemented in the MRS and local government town planning scheme.

In addition the WAPC, under the umbrella of the overarching State Planning Strategy, has prepared Statement of Planning Policy (SPP) 2 - Environmental and Natural Resources Policy and the following SPPs to deal with water resources; SPP 2.7 Public Drinking Water Source Policy; SPP 2.2 Gnangara Groundwater Protection Policy; SPP 2.9 Water Resources Policy to provide land use and development controls.

As an example, the East Wanneroo Land Use and Water Management Strategy (EWLUWMS) is being prepared to address the issues raised by the City of Wanneroo and the east Wanneroo community about the impact that current water planning, allocation, and land use planning is having on rural land in the east Wanneroo area.

The key issues to be resolved by the Strategy are:

- to determine future land use options that achieve the desired environmental, economic and social outcomes for the benefit of the whole community;
- to provide for some form of future land development opportunities;
- to facilitate the continuance and expansion of the existing agricultural industry and local economy that is currently based on the use of irrigation from the limited groundwater from the Gnangara Mound, and
- to apply a whole of government approach to land use planning, groundwater management and pine plantation clearing to manage land use change and groundwater demands for public drinking water, private agricultural uses and environmental water requirements.

2.1.2 East Wanneroo Land Use and Water management Strategy

Background

Agriculture and horticulture is a significant economic and social activity in the east Wanneroo area worth some $110M – $150M per annum and employing some 4-7,000 people.

Some 8,077 hectares of land is zoned for rural purposes, however, only some 2,480 hectares (30%) is actually under irrigated agricultural or horticultural cultivation. Much land is vacant or used for rural living.

The Wanneroo Groundwater Area (WGA) comprises eleven sub areas and the available groundwater in all sub areas is now mostly fully allocated and no new water licences can be issued to landowners for establishing new, large agricultural or horticultural uses unless acquired by trading water entitlements.

The combination of a drying climate trend, lack of groundwater, small lot sizes (18% less than 2 ha, 40% between 2-4 ha) and the very high price of Rural zoned land in south east Wanneroo makes the ongoing long term viability and survival of a horticultural industry in the south east Wanneroo area questionable.

Land Use Scenarios

A preliminary Discussion Paper "East Wanneroo Land Use and Water Management Strategy' (EWLUWMS) and three land use scenarios released in May 2004 for public comment. Over 400 submissions were received with some 66 per cent in support of a change in land use to enable some form of rural or urban subdivision to take place in the southern portion of east Wanneroo.

It is clear from preliminary modelling, undertaken by the Department of Environment that lower rainfall over the past 30 years is resulting in lower water table levels of the Gnangara Groundwater Mound.

Modelling of the land use scenarios presented in the EWLUWMS shows that land use change alone, from Rural to Urban, will not result in ‘extra’ groundwater being obtained from recouped licences as rural uses change to urban. There will not be any water to be “reallocated” to allow all the land that is currently zoned for Rural to be used for irrigated agricultural /horticultural in the east Wanneroo area.

EWLUWMS Direction

An integrated Strategy for the east Wanneroo area and the Gnangara Mound needs to be formulated to accommodate all the competing demands on the Gnangara Mound groundwater resource.

The Strategy would adopt the State Sustainability Strategy and the State Water Strategy target of achieving 20 per cent reuse of treated wastewater by 2012, and the integration of land use planning and water resource planning.

This target and a range of other significant environmental, social and economic benefits can be achieved by formulating a land use plan and water resource management plan based on providing a new water source for east Wanneroo area by using recycled water from the proposed Alkimos and/or Beenyup Treatment Plant.

A land use concept for the east Wanneroo area based on the use of recycled water can supply additional water (independent of drier climatic trends and existing private licensed water allocation) for use by private agricultural users and support the establishment of additional new agricultural areas east of Carabooda to replace the areas lost to urbanisation in the south east Wanneroo area.

The additional areas may need to be leasehold in tenure, with a recycled water allocation tied to the lease. In this way, there is a guarantee that the land will always be used for horticultural purposes.

The use of recycled water can also supplement the environmental water requirements for the Yanchep cave system and the Wanneroo wetlands and, in concert with the controlled clearing and thinning of the pine plantations, buffer the impact of the predicted lower rainfall conditions.

However, there are still many planning, health and technical issues to be more fully investigated and resolved including:

- capital costs and timing of a recycled water scheme;
- the use of State Forest lands to enable new leasehold agriculture areas to be established, and the co-ordinated clearing of pine plantation areas, and
- overcoming the negative public perception of the use of recycled water for growing edible products.

To achieve this a genuine ‘whole of government’ and coordinated approach to the management of the land and water resources of the Gnangara Mound between State Government agencies and local government is needed to deliver a sustainable solution to all the competing demands on the Gnangara Mound groundwater resource.

2.2 Department of Conservation and Land Management

These points are taken from the slides presented by the Department of Conservation and Land Management.

2.2.1 Sustainable Management

Biological diversity is a key element and needs to be managed sustainably. Sustainable management involves

- sustaining the resource at a useable level, while maintaining other values
- sustaining biological diversity: the maintenance of species and discrete ecosystems
- identifying and conserving species and ecosystems most at risk

Examples of threatened species and ecological communities include

- Blue Babe in Cradle Orchid (Critically Endangered)
- Western Swamp Tortoise (Critically Endangered)
- Western Swamp Tortoise (most threatened reptile in Australia)
    - partial dependence on Gnangara water levels
    - research, recovery actions over 30 years, including pumping water to swamps
    - captive breeding by Zoo (translocation)

2.2.2 Threatened Ecological Communities Influenced by the Gnangara Mound.

Perth to Gingin Ironstone Association (Critically endangered)

- Number of occurrences – three
- Total area - 60 ha.
- Level of dependence on Gnangara water is uncertain

Tumulus Organic Mound Springs Community (Critically endangered)

- Totally dependent on Gnangara water
- Number of occurrences – 3
- Total area - 7.4 ha
- Total number of species - >50
- Several known only from these springs

Aquatic Root Mat Community of Yanchep Caves (Critically endangered)

- Totally dependent on Gnangara water
- Number of occurrences – 6
- Total area - 1 ha
- Total number of species – 100
- Crystal Cave Crangonyctoid
    - About 60 animals remaining

    - Artificial watering for 30 in cave pool
    - 33 in aquaria
- Declining Water Levels in Caves
    - Mound declined by 2.5 m since 1976
    - Cave streams stable until early 1990s
    - Cave streams stable until early 1990s
    - Jilgie Cave dried out in summer 1996
    - 4 out of 5 caves artificially watered since 1998
- Yanchep Caves key points
    - Many cave and spring species are totally dependent on Gnangara Mound
    - Many species cannot tolerate drying out
    - Cave and spring waters have been permanent in the past, including during very dry periods
- Current Emergency Actions
    - Artificial watering
    - Regular monitoring: fauna; water levels
    - Upgraded watering system since apparent decline in 2001
    - 2004, installation of a major supplementation scheme to seven caves

Forests and woodlands of deep seasonal wetlands (Vulnerable)
Herb rich saline shrublands in clay pans (Vulnerable)

2.2.3 Achieving Sustainability

- Continue emergency actions while needed
- Clarify drivers and contributors to groundwater decline
- Participate in integrated (multi-agency and stakeholder involvement) approaches towards achievement of sustainability
- Long-term strategy - recovery of water level

2.2.4 Fire for Life

CALM implements fire regimes to

- conserve biodiversity
- provide acceptable level of protection to life and property in South West WA.

Key fire planning principles

- Fire is a natural environmental factor that has and will continue to influence the nature of South West landscapes
- Species and communities vary in their adaptations to, and reliance on, fire
- Other environmental factors influence the way in which ecosystems respond to fire
- Fire management should be precautionary and adaptive
- Fire diversity enhances biodiversity both at the landscape level and the local scale

- Avoid applying the same regime over large areas for long periods of time
- Fine scale fire-induced mosaics promote habitat biodiversity
- Use available knowledge to determine regime and scale
- Know your fire history
- Assess and mange the wild fire risk
- Adaptive management, continuos improvement

Broad fire strategies – landscape scale

- Maintain a mosaic of patches of vegetation at different scales of serial succession including recently burnt and long unburnt and patches burnt at different seasons and frequencies
- The range of fire interval, season, intensity and patchiness (scale) set by knowledge of vital attributes flora and fauna

Fire management objectives – fire management unit scale

- Objective – to conserve biodiversity through time
- Broad strategies
  - Implement patchy burns at various intervals and seasons to provide a variety of habitats, serial states and structures through time
  - More flammable (fire resilient) habitats burned at intervals ranging from frequent (eg. 2-4 years) to infrequent (eg. 12 to 16 yrs)
  - Less flammable (more sensitive) habitats (eg. riparian zones, some swamps, valley floors, granite outcrops) should be burned less frequently (eg 15-25 yrs) or not at all
- Incorporating other needs
  - Protection of life and property
  - Silviculture
  - Water production
  - Research
  - Reference areas

2.3 Forest Products Commission

2.3.1 Key issues and observations on Gnangara mound

What can we agree on?

- Land use changes do have an important impact on groundwater levels.
- Closed canopy pines reduce recharge relative to regularly burnt *Banksia* (woodland)
- Parts of Pinjar and Yanchep entered this state in the 1990's
- We can modify water use using silviculture

What do we still have concerns about?

- Prescribing impacts to one land use other than broadly is fraught with problems
- The net total impact of pines includes an increase of water tables due to clearing which would have a rebound period. Often these net impacts are small or even positive. The use of 1979 as a base year will suffer from the impact of a large clearing surge in water table due to clearing for establishment of pine. This needs to be taken into account as we maybe seeing a decline from a higher base and prescribing all this loss to other factors incorrectly

Native vegetation and fire

- If there is now a reduction of one autumn burn per decade and Farrington et al (1989) is correct. Then recharge from these events is occurring less frequently
- If we assume that
  - Year 1 25 per cent extra recharge
  - Year 2 18.75 per cent extra recharge
  - Year 3 12.5 per cent extra recharge
  - Year 4 6.25 per cent extra recharge
  - Year 5 to year 10 0 per cent extra recharge
- Average yearly extra recharge of 6.25 per cent
- Given 800 mm per annum rainfall then 50 mm additional recharge per annum
- Over 67,000 ha this is 33.5 GL per annum lost if fire frequency has been reduced by one autumn fire per decade.
- A similar order of magnitude to that thought to be from Pine
- If model calibration does not take this into account then it could be over prescribing the other land use impacts of abstraction and Pine plantations.

2.3.2 Pine Harvesting Options

- Meet agreement act obligations
- Don't meet agreement act obligations

Constraints

- Original set up was for maximum product with no excess left over Already require 28% top up to make volumes
- Inability to substitute
- Age class
- Forest condition
- Economic and logistical
- Legal
- Different volume penalties to changes

2.3.3 Objective

The FPC objective on the mound is to ‚Maximize water recharge within constraints'.
Issues needed to be addressed are :-

- LVL
- Watercorp need
- Caves
- Horticultural precinct
- 9 zones, 7 relevant. This adds a layer of additional complexity. It may not be able to once combined meet all objectives in all 7 areas.

The question is 'Is this too many to optimize?' The answer is yes and clarification will be needed to find best outcome.

Other issues

- Unknown value of the processed timber resource forgone.
- Model calibration.

Scenario comparison.

- Existing log plan
- 2GL per year 2004 -2008
- 2009 -2029 1.6 GL per annum additional gains above this
- Watercorp bores areas CF 2500 ha
- Cumulative gain over existing log plan.
- 35 GL for a loss of 250000 m3 or
- 50 GL for a loss of 550000m3

This is not a large amount of water for a substantial loss of timber

Way forward

- Clarify and simplify objectives and constraints
- Be prepared to negotiate with Wesbeam
- Model only those scenarios likely to result in a reasonable mutual outcome
- Tool is Mixed Integer Linear program which optimizes for maximum recharge under pine within constraints (in development)

2.4 Water Corporation

2.4.1 Current and future water supply

Figure 7 shows the 'firm yield' required to supply the Integrated Water Supply System (IWSS) with 260 GL in 2004/05 without a total ban on sprinklers for a range of average stream flows to surface water sources. The average stream flows are ~ 120 GL/yr, 160 GL/yr and 220 GL/yr for the 2001 to 2004, 1997 to 2003 and 1975 to 2003 periods respectively. Without a 45 GL/yr seawater desalination plant (SWRO), the climate of the last four years requires a firm yield from other sources such as Gnangara of ~ 180 GL. With SWRO this reduces to ~ 135 GL/yr. With SWRO a firm yield of ~ 100 GL/yr is required if the climate since 1997 persists. Most of this firm yield will need to be sourced from Gnangara.

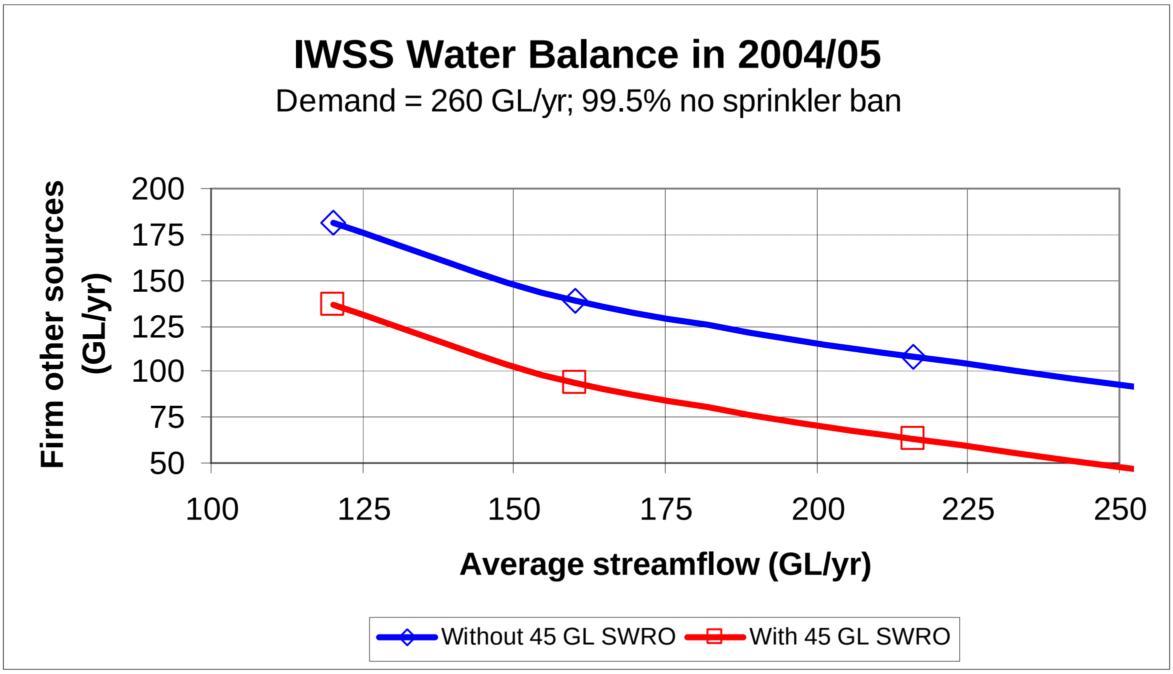


Figure 7: Firm yield as function of average stream flow

Over the next 20 years an additional ~ 100 GL/yr of firm supply will be required for average demand at a rate of 155 KL/person. Supply from Gnangara will be critical over at least the next 5 years while other source options listed in Table 2 are developed.

Table 2: Potential future sources for the IWSS.

Source	Confidence	Yield (GL/yr)	Capital ($M)	Operating (c/KL)
Seawater desalination	High	30-45	240-350	53
South west Yarragadee	High	45	310	20
Water trading – Waroona & Harvey districts	High	6-17	?	?
Wellington	Medium	12	40	12
Eglinton groundwater	Medium	16	45	22
Catchment management – Wungong	Medium	6	R&D	20
Catchment management – other catchments	Low	32		20
Gnangara groundwater – harvesting of pines	Low	20		20
Gingin groundwater	Low	30	350	26
Yanchep groundwater	Low	10	30	22
Brunswick River	Low	25	220	12
Aquifer storage & recovery	Low	30?	250?	?

Figure 8 shows the history of groundwater source development for the IWSS. The value of groundwater assets is more than $300 million. Note that the recently commissioned Neerabup (coastal wellfield) and Lexia schemes were developed to meet growth, not in response to drought. Groundwater supplies 60% of the current IWSS demand and about 66 per cent of this is from the Leederville and Yarragadee aquifers. Only some 15 GL is from the superficial aquifer in areas protected as Priority 1 source protection on the Mound. The remaining 45 GL of superficial groundwater is from beneath or close to urban and rural areas.

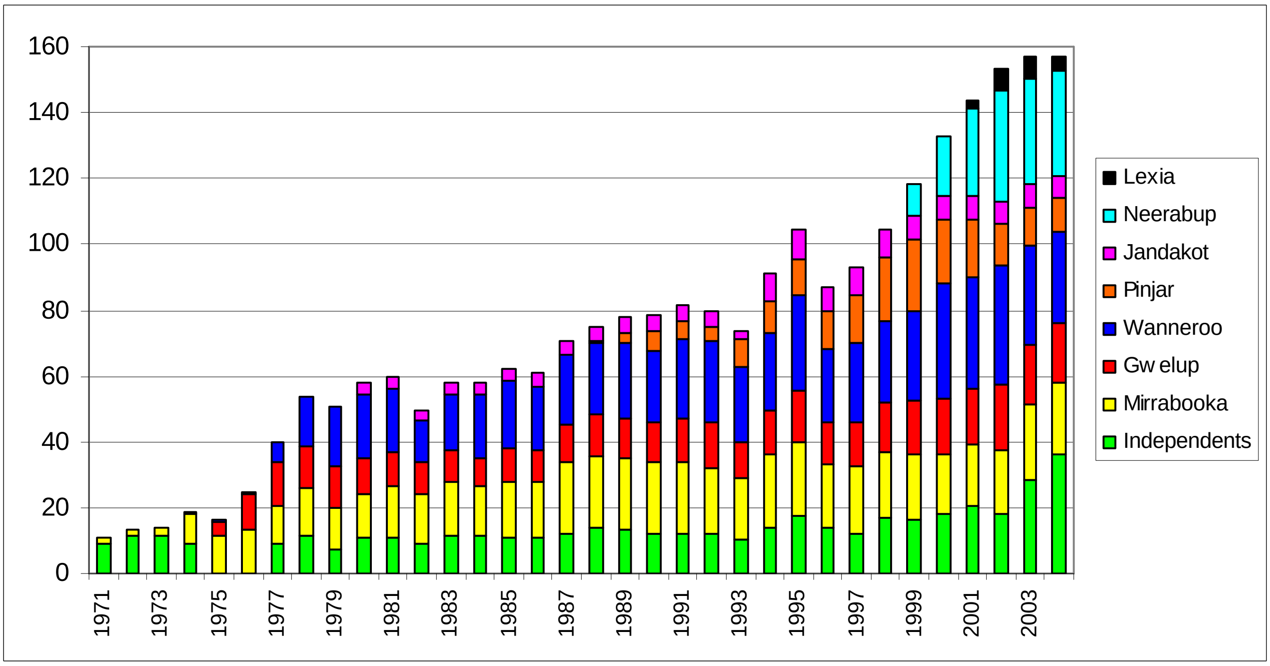


Figure 8: Groundwater source development

Since 1998 an additional ~ 110 GL/yr has been abstracted from the Leederville and Yarragadee aquifers as a drought response measure to compensate for the more than 30 superficial wells turned off for ecological reasons (note the decreased abstraction from the Pinjar scheme). Model simulation indicates that this additional abstraction should have no detectable impact on groundwater dependent ecosystems (GDEs).

The Corporation expects to need to abstract between 105 and 135 GL from Gnangara for at least the next five years and model simulation indicates that there is unlikely to be adverse impacts on GDEs. The next two years will be critical with abstraction between 150 and 165 GL until the seawater desalination plant at Kwinana is operational and / or the winter rainfall is significantly higher than it has been in recent years.

The replacement cost for Gnangara groundwater for public water supply which is reduced for ecological or other reasons is $10 million per GL in total present value terms (capital and operating). This does not include the write-off cost of abandoned assets.

Groundwater simulation indicates that the reduction in groundwater levels is being driven in approximately equal measure by a drier climate, abstraction (public and private) and by reduced recharge because of pines and less frequent and/or intense burning of native woodland. Opportunities for management of native vegetation and the pine plantation to increase groundwater recharge must be pursued. This includes a strategic revisit of the proposed Gnangara Park land use to recognise the fact that Gnangara Mound is and is likely to remain the strategic water source for the IWSS.

The State Water Strategy commits to '*Develop and implement a sustainable management framework for land and water use of the Gnangara Mound. This will be an important step in the utilisation of* *sustainability assessment within Western Australia and will ensure that the Government's leadership in this area continues'* The Corporation position is that this is required before revised environmental water provisions are set under the *Environmental Protection Act 1986* and water allocations are revised.

2.5 Department of Environment

2.5.1 Background

The Department of Environment is tasked with managing the groundwater resources of the Gnangara and Jandakot Mounds in a sustainable manner. Management strategies need to consider and balance the environmental (GDEs), social (public water supply) and economic (private abstraction, primarily for irrigated horticulture) benefits of using the groundwater resources.

The current mechanism for determining the success of management strategies is compliance with the Ministerial Conditions set for a range of sites across the Mounds. These conditions are primarily based on minimum water levels considered as limits for maintenance of the ecological water requirement (EWR) for the particular GDE. Administration of these Ministerial Conditions is carried out by the EPA.

Most of the Ministerial Conditions were set in 1985 with some revision in 1995. It is freely acknowledged that a number of the external factors that influenced the setting of the minimal water levels for certain GDEs are now redundant or have not occurred.

There have been ongoing non-compliances with the Ministerial Conditions since 1996 with a total of 22 non-compliances recorded for 2003-04. Most of the non-compliances have not been accompanied by severe degradation of the associated GDE. However, a small number of GDEs have experienced significant impacts and changes to vegetation and macro invertebrate biodiversity have been observed at many of the GDEs as a result of declining water levels and reduction in water body depth and quality.

2.5.2 Response to declining groundwater levels

The declining water level trend being experienced across the Mounds is considered to be a reflection of a drying climate coupled with localised impacts from a combination of pine plantations, public water supply abstraction, private abstraction for irrigated horticulture and land use changes.

The over riding impact of a drying climate represents an over allocation of the groundwater resources under current rainfall conditions. There is a pressing need for a revised management regime that takes into account all land and water uses

The current activities being undertaken by the Department of Environment to deal with management issues on the Mounds include the following actions.

- A Section 46 review through the EPA that aims to review EWRs, revise EWPs and determine more appropriate allocation limits taking into account the drying climate.

- Artificial maintenance of some GDEs.
- Formation and executive support for the inter-agency Gnangara Co-ordinating Committee.
- Reduce public water supply draw from superficial aquifer bores near GDEs.
- Initiate a metering project in the Wanneroo Groundwater Area to determine private abstraction levels.
- Support the Waterwise on the Farm program with a target efficiency gain of a 20 per cent reduction in irrigation abstraction.
- Initiate the formation of a Water Resource Management Committee for the Gnangara Mound (Perth North).

Other actions that the Department can or needs to initiate include the following steps.

- Identification and investigation of all options for future management.
- Ensure broad community support, through appropriate consultation, for any changes.
- Reduce private allocations. This may require severe reductions around some GDEs.
- Undertake supplementation of additional GDEs.
- Investigation and implement regional scale aquifer recharge using recycled water.

In summary, it is considered that there is an immediate and pressing need for sound science and consensus to direct the decision making process.

The process has to be a whole of government effort or it is doomed to failure.

For the purposes of management, the Gnangara Groundwater Mound (GGM) has been divided into nine functional zones as shown in Figure 6. These were used as the basis for defining changes to land and water uses that could collectively be considered as alternate scenarios for the Mound. The methodology for data collection for each zone is described in Section 1.3. At the same time as the options were being explored and scenarios developed by the participants, areas of bio-physical and policy uncertainties were identified and noted separately. Suggested issues are presented in Section 4.2.

3.1 Yeal Zone

Since 1979 generally a 2 to 3 m groundwater level decline, with some areas up to 4 m since 1979. The 'business as usual' scenario, and suggested changes made at the workshop are presented in Figure 9.

Figure 9: Land and water use in Yeal Zone

Groundwater Level influences		'Business as usual' Current practice and committed developments		What can be done to protect the Mound?	
		Current / planned practice	**Relative impact on Mound***	**Actions**	**Barriers and drivers**
Land use and Water use	Pine plantation management	Pine impacts important in the west.	-1		Very young pines in the area are uneconomic to remove
	Urban development		0		
	Public abstraction	Confined aquifer abstraction may be impacting.	-1	Improve understanding of interaction between Yarragadee and superficial aquifer	Additional bores required across area for monitoring inputs to Yarragadee. Resources needed to monitor the area better, and in particular recharge areas. Needs use of wide range of expertise (botany, hydrogeology in designing research programs and interpreting data
	Private abstraction	Confined aquifer abstraction may be impacting.	-0.5	Water rights options for negotiating with landholders for water rights (transferring rights from private to public use)	
	Native vegetation management	Native vegetation impacts occur mostly in the north and east. Some areas are very dense.	-2	Bring burning regime to less than 10 yrs within the next 3 years Priority for burning – pristine areas with low risk of weed invasion	Need more efficient MoU with the Commonwealth to ensure that appropriate action can be taken (i.e. burning regimes) Appropriate resourcing (DCLM) – fire management, biodiversity research Address Commonwealth's low priority for burning on its land
	Agricultural development		0		
	Supplementation of GDEs		0		
	Recharge using recycled water		0	Uncertainty about its applicability in this area	
Climate change		2 to 3m (some bores show up to 4m) decline by CDFM, although some bush fire impacts have partially mitigated these declines.	-3		
PRAMS Combined Scenario 2 prediction		2 to 3 m of additional decline anticipated in the next ten years.	N/A		General barrier – need for integration of skills, capacity building, retention of knowledge

* Relative impact on Mound. 3 (large change) to 1 (small change). Sign (+/-) indicates direction of change, i.e. +ve rising, -ve falling, 0 is no impact.

The Yeal Zone is an important nature conservation area, with high biodiversity and important wetlands. There are core reference sites that have high priority for conservation. It is a recharge area for the aquifer. Parts of the zone are experiencing the impacts of confined aquifer pumping.

3.1.1 Research and development needs in this zone

- The detailed leaf area index (LAI) research that has been conducted needs to be ground-truthed within the zone and then the relationships between LAI and water use extrapolated across the whole area.
- The interaction between native vegetation and fire regimes needs investigation in respect of water use, recharge and biodiversity impacts.
- Additional groundwater monitoring is required to better understand the connection between the Superficial and Yarragadee aquifers.

3.1.2 Policy needs in this zone

- There is a need for more coordination of research and management in the zone between agencies (e.g. in the development of fire regimes).
- Agreement is required between the State and Commonwealth on appropriate fire regimes for land owned by the Commonwealth.
- Development of regional satellite cities should be investigated – for example it was suggested that the next university could be developed at Guilderton.

3.2 Pinjar Zone

Since 1979 generally a greater than 3 m groundwater level decline, with some areas as much as 5 m (in the west). The ‘business as usual’ scenario, and suggested changes made at the workshop are presented in Figure 10.

Figure 10: Land and water use in Pinjar Zone

Groundwater Level influences		**‘Business as usual’ Current practice and committed developments**		**What can be done to protect the Mound?**	
		Current / planned practice	**Relative impact on Mound***	**Actions**	**Barriers and drivers**
Land use and Water use	Pine plantation management	Pine impacts important in the west.	-1	Thinning 100 per cent of pines to west of Pinjar borefield (near future)	Currently monitoring impact of thinning
	Urban development		0		
	Public abstraction	Major impacts near the Water Corp. borefields. Confined aquifer abstraction may also be impacting.	-2 (confined aquifer abstraction *is* also impacting)	P5O project – researching current impacts of drawdown on Banksia woodlands. Determine sub crop of Leederville aquifers	
	Private abstraction		0		
	Native vegetation management	Native vegetation impacts occur mostly in the east.	-1.5	Biodiversity and fire impacts research	Vegetation is already separated from the groundwater table. Commonwealth land to the east of the zone – the state has no control over burning regimes.
	Agricultural development		0		
	Supplementation of GDEs		0		
	Recharge using recycled water		0		
Climate change		3m decline by CDFM	-3		
PRAMS Combined Scenario 2 prediction		3 m of additional decline anticipated in the next ten years.	N/A		

* Relative impact on Mound. 3 (large change) to 1 (small change). Sign (+/-) indicates direction of change, i.e. +ve rising, -ve falling, 0 is no impact.

3.2.1 Research and development needs in this zone

- Research to determine how far and wide perching layers extend, particularly on the Rosella Flats.
- Further definition of the location and identification of biodiversity assets as affected by impacts of fire and water recharge/ discharge relations.
- The interaction between native vegetation and fire regimes needs investigation in respect of water use, recharge and biodiversity impacts.
- Further taxonomic classification on invertebrates.

3.2.2 Policy needs in this zone

- Inter-agency cooperation is needed to ensure that research scientists have access to areas of land for research purposes.
- Review the Commonwealth-State Agreement on land use and management to enable appropriate burning regimes on Commonwealth-owned land.

3.3 Yanchep Caves Zone

Since 1979 groundwater level declines range from 1 to 2 m in the west to 3 to 4 m decline in the east. The 'business as usual' scenario, and suggested changes made at the workshop are presented in Figure 11.

Figure 11: Land and water use in Yanchep Caves Zone

Groundwater Level influences		'Business as usual' Current practice and committed developments		What can be done to protect the Mound?	
		Current / planned practice	**Relative impact on Mound***	**Actions**	**Barriers and drivers**
Land use and Water use	Pine plantation management	Pine impacts important in the east.	-2	Thinning and harvesting of pines Monitoring of pine removal to measure impacts	Large depth to groundwater – recharge issue (there will be a slow response. Negotiate compensation with Wesbeam
	Urban development		0		
	Public abstraction	Minor impacts near the pine plantations in the east.	-0.5	Review effect of Leederville drawdown on water levels in the superficial aquifer	
	Private abstraction	Some impacts close to the caves in the west.	-1	Undertake a survey on water use Implement metering (already happening) Restricting water trading to 10,000 m3 assuming water available (possible sustainable limit reduction)	Impacts on southern caves from Carabooda (horticulture)
	Native vegetation management	Native vegetation impacts occur mostly in the west.	-1	TEC research required (other than caves TECs) to inform burning responses. Maintain the Tuart woodlands so we have tuart roots for the caves (bore, long-term viability) Burn bushland to the east of the caves and wetlands regularly	Native vegetation quite dense Biodiversity issues Presence of TECs
	Agricultural development		0		
	Supplementation of GDEs	Caves supplementation could be a long-term solution.	+1		
	Recharge using recycled water		0		
Climate change		2-3 m decline by CDFM	-3		
PRAMS Combined Scenario 2 prediction		2 to 3 m in the east and 1 to 2 m in the west of additional decline anticipated in the next ten years	N/A		

* Relative impact on Mound. 3 (large change) to 1 (small change). Sign (+/-) indicates direction of change, i.e. +ve rising, -ve falling, 0 is no impact.

The Yanchep Caves zone contains Threatened and Endangered Communities (TEC) in the caves that have been subjected to drying stresses since the early 1990s. Supplementation is underway.

3.3.1 Research and development needs in this zone

- Monitoring the impact of pine thinning and harvesting on groundwater levels. A thorough analysis of all existing and new data is required.
- Further development of a local groundwater model that links with the PRAMS regional model (geographical extent of MODFLOW model current for caves).

3.3.2 Policy needs in this zone

- The location of the planned horticultural precinct in relation to the Yanchep National park and the caves needs to be reviewed at a policy/ strategic planning level.

3.4 North Wanneroo Zone

Since 1979 groundwater levels have declined by 2 to 3 m over most of the area. The 'business as usual' scenario, and suggested changes made at the workshop are presented in Figure 12.

Figure 12: Land and water use in North Wanneroo Zone

Groundwater Level influences		'Business as usual' Current practice and committed developments		What can be done to protect the Mound?	
		Current / planned practice	**Relative impact on Mound***	**Actions**	**Barriers and drivers**
Land use and Water use	Pine plantation management	Impacts occur in the east.	-2 (may only be –1)	Accelerate harvest/ total clear fell Define after harvest land use (change to what?)	Economics LVL agreement (State Agreement Act) Desired water outcomes
Land use and Water use	Urban development		0	Change from no urban development to increased urbanisation	Cost of infrastructure Increased costs of food because of displaced horticulture Social values
Land use and Water use	Public abstraction	Minor impacts, no more abstraction planned.	-0.5 (possibly –1)	Artificial recharge	Social issues
Land use and Water use	Private abstraction	Major impacts, allocation limit reached.	-3	Implement a percentage reduction in abstraction Increase water use efficiency through education means Introduce a charge for water abstracted Relocation of Abstraction for horticulture	Economics Need for compensation for relocation Deciding what to replace relocated uses with?
Land use and Water use	Native vegetation management	Very little native vegetation left in the north of this area, but some large areas remain in the south.	-0.5	Increase frequency and extent of burning of native vegetation Removal of native vegetation	Political issues Public perception Air pollution (from burning) Loss of ecological values Research needed to support case for increased frequency of burning
Land use and Water use	Agricultural development	Possible horticultural precinct.	-1	Development in alternate locations as existing horticultural areas are urbanised Analyses of crop suitability (aim for low water use crops)	Economics Infrastructure needs Impact on water table
Land use and Water use	Supplementation of GDEs	Coogee Springs and Lake Nowergup	+1	Supplementation where (environmental) values are identified	Unsustainable, could create a deficiency elsewhere
Land use and Water use	Recharge using recycled water	Could be used to mitigate declines or facilitate additional horticulture.	+1?	Recharge for horticulture and environment	Aquifer clogging Public perception of actions Water quality issues
Climate change		~1.5-2.0 m decline by CDFM	-1.5		
PRAMS Combined Scenario 2 prediction		Additional 2 to 3m over next 10 years	N/A		

* Relative impact on Mound. 3 (large change) to 1 (small change). Sign (+/-) indicates direction of change, i.e. +ve rising, -ve falling, 0 is no impact.

There was a suggestion that the relativities between impact of the land uses on the Mound are exaggerated and it may be that they have a more or less equal impact on the Mound.

3.4.1 Research and development needs in this zone

- More water efficient crops are needed that are suited to the area and which can be grown commercially.
- Defining uses for clear-felled pine trees (that cannot be handled by the LVL Plant),
- Land use options for the areas after clear-felling is completed.
- Get a better understanding of the level of water use by horticulture and how much water can be saved by more efficient agricultural practices .
- Implement a research program in bio-climatic modelling that considers the relationships between changed climate, vegetation structure and function, and water use and recharge below vegetation. This research should be directed at identifying thresholds for critical change in environmental functioning.
- Developing a better understanding of the relationship between burning regimes, biodiversity and water relations.

3.4.2 Policy needs in this zone

- Determining preferred post-pine land uses.
- Determining what the real constraints are to amending the State Agreement Act for pine harvesting and processing in a way that generates better groundwater outcomes.
- Developing a policy that accounts for climate change in setting sustainable limits to land and water use management.

3.5 South Wanneroo Zone

Since 1979 groundwater levels have declined by 1 to 2 m over most of the area. The 'business as usual' scenario, and suggested changes made at the workshop are presented in Figure 13.

Figure 13: Land and water use in South Wanneroo Zone

Groundwater Level influences		'Business as usual' Current practice and committed developments		What can be done to protect the Mound?	
		Current / planned practice	**Relative impact on Mound***	**Actions**	**Barriers and drivers**
Land use and Water use	Pine plantation management	Some impact occurs along the eastern boundary.	-1	Accelerated clear felling followed by replacement with suitable vegetation (as for North Wanneroo)	Economics LVL agreement (as for North Wanneroo)
	Urban development	Still in planning stage, large range from none to total urbanisation.	+1	Discourage garden bores Maximise urban run-off/ recharge Impose a charge ($) for garden bores Grey water use 'Xeriscaping' with native vegetation to reduce garden water use Manipulating bore size, bore sharing, optimise location of householder bores	More complexity in the allocation of scarce groundwater resources eg acid sulphate soils, water trading, number of urban/special rural bores, enhanced environmental criteria.
	Public abstraction	Wanneroo bore field has a major impact when used.	-1	Further reduction of abstraction Development of alternate sources More public bores located in limestone	Cost of changing abstraction arrangements Compressed timeframe may not allow full use of assets High transmissivity in limestone may facilitate salt water incursion into the aquifer
	Private abstraction	Major impacts, allocation limits reached.	-3	Accelerate urbanisation across the zone Restrict allocations Implement water trading	Compressed timeframe may not allow full use of assets, compensation possibly required
	Native vegetation management	Very little dense native vegetation left in this area.	-0.5	Protection of wetlands Line wetlands to reduce wetland discharge Fill wetlands Address acid sulphate soil issues Hobby farms less monoculture	Aesthetics Legislation
	Agricultural development	Minor amounts of additional horticulture occurring due to trading	0	Accelerate development	
	Supplementation of GDEs	Lake Jandabup	+1	Fill in damaged GDEs with soils Top up (remaining) wetlands	Public perception More urban land
	Recharge using recycled water	Could be used to mitigate declines or facilitate additional horticulture.	0	Recharge for horticulture and environment	Aquifer clogging Public perception of actions Water quality issues
Climate change		~0.5 m decline by CDFM, but in a discharge zone with frequent surface water bodies	-1.5		
PRAMS Combined Scenario 2 prediction		Additional declines anticipated, but model is not well calibrated here	N/A		

* Relative impact on Mound. 3 (large change) to 1 (small change). Sign (+/-) indicates direction of change, i.e. +ve rising, -ve falling, 0 is no impact.

3.5.1 Research and development needs in this zone

- Understanding what size urban blocks will community demand/ use in the future and the implications for water use and recharge within preferred urban structures (e.g. block size 1,000 m^2 or 600 m^2).
- Examine the demographics for the zone now and in the future and relate this to the design of urban settlements. The assumption is that the bigger the dwelling (resulting from family demographics), the smaller will be the garden.
- Investigate the best locations for new urban areas with the objective of maximising environmental benefits.
- Recalculate household water use and demand – e.g. garden use, household appliances.
- Investigate the abstraction implications of introducing a water trading scheme versus limits on new allocations.

3.5.2 Policy needs in this zone

- Address incompatibilities between legislation and policy.
- For example, rebates are provided by Government for installing garden bores that may be having an adverse impact on groundwater levels.
- The policy environment for managing native vegetation needs to be reviewed to address apparently competing requirements for biodiversity conservation, and burning regimes that will maximise recharge.

3.6 Perth Metro Coastal Zone

Since 1979 a groundwater level decline of between 0 and 1 m over much of the area. Some areas have had a water table rise. The ‘business as usual’ scenario, and suggested changes made at the workshop are presented in Figure 14.

Figure 14: Land and water use in Perth Metro Coastal Zone

Groundwater Level influences		‘Business as usual’ Current practice and committed developments		What can be done to protect the Mound?	
		Current / planned practice	**Relative impact on Mound***	**Actions**	**Barriers and drivers**
Land use and Water use	Pine plantation management		0	N/A	
	Urban development	Very large areas of urbanisation have often created watertable rises.	+2	Protection of wetlands Maximise groundwater recharge up gradient	Potential groundwater contamination
	Public abstraction		0	Increase abstraction in this Zone	
	Private abstraction	A minor impact, mostly in southern areas, saline water incursion is a potential issue.	-1	Encourage sharing of garden bores	
	Native vegetation management		0	N/A	
	Agricultural development		0	N/A	
	Supplementation of GDEs		0	Maintenance of marine ecology	
	Recharge using recycled water		0	N/A	
Climate change		0 to 0.5 m decline by CDFM, but area is near discharge zone	-0.5		
PRAMS Combined Scenario 2 prediction		Very minor additional declines anticipated.	N/A		

* Relative impact on Mound. 3 (large change) to 1 (small change). Sign (+/-) indicates direction of change, i.e. +ve rising, -ve falling, 0 is no impact.

3.6.1 Research and development needs in this zone

- Improve the understanding and knowledge of groundwater quality below urban land use.
- Undertake salt water wedge and water quality monitoring.

- Research is needed on the importance of fresh water discharge from this zone in sustaining marine ecosystems, and the relative impacts of different levels of abstraction.
- Model the impact of water recycling within and into the zone on the behaviour of the aquifer, the water quality and the impact on marine ecosystems (see previous point). Specific issues include clogging of the aquifer for waste water re-use/ injection in Bassendean sands and Tamala limestone.
- Investigate the impacts of both surface water and groundwater drainage on the aquifer.
- Investigate the Underground Water Pollution Control Area (UWPCA) boundary between Perth Coastal Metro Zone and Wanneroo Groundwater Area (WGA) to increase the water available in the WGA by changing groundwater sub area boundaries based on hydrogeology rather than land system boundaries).

3.6.2 Policy needs in this zone

- Change the Perth Coastal Metro Zone so that it perfectly matches the distribution of the Tamala Limestone sediments.

3.7 Lexia Zone

Since 1979 groundwater level declines of 1 to 3 m. The 'business as usual' scenario, and suggested changes made at the workshop are presented in Figure 15.

Figure 15: Land and water use in Lexia Zone

Groundwater Level influences		'Business as usual' Current practice and committed developments		What can be done to protect the Mound?	
		Current / planned practice	**Relative impact on Mound***	**Actions**	**Barriers and drivers**
Land use and Water use	Pine plantation management	Pine impacts important in the west.	-1 (believed to be an underestimate – DCLM)	Clear or thin	Legislation, the LVL MoU
	Urban development		0 (suggested to be +0.5)	Wastewater recharge Stormwater management/ infiltration Water for POS and urban lakes (education issue if waste water used) WSUD/ redesign of urban vegetation Register garden bores for better understanding of water use	Water quality protection/ public health protection
	Public abstraction	Major impacts near the Water Corp. borefields. Confined aquifer abstraction may also be impacting.	-2 (localised impact, may be – 1.5 overall - need > 8 GL/a to impact GDEs)	1. Alternative sources 2. Turn-off bores near GDEs 3. Import water for local irrigation (second class water) 4. Wastewater reuse in urban areas 5. Manage local demand through restrictions	1. Costs of development and transfer of impacts to other catchments 2. Other externalities 2. Loss of water
	Private abstraction	Some impact in the west.	-0.5	Review allocations Review Mirrabooka abstraction Metering of use	
	Native vegetation management	Native vegetation impacts occur mostly in the east.	-1	Vegetation management (burning regime)/ planning/ location is important to maximise positive impacts Burn the native vegetation to less than 10 years frequency across area	Public resistance to burning and smoke haze Area has high conservation value (mound springs, wetlands on east side of Swan Coastal Plain) Resourcing of DCLM for managing altered fire regime
	Agricultural development		0 (may be having some negative impact)		There is agric development in the east of the zone, plus POS and corridors. Grazing controlling vegetation density with implications for recharge
	Supplementation of GDEs		0		
	Recharge using recycled water		0		
Climate change		0-3 m decline by CDFM	-2		
PRAMS Combined Scenario 2 prediction		3 m of additional decline in the next 10 years. Greater near abstraction.	N/A		

* Relative impact on Mound. 3 (large change) to 1 (small change). Sign (+/-) indicates direction of change, i.e. +ve rising, -ve falling, 0 is no impact.

Population growth overall was identified as a significant driver of change in this zone. One overall positive action could be to encourage improved water use efficiency by users of groundwater.

3.7.1 Research and development needs in this zone

- Analyse hydrographs in the zone according to the land use in the immediate area.
- The hydrology in the Zone is uncertain, there is a need to determine the connectivity of aquifers in the Zone and the connection between the borefield and wetlands.
- Investigate the impact of water sensitive urban design on urban stormwater run-off quantity, and hence its effectiveness in encouraging *in situ* recharge.

3.7.2 Policy needs in this zone

- The planned state Biodiversity legislation and complementary Commonwealth legislation could have implications for the management of wetlands in the Lexia Zone.
- Review is needed of the fire and land management policies of the Department of Conservation and Land Management, particularly in respect of the frequency of burns.
- Review of Department of Planning and Infrastructure and WA Planning Commission policies on water sensitive urban design (WSUD) and lot sizes for their impact on water use/ recharge in the zone.

3.8 Mirrabooka Zone

Since 1974 a groundwater level decline of 2 m, a period of recovery occurs in the early 1990s. The 'business as usual' scenario, and suggested changes made at the workshop are presented in Figure 16.

Figure 16: Land and water use in Mirrabooka Zone

Groundwater Level influences		'Business as usual' Current practice and committed developments		What can be done to protect the Mound?	
		Current / planned practice	**Relative impact on Mound***	**Actions**	**Barriers and drivers**
Land use and Water use	Pine plantation management	Pine impacts important in the north.	-0.5		
	Urban development	Urbanisation has increased recharge and storage by a small amount.	+0.5		
	Public abstraction	Major impacts near the pine plantations and Water Corp borefields.	-3 (impacts restricted to western side)	Manage demand and restrictions Identify alternate sources vv business as usual	Difficulty in meeting demand Infrastructure isolation ('stranded asset') if abstraction reduced Cost
	Private abstraction	Some minor impacts in the north.	-0.5		
	Native vegetation management	Native vegetation is present but at low density.	-0.5		
	Agricultural development		0		
	Supplementation of GDEs		0		
	Recharge using recycled water		0		
Climate change		1 m decline by CDFM.	-2		
PRAMS Combined Scenario 2 prediction		Most of the area is predicted to be stable, with up to 1 m declines in the north and west.	N/A		

* Relative impact on Mound. 3 (large change) to 1 (small change). Sign (+/-) indicates direction of change, i.e. +ve rising, -ve falling, 0 is no impact.

There were no zone-specific' research and development or policy issues identified for the Mirrabooka Zone.

3.9 Gwelup Zone

Since 1992 there has been a groundwater level decline of between 1 to 3 m. The 'business as usual' scenario, and suggested changes made at the workshop are presented in Figure 17.

Figure 17: Land and water use in Gwelup Zone

Groundwater Level influences		'Business as usual' Current practice and committed developments		What can be done to protect the Mound?	
		Current / planned practice	**Relative impact on Mound***	**Actions**	**Barriers and drivers**
Land use and Water use	Pine plantation management		0		
Land use and Water use	Urban development	Urbanisation has increased recharge.	+1	Increase local recharge of stormwater by modifications to the drainage systems Manage potentially acid sulphate soils (PASS)	Population growth in the zone Occurrence of acid sulphate soils
Land use and Water use	Public abstraction	Major impacts near the Water Corp borefields, mostly in the last 10 years	-2 (could be –3)	Abstraction from coastal limestone (high conductivity, resulting in small draw down) Develop other sources Water re-use within the Zone Manage demand/ restrictions Water supplementation of GDEs at risk	Water quality (EC levels)
Land use and Water use	Private abstraction	Private abstraction impacts dominate in the early, pre-1990 years	-3 (could be –3)	Move horticultural businesses to the planned new precinct Promote water use efficiency	Data on private abstraction are unreliable Development of golf courses in the early 1990s
Land use and Water use	Native vegetation management		0		
Land use and Water use	Agricultural development	Decreasing	0		
Land use and Water use	Supplementation of GDEs	Lake Gwelup	+1		
Land use and Water use	Recharge using recycled water		0		
Climate change		1.5 m decline by CDFM in the last 10-12 years. Rising trend prior to that.	-1	Population management (at state scale) Development of alternative energy sources	
PRAMS Combined Scenario 2 prediction		Unrealistically high due to poor calibration significant additional declines are anticipated.	N/A		

* Relative impact on Mound. 3 (large change) to 1 (small change). Sign (+/-) indicates direction of change, i.e. +ve rising, -ve falling, 0 is no impact.

3.9.1 Research and development needs in this zone

- Improve the private allocation database.
- Undertake an urban water study that defines the relationship between urbanisation, recharge and water use and use the information in developing a local model.
- Undertake detailed mapping of the occurrence of potential acid sulphate soils (PASS).
- Monitor household (garden) bores for the occurrence/ development of acidity in abstracted water as a guide to the location of PASS.

3.9.2 Policy needs in this zone

- Explore incentives that will enable horticulture (that is abstracting water from the GGM) to relocate to other areas.
- Understand what the values are in the zone that are desired by the local community.
- Understand what the values are in the area that are desired by communities outside the zone.

Plenary discussions throughout the workshop identified the following key findings, observations and conclusions. These considered the state of the GGM, the pressures on it, and the required management responses. Additional commentary considered the outstanding uncertainties that need to be addressed through further research and development.

4.1 Current and planned and water use in the GGM

4.1.1 The state of the GGM

The presentations at the workshop confirmed that groundwater levels are dropping at nearly all locations across the GGM. The context for this decline is the drying climate, which is also affecting wetlands, other GDEs and the distribution of some biodiversity. The physical environment's response to climate change is a step-wise process and it is unlikely to collapse in functionality. However, the community and Government need to understand that change in the bio-physical state of the Mound is inevitable. Further, stakeholders need to be aware that the predictions from the modeling are probabilities not certainties.

4.1.2 Pressures on the GGM

The impact of climate change dominates and all decisions need to be made with this as background. A continuation of the rainfall trends of the last seven years will have severe impacts on the Mound regardless of management. Conversely, if the climate stabilises at the 25 year historic pattern, the change is manageable.

The other principal impacts on groundwater levels are imposed by pine trees, native vegetation and abstraction. Summary modelling information from Vogwill (2004) presents a qualitative estimate of the relative contribution of various pressures to water level decline, adapted from the 'bandwidth' in future predictive scenarios. These estimates do not represent equal amounts of manipulation in each parameter and the scenarios used to generate these difference volumes are given below in Table 3. For more information see Vogwill, (2004).

While these are estimates are for the Mound as whole, the impact at individual zones will vary according to the distribution of these land and water uses (as shown in the comparative estimates in the matrices in Section 3). If information on the location of parameter impacts is required the reader is directed to Vogwill, (2004), which is available from the DoE website.

Table 3: Impact of different scenarios on water volumes in the Mound

Model Parameter	Volume in GL	Component Scenarios Used to Generate Differences
Climate	1100	Difference between Increased and Decreased Rainfall Scenarios which equal an ~20% difference in total annual rainfall at the Perth Regional Office.
Native Vegetation	230	Difference between native vegetation at 2002 density and at low density (all high density banksia cells converted to low density)
Private allocation	190	Difference between 80% and 120% of 2003 allocation
Public water supply	180	Difference between Public Water Supply at 105GL/yr and 167GL/yr.
Pines	75	Difference between existing FPC-LVL clearfelling/thinning regime and almost a total clearfell of the southern plantations and some of the northern plantations.
Urbanisatio n	45	Difference between urbanisation of the planned urban areas in 10 and 20 years.
Total	1,820	

4.1.3 Required responses in use and management

At the end of the workshop, discussion about the required management responses focused on four themes. Comments under these themes attempt a summary of the conclusions reached in these discussions.

Deciding what 'we' want for the Mound

Participants recognised that the focus of the workshop was in managing land and water use and management to generate some level of relative improvement in the condition of the groundwater resource. However, the GGM provides multiple services to address multiple objectives. The desired future state of the Mound ('What we want it to look like') needs urgent consideration at a policy level (see item in Table 5. This will need engagement of the community in considering options and ultimately decisions that need to be taken at a whole-of-government level.

The need for 'informed adaptation' in a dynamic environment

Climate change poses a unique challenge in modelling the GGM and the impact of changing land uses. The difficulty in modelling in this uncertainty, and in deciding scenarios that will result in desired outcomes means that management must proceed on the basis of 'informed adaptation'.

The implication is that waiting for further research findings is not an acceptable option, and decisions need to be made now, given existing technical information and understanding of system behaviour, with a capacity to adjust those decisions as new information becomes available.

This difficult decision-making environment will require clear leadership, close agency collaboration with creative and flexible management, and an ability to inform the community of the constraints imposed by the uncertainties. Ultimately, the community and agencies will have to accept the need for significant change in how we use and manage the Mound's land and water resources. Further, they need to appreciate that given climate change, the Mound will inevitably be different in the future compared to the past.

The imperative of changing land and water use

It follows that changes in land and water use will be required as a matter of urgency, and that existing legislative and agency responsibilities will have to accommodate changes that may not be optimal for achieving other objectives. In short, participants at the workshop recognised that the responsible agencies may need to 'give some ground' in making whole of government decisions that address the overall health of the Mound.

Implications for resources

Workshop participants also recognised that decisions required will have significant resource implications. For example, a decision to change the pine harvesting regime could incur compensation to the processors. Similarly, a decision to withdraw some private allocations will require restitution to those disadvantaged. The community and government need to have the options clearly spelt out so that the trade-offs to be made in protecting the Mound can be appreciated, and the reasons for them understood.

4.2 Technical uncertainties in managing the Mound

The uncertainties identified in the Agency presentations and in the Zone working groups summarise to five major areas.

- Modelling the behaviour the groundwater in a dynamic climatic environment is difficult.
- There is a need for further conceptual hydrogeology that can reduce the uncertainty in modelling the impacts of various land and water use options.
- The relationship between vegetation and water use remains contentious, with uncertainty in the relative levels of water use by native trees, tall and medium shrubs and low shrubs.
- The impact of shifting from pines to native vegetation and from mature to immature pines needs comparing.
- Water level trends under urban development have been modelled using assumptions of the relationship between house and block size that may not be relevant in the future, given the trend to more intensive urban settlement resulting in reduced garden area.

The recommended approaches to addressing some of these uncertainties are presented in the two following sections.

4.2.1 Research and development needs

The research and development needs across the Mound as a whole and those identified by participants for each zone (as presented in Section 3) were collated under the headings of the Gnangara Groundwater Mound Research Program. This Program has been established through a Memorandum of Understanding between responsible agencies. The information was presented to the workshop participants by Dr Don McFarlane (CSIRO Land and Water). The needs are presented in Table 4.

Table 4: Research and development needs

Research program	Leader	Needs identified in the workshop
1. Hydrogeology	Chris O'Boy, DoE	**Generic needs** Improved stratigraphy/ hydrogeology understanding to improve the PRAMS model calibration **Yeal**: Monitoring/ management of Yarragadee intake area – South Gingin Brook **Lexia** – aquifer connectivity; wetlands with borefield. Local area model **Pinjar** – location of perching layers, especially Rosella Flats
2. Reviews	CSIRO/ Water Corporation	No needs identified
3. Real time monitoring	Claus Otto, CSIRO	No needs identified
4. Groundwater level changes	Chris O'Boy, DoE	**Generic needs** Is 1979 a good year to compare changes in levels? Time to equilibrium/ dynamic system is hard to model Do we have the tools to change the downward trend (what are the thresholds for the system?) **Gwelup** – acid sulphate soils (ASS) and Potential ASS maps and groundwater levels – defining the potential hazards?
5. Native vegetation	Michael Martin, Water Corporation	**Generic needs** Burning frequency impacts on hydrology and biodiversity and weed infestations – information required across all native vegetation on the Mound Climate change impacts on biodiversity values, distribution of vegetation, plant water relations and hydrology Deciding land use and management of the Gnangara Park after pine plantation removal? **Yeal** – Leaf area index (LAI) work on pines – extend LAI studies to include native vegetation **North Wanneroo** – Air pollution from burning: understanding the public perception

Research program	Leader	Needs identified in the workshop
6. Water use by pines	John McGrath, FPC	**Generic needs** The relative hydrological impacts of clearing pines versus burning native vegetation **Yanchep caves –** Good analysis of impacts of thinning/ harvesting on groundwater levels.
7. Horticulture management	Ron Colman, DoE	**Generic needs** Viability of ASR/ MAR for horticulture, re-pressurising, environmental water provisions? **North Wanneroo** – Clogging of aquifers using treated wastewater; public perception (of wastewater recharge), water quality - relocation issues - impact of reduced abstraction groundwater levels **Gwelup** – improve private allocation database
8. Land use change	Andrew Moore, DPI/ Ryan Vogwill, DoE	**Lexia** – use of stormwater/ water quality issues in treated wastewater for EWRs, and Public open space (POS) (e.g. Ellenbrook) **South Wanneroo –** Location of new urban areas so that benefits are maximized across all objectives **Perth Coastal** – water quality under urbanization? **Gwelup –** urban areas that still include rural allocations – this needs to change – what will the impacts be?
9. Threatened ecological communities	John Blyth, DCLM	**Generic needs** Determining the viability of supplementation (of GDEs) into the long-term? (e.g. Jandabup, Nowergup to continue?) Understanding the impact of abstraction on the level of freshwater discharge into marine environments, and on the offshore ecosystems. **Pinjar –** identification and distribution of biodiversity assets, and classification of invertebrates?
10. Integrated water supply system (IWSS)	Bob Stokes, Water Corporation	No needs identified
11. Integrated systems modeling (socio-economic, institutional arrangements)	Blair Nancarrow, CSIRO, Harry Ventriss, Strategen	**Generic needs** Need integrated/ simplified decision 'tool' for government decision making and community input. Integration of skills and models being used across discipline and across the Mound Introducing climate change scenarios to the community **Pinjar –** Improving inter-agency cooperation allowing researchers access to all sites - Risk analysis based on an understanding of values that enables sound setting of EWPs to address EWRs
12. Local area modeling	Ron Colman and Chris O'Boy, DoE	**Gwelup** – development and validation of an urban land use hydrological model
13. Superficial	Don McFarlane,	**Generic needs**

Research program	Leader	Needs identified in the workshop
aquifer under Perth	CSIRO	Does urbanisation result in sustained rises in groundwater levels? **South Wanneroo –** understanding the relationship between Urban density (R values for subdivisions), house size and water balance **Perth Coastal** – location of any salt water wedges in the zone Drain impacts on groundwater levels – what are the opportunities? What are the risks?

4.2.2 Policy and institutional needs

Policy and institutional needs were identified by participants at zone scale. These have been aggregated under six headings in Table 5. The information was presented to the workshop participants by Catherine Harrison (Manager Water Allocation, DoE).

Table 5: Policy needs

Domain	Policy issue
Governance	• Deciding ultimate (i.e. 'peak') responsibility for the Mound? Is it one Minister, more than one Minister, one agency, multi-agency • Including each agency's responsibilities, needs and actions within an Integrated Management Strategy (see Section 1.1.2) • Addressing incompatible Government/ Agency aims and programs – e.g. garden bore rebate vv maintenance of urban groundwater levels • Ensuring that the impacts of current and planned horticultural precincts (and water resource management) do nor adversely affect the hydrology in the Yanchep National Park (and caves) – issues to be addressed include water quality and aquifer clogging.
Native vegetation management	• Improve coordination (between Agencies) of research into, and management of burning of native vegetation. • Encourage the Commonwealth to be more accountable in its management of Department of Defence land within the Mound, by reviewing Commonwealth/ State Agreements. • Understand the implications of the Federal *Environmental Protection and Biodiversity Conservation Act* for management of native vegetation in the area • Resolve the apparent conflict between burning regimes for groundwater enhancement and the needs for biodiversity conservation and develop an appropriate strategy.
Pine estate management	• Determining the appropriate land tenure and use after removal of the pines. • Understanding the opportunities and constraints in the State Agreement Act for pine harvesting. • Conversion of state forest to agricultural land (for a horticultural precinct) – this will need approval by both Houses of Parliament via a Reserves Bill.
Public abstraction	• Investigate allocation credits provided to Water Corporation for managed aquifer recharge (MAR)
Private abstraction	• Investigate the value of economic incentives/ mechanisms to move high water use activities away from, or to cease altogether, in the vicinity of sensitive environments.
General	• Integrating climate change into Agency and Government strategic assessment and decision-making processes

Domain	Policy issue
	• Managing the impacts on the mound by decentralising the population from Perth city to other urban centres in the region • Encouraging (and managing) a shift in public perception from the 'traditional' environment of cheap water and high water use gardens, to the 'new'; environment where water is a precious and limited resource.

4.3 Final comments

Catherine Harrison (Manager, Water Allocation, DoE) presented the following wind-up comments.

Catherine began by noting that the workshop had largely met the three aims presented in Section 1.2, with participants thanked for their interest and honesty in proposing and discussing possible actions. This indicates a growing level of trust between agencies and individuals, which needs to be further developed in the connections and co-ordination between agencies. As part of this process, the outputs from the workshop will be discussed by the Gnangara Coordinating Committee (GCC).

The presentations and discussions at the workshop highlighted that although the magnitude of climate change is uncertain, it is definite that it will have a significant impact on the environmental values of the Mound, which as a consequence will look very different in the future under any management regime.

The workshop dealt mainly with the Mound's values as a source of water to sustain the environment and meet public and private needs to abstraction. Further planning for the GGM needs to be broadened to consider all of the values of the Mound, not just groundwater.

The inevitability of a different future for the Mound needs to be understood by stakeholders. The community needs to be aware of the range of possible scenarios for the GGM, and in considering the options, accept the need for significant change in how the Mound's resources of land and water are used and managed. Building future arrangements is a large task, one that is too big for any one agency alone. Developing an agreed plan will only occur with community engagement, and sound inter-agency collaboration that results in a shared vision and coordinated actions.

As a start, the workshop outputs will be used by the DoE is undertaking the Section 46 Review for the Environmental Protection Authority (EPA) which will provide the current state of knowledge and preliminary assessment of the options. In addition, the outputs should also be used to develop the Integrated Management Strategy for whole of government action for presentation to Government.

The presentations and discussions at the workshop have highlighted the need for a broader, more long term strategy that coordinates management in deciding the actions that all relevant agencies can take. This strategy also needs to confirm the overall responsibility for managing the Mound, which is an issue that should be discussed by the GCC.

Finally, the presentations and discussions at the workshop have highlighted the urgency of the issues, and the need to take action now, based on current knowledge - we cannot afford to wait for results from more research. The documentation of the issues, the possible scenarios, potential outcomes and needs for change identified in this Report need to promote action.

4.3.1 Closure

The workshop was closed by Ed Hauck (Manager, Hydrology and Water Resources Branch, Department of Environment), who thanked all those for their attendance and the quality of their participation.

Vogwill, R.I.J. (2004). *Sensitivity of the Water Table in the Perth Region to Changes in Climate, Land use and Groundwater Abstraction using the PRAMS model*, Department of Environment, HR 223.

6.1 Workshop Agenda

Coffee on arrival	**Presenter**	**8:45 to 09:00**	**Time**
Welcome	Ed Hauck	09:00 to 9.05	5 min
1.1 Workshop Purpose	Don Burnside Catherine Harrison	09:05 to 09:15	10 mins
GROUNDWATER LEVEL CHANGE – WHAT IS HAPPENING			
1.1 Groundwater level history – climate impacts and major factors affecting change	Ed Hauck	09:15 to 09:35	20 mins
1.2 Modelling scenarios on management of the Gnangara and Jandakot Mounds	Ryan Vogwill	09:35 to 10:05	30 mins
1.3 DISCUSSION – climate, groundwater level changes, approaches to scenario planning – confirming the science	Don Burnside	10.05 to 10:25	20 mins
Coffee break		**10:25 to 10:40**	**15 mins**
KEY ISSUES AND OBSERVATIONS ON LAND AND WATER USE AND MANAGEMENT – SECTORAL OPPORTUNITIES FOR IMPROVING THE MOUND			
2.1 Presentation by Department of Planning and Infrastructure	Andrew Moore	10:40 to 11:05	25 mins
2.2 Presentation by Department of Conservation and Land Management	Alan Walker	11:05 to 11:30	25 mins
2.3 Presentation by Forest Products Commission	Scott Wood	11.30 to 11.55	25 mins
2.4 Presentation by Water Corporation	Bob Stokes	11.55 to 12:20	25 mins
2.5 Presentation by Department of Environment	Ron Colman	12:20 to 12:45	25 mins
Lunch		**12:45 to 13:30**	**45 mins**
KEY ISSUES IN LOCAL AREAs – OPPORTUNITIES FOR ACTIONS TO PROTECT THE MOUND			
3.1 Analysis framework – water level change – management responses – key elements for scenario planning	Don Burnside & Ron Colman	13:30 to 13:45	15 mins
3.2 Yeal, North Wanneroo, Lexia	Working groups	13:45 to 14:25	40 mins
3.3 Pinjar, South Wanneroo, Mirrabooka	Working groups	14:25 to 15.05	40 mins
3.4 Yanchep caves, Perth Metro Coastal, Gwelup	Working groups	15:05 to 15.45	40 mins
3.5 Plenary – highlights, gaps – research needs – policy needs	Led by …. Don Burnside Don McFarlane Catherine Harrison	 15.45 to 16.05 16.05 to 16.25 16.25 to 16.45	 20 mins 20 mins 20 mins
Wind-up and next steps	Catherine Harrison	16:45 to 17:00	15 mins

6.2 Participants

Facilitator
- Don Burnside

Gnangara Coordinating Committee
- Jos Mensink

Department of Environment
- Ed Hauck
- Chris O'Boy
- Phil Commander
- Ryan Vogwill
- Wen Yu
- Catherine Harrison
- Phillip Kalaitzis
- Ron Colman
- Alex Kern
- Roy Stone
- Rob Donohue
- Tracy Calvert
- Rob Hammond
- Natti Hundi
- Steve Bellussi
- Jeff Camkin
- Louisa Kinnear

Water Corporation
- Bob Stokes
- Cheng Xu
- Mike Canci

Forest Products Commission
- Gavin Butcher
- John McGrath
- Scott Wood

EPA Service Unit
- Kim Taylor
- Colin Murray

CSIRO
- Don McFarlane
- Tony Smith
- Richard Silberstein

Department of Agriculture
- Joe Sherrard

Department of Planning and Infrastructure
- Mike Allen
- Rob Griffiths
- Andrew Moore

Department of Health
- Richard Theobald

Consultants
- Neil Milligan (Cymod Systems)
- Joanne Beckwith (Consultant)
- Keith Smettem (Centre for Water Res.)
- Harry Ventriss (Strategen)
- Lloyd Townley (Townley and Associates)
- Libby Mattiske (Mattiske Consulting)
- Adrian Peck (A.J. Peck and Associates)

Edith Cowan University
- Ray Froend
- Robyn Loomes

Department of Conservation and Land Management
- Alan Walker
- John Blythe
- Leigh Sage
- Drew Haswell
- Paul Brown

URS Australia Pty Ltd (URS) has prepared this report for the use of the Department of Environment in accordance with the usual care and thoroughness of the consulting profession. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal dated October 2004.

The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

This report was prepared between November 16, 2004 and March 18, 2005 and is based on the conditions encountered and information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

Appendix 5 – Analysis of Stakeholder Issues and Perspective's

MANAGING A SUSTAINABLE FUTURE
FOR
THE GNANGARA GROUNDWATER RESOURCES

ANALYSIS OF STAKEHOLDER ISSUES AND PERSPECTIVES

Prepared by

Beckwith & Associates

for

Water Allocation Branch
Department of Environment
Government of Western Australia

May 2005

Acknowledgements:

The study team would like to thank the many individuals who generously made themselves available for interviews. Without their willingness to share their perspectives and insights this report would not be possible.

This report was funded by the WA Department of Environment's Water Allocation Branch.

Study team:

Louisa Kinnear (DoE)
Deb Booker (DoE)
Sabrina Genter (Beckwith & Associates)
Jo Ann Beckwith (Beckwith & Associates)

Table of Contents

1.0 Introduction

The most valuable and largest source of affordable good quality fresh water in the Perth region is the Gnangara groundwater resources. These resources have for many years supported a variety of ecological, social and economic uses.

Over the years, the groundwater resources have come under pressure from a number of sources. The combination of low rainfall and increasing demand has resulted in a situation that is no longer sustainable. The current situation threatens not only the ecological but the many social and economic uses supported by the groundwater resources. The immediate task is deciding how to return the Gnangara groundwater system to a condition of sustainability for the generations of today and the future.

The Department of Environment (DoE), through the Water and Rivers Commission (WRC), has responsibility for developing a management plan for the Gnangara groundwater resources. As one of the early steps in the planning process, interviews were conducted with representatives of the many groups and organisations with an interest in the future of the Gnangara groundwater resources. The goal was to acquire an overview of the various views and perspectives of key stakeholders regarding the current and future management of the resources.

The objectives of the interview process were to:

- provide stakeholders with background information on why a groundwater management plan is needed;
- identify stakeholder issues and concerns regarding existing and future uses of the Gnangara groundwater resources;
- identify issues on which consensus exists and those where there are differences.
- access the local knowledge of stakeholders;
- explore how best to involve stakeholders and the public in planning the future of the Gnangara groundwater resources; and
- build working relationships with key stakeholders.

This report describes the study methodology and provides an analysis of stakeholder perspectives on the current and future management of the Gnangara groundwater resources.

2.0 Methodology

In total, 76 individuals were interviewed in the period 15 February to 19 April 2005 (Appendix A). Collectively, these individuals represent a cross-section of the many private and public sector stakeholders associated with the Gnangara groundwater resources. Interviews were conducted with representatives of community groups, environmental groups, university-based academics, industry groups, agricultural interests, state government agencies, local governments, and ratepayer groups.

A key stakeholder not included in the interview process was the Aboriginal community. A separate Department of Environment funded study into Aboriginal water issues will be conducted by Estill and Associates, specialists in Aboriginal cultural and social issues. Their findings will be available later in the year.

Each potential participant was initially contacted by telephone to request an interview. If the individual agreed to the interview, a convenient day, time and location was arranged and they were sent a confirmation letter and a brief background document (Appendix C & D).

The interviews were conducted in a face to face fashion. An interview guide was used to ensure that the following four themes were explored across all interviews (Appendix B):

- Theme 1: The planning challenge and key issues/concerns surrounding the future of the Gnangara groundwater resources;
- Theme 2: Allocation of the Gnangara groundwater resources;
- Theme 3: Actions needed to ensure a sustainable future for the Gnangara groundwater resources; and
- Theme 4: Community involvement in the planning process for the Gnangara groundwater resources

Notes were taken during the interviews and, with the individual's permission, tape recordings were also made. The interviews ranged in duration from 40 minutes to 2 hours. Completed interviews were typed up in an expanded note format. To confirm the accuracy of the notes, the tape recordings were checked and the interview notes were sent to interviewees for their review, if requested.

The interviews were conducted by three trained individuals. In addition to the use of an interview guide, consistency of data collection was addressed through interviewer observation. At the start of the interview process, several of the interviews were attended by two interviewers. In such instances, one of the interviewers took the lead, while the second interviewer observed the process.

The interview results were analysed via a coding process. The process was used to organise data around the four initial themes and to identify emergent (i.e., additional) themes. The interview notes and tape recordings were reviewed multiple times and, a number of dominant themes emerged (see Chapter 3). On some themes there was considerable agreement while others revealed sharp differences of opinion among stakeholders.

The major strength of in-depth interviewing as a research methodology is the rich data it generates. In contrast to a methodology such as a questionnaire, the conversational style of interviews allows the individual to use their own words and delve more deeply into the reasons behind their positions and perceptions.

However, due to its qualitative nature, the ability to calculate empirical results is limited. It is not possible to do the same statistical analysis on the interview data collected in this study that one could with questionnaire-based survey data. There are several reasons for this. Firstly, the methodology did not require that the same number of individuals be interviewed from each stakeholder category (e.g., horticulture, state government agencies, environmental interests, industry) and the overall number of individuals is small. Secondly, the same questions were not asked of each interviewee. Although each was asked to comment on the same four themes, the exact same questions were not asked of each individual. In addition, there were instances in which certain interviewees raised additional issues that were not discussed during other interviews.

For the purposes of this study the above limitations were not problematic since the intent of the interviews was to gain an overview of the range of issues important to key stakeholders. The objective was not to determine what percentage of each stakeholder category held a specific position on a particular issue. To the extent possible we have employed qualitative terms to provide the reader with an indication of the extent to which certain issues or perceptions were held across or within particular stakeholder categories.

Finally, the findings in this report should be treated as a snap shot in time. Stakeholders expressed their views based on the information they had at the time of the interviews. Many interviewees noted that at this early stage in the planning process it was difficult for them to comment on certain themes and issues because they had limited background information. As additional information is provided to stakeholders, it would not be surprising if some individuals or groups modify some of their views.

3.0 Analysis of Themes

The analysis of interview data revealed the themes and sub-themes shown in Table 1. Each is discussed in the following sections of the report.

Table 1. Themes and sub-themes

Theme	Sub-Theme
A. Existing conditions	• Declining groundwater levels • Water quality
B. Resource management	• Past and current management • Sustainability • Whole of government approach
C. Groundwater allocation	• The allocation process • Natural environment as a water user • Water trading
D. Demand management	• Water use efficiency • Water pricing • Water reuse
E. Management options	• Ecological features • Pine plantations • Horticulture • Private unlicensed bores
F. Community involvement	• General public • Key stakeholders

3.1 Existing Conditions

Prior to the interviews, participants were sent a brief background document which described the existing pressures on the groundwater resources and some of the impacts that had already been experienced at several locations (Appendix D). This included the fact that the water table had dropped significantly in some parts of the study area and some groundwater dependent ecosystems (e.g., wetlands, Banksia woodlands, etc) had shown signs of stress.

3.1.1 Declining Groundwater Levels

All of the interviewees agreed that the water levels were indeed declining. Several individuals indicated that the water table was dropping to different extents over the study area. This is consistent with the background information provided to the participants (Appendix B). However, others believed the water levels were dropping in a uniform manner across the study area.

Some interviewees noted that they had witnessed surface water levels dropping and the death of some groundwater dependent vegetation. Some owners of private bores had noted the decline in surface water levels but had not experienced any lowering of water levels in their backyard bores.

All of the interviewees perceived the declining water levels as a problem. Several believed the problem was at a critical point. The impact on horticulture and ecological values in the area were provided as evidence in support of this view; as was the ever increasing demand for water arising from urban growth.

There was consensus that the existing condition of the groundwater resources warranted immediate action on the part of government. However a couple of individuals viewed the water levels as a relatively minor issue. Rather than focusing efforts on the management of the Gnangara groundwater resources, they advocated concentrating efforts on finding additional water sources to meet the needs of the Perth metropolitan region (e.g., water transfer from the Kimberley and/or South West Yarragadee).

Interviewees pointed to a variety of water users as the source of the problem. Water consumers (public and private sector) were identified because they are responsible for the direct abstraction of the water. Government agencies were also blamed for how they managed the resources, allocated the water amongst users and managed land uses.

Almost half of those interviewed identified the pine plantations as a significant contributor to the lower groundwater levels. The horticulturalists in particular viewed the pine plantations as the primary source of drops in water levels. Others viewed horticulturalists and local government as over-consumers of groundwater and hence the source of declining water levels.

More than a third of interviewees attributed declining water levels to two additional factors: climate change and natural climatic fluctuations (cycles). Of these interviewees, several viewed climate change and natural climatic fluctuations as primary causes of declining water levels, but most viewed them as secondary factors.

3.1.2 Water Quality

Water quantity issues dominated those of water quality. Only a few interviewees brought up the issue of water quality. When water quality was raised it was most often with respect to acid sulphate concentrations in the soil, the potential for dryland salinity to affect the region and for fertilizer run off to cause contamination. As discussed in section 3.4.4, a few interviewees mentioned water quality issues in relation to water reuse. When prompted, most interviewees acknowledged the importance of water quality but placed it a distinct second to issues of quantity as a concern.

3.2 Resource Management

3.2.1 Current and Past Management

There was consensus that the Gnangara groundwater resources needed better management. This concern was expressed in a number of ways, predominately:

- little was being done to manage the resources;
- lack of tangible evidence of action being taken to manage the resources; and
- current management is too slow to be effective.

The majority of those interviewed believed that if additional measures had been taken earlier to better manage the consumptive uses, the current level of negative impact on the groundwater resources would not be evident today. Almost everyone wanted to see steps taken to manage the Gnangara groundwater resources in a manner that would result in a sustainable future.

Some interviewees believed that current management efforts were occurring too slowly to be effective. A number of the state agency representatives in particular attributed this to resource managers being overburdened by day to day groundwater-related issues. This left them with too little time to dedicate to longer term strategic planning for the future of the groundwater resources. Hence, management has been reactive instead of proactive, responding to the outcomes rather than the causes of the problems. One interviewee summarised their perception of past and current management efforts by stating: “our collective management has been a dismal failure”.

Criticism of past and current resource management efforts was typically accompanied by an acknowledgement that management of a complex system, such as the Gnangara groundwater resources, is a daunting task. At the same time this was not viewed as a legitimate excuse for perceived inaction. Many of those interviewed expressed frustration with the perceived lack of action by government to rectify the existing situation. When asked what they would like to see happen, several individuals summed up their feelings by simply stating “Do Something!”

State government agencies in both the water resource and land management sectors were identified as contributing to the existing problems with the groundwater resources. A common view was that no single agency had full jurisdiction over management of the system, hence a combination of agencies were at fault. The DoE, as the resource manager, and the Water Corporation, for perceived over abstraction as a major licence holder, were among the most frequently mentioned agencies. The Department of Conservation and Land Management (CALM), the Department of Planning and Infrastructure (DPI) and Forest Products Commission (FPC) were also identified due to the roles played by land management and land use planning. It was also evident that some interviewees did not have a clear understanding of the various roles and responsibilities of these agencies.

3.2.2 Sustainability

The goal of a groundwater management plan would be to ensure a sustainable future for both the groundwater resource and its dependent uses. The concept of sustainability is central to the planning exercise.

The State Sustainability Strategy defines sustainability as "meeting the needs of current and future generations through an integration of environmental protection, social advancement and economic prosperity".

The concept of sustainability was raised either explicitly or implicitly during most interviews. A couple of individuals referred to the State Sustainability Strategy when defining the term. Some interviewees defined 'sustainability' as the consideration of social, economic and environmental issues and concerns so as to achieve a balance between the three in decision-making. Many commented that reaching decisions that reflect a good balance or integration among environmental, social and economic objectives was not easy and may require trade-offs.

Others discussed the concept of sustainability implicitly. They talked about the various characteristics of sustainability, including: incorporating social, economic and environmental factors and goals in decision-making, intergenerational equity (i.e., impact on future generations) and the precautionary principle.

Interviewees discussed not only the value of the resource to current users but the need to maintain its value for future generations. The majority of those interviewed perceived the risks associated with inaction as much greater than those resulting from moving forward in the resource management process despite not having a full understanding of the resource.

3.2.3 Whole of Government Approach

An overwhelming number of interviews felt that a groundwater management plan should be developed through a 'whole of government' process. This approach reflected the perception that no single agency caused the problem and no single agency had full jurisdiction to fix the problem.

It was also seen as appropriate because groundwater management needs to incorporate not only environmental but social and economic considerations. Many noted the relationship between land use and water resource planning. This meant that not just water resource oriented agencies but agencies involved in land use planning needed to be involved. The DPI was identified as a key agency because of the impact land use has on groundwater resources (e.g., rate of recharge, contamination in run-off from urbanised areas). There was also recognition that the availability of groundwater could restrict land use activities in some areas.

There was some recognition that government agencies have begun to work together. Examples include the East Wanneroo Land Use and Water Management Strategy (DPI and local government) and the Waterwise on the Farm program (Department of Agriculture and DoE). These initiatives were seen as steps in the right direction but provisions for a whole of government approach to planning for the Gnangara groundwater resources were still needed.

The majority indicated that successfully achieving a 'whole of government approach' would not necessarily be an easy task. One individual compared the challenge of successfully implementing a 'whole of government' approach to a "unicorn – absolutely beautiful but does not truly exist". Others were more optimistic, noting that not only was such an approach possible but necessary if the groundwater resources are to be managed in a sustainable manner.

A number of potential barriers to successful implementation of a 'whole of government approach' were identified. A perceived lack of political will was identified by some as a barrier to success. Strong political will was viewed as important since a number of tough decisions may need to be made by government. Among the tough decisions most frequently identified was the issue of water allocation, that is, who would receive water and in what quantities. It was speculated by some that political will might be low because tough choices are not always popular choices and thus carried risks for politicians hoping to be re-elected.

A second barrier was the perceived lack of coordination between state government agencies with an interest in the future of the Gnangara groundwater resources. Those holding this view came from both the public and private sectors. Agencies were seen as too often working within their own boxes (i.e., just within their agency) rather than collaborating with other agencies to find solutions to resource management issues.

Some attributed this to state agencies competing for the same financial resources or seeking lead agency status over a natural resource (e.g., groundwater). Others felt that higher levels of government involvement (e.g., Ministerial and/or Cabinet level) were required to encourage agency coordination by supplying agencies with appropriate funding to cover the additional work created by multi-agency planning initiatives. Some contended that state agencies were so financially stretched by day to day operations that there were few funds left for collaborative planning efforts among agencies.

Those individuals who went so far as to describe how a 'whole of government approach' might be set up for a Gnangara groundwater planning initiative typically identified a similar approach. A first step would be ensuring that each of the agencies had a shared understanding of the needs and problems faced by the other agencies. The creation of an institutional arrangement conducive to collaborative multi-agency planning was also important. Additional conditions included the active support of higher levels of government, such as Ministers and/or Cabinet members, to get such an approach moving. Strong leadership was also viewed as important in order to mobilise the agencies involved and hold them accountable. Several interviewees felt that such leadership needed to come from outside government whereas others saw a particular government agency (e.g., the DoE, CALM, or the DPI) spearheading the multi-agency planning initiative.

3.3 Groundwater Allocation

3.3.1 The Allocation Process

Water allocation requires making decisions regarding how much water will be made available for different types of uses (e.g., public water supply, horticulture, other agriculture, industry, recreation, private household bores, etc) and under what conditions. The majority of interviewees recognized that making water allocation decisions was not easy.

During the interviews, individuals were often asked how they would prioritise among users in an allocation process. Most were hesitant to do so. They often indicated that they either did not know enough about the groundwater resources or were unfamiliar with current allocation processes. In particular, they wanted to possess a better understanding of the amount of water entering the groundwater system as well as the amount leaving the system (e.g., due to abstraction). They also wanted to know the amount of water currently abstracted by each type of user (e.g., gardens, horticulture, public water supply, etc). Even if this information was known to them, many felt they would still want to rely on experts to help prioritise user allocations.

Others began prioritising among users but stopped mid-way because they did not want to disadvantage any single user. They often identified that it was hard to find a *balance* between users, one that did not result in sizeable negative impacts for any single user.

One interviewee commented that the primary allocation principle of 'first come, first served' used by the DoE, through the Water and Rivers Commission (WRC), had proven problematic. It resulted in those who made their applications first receiving groundwater allocations while little, if, any water remained for others in the same area if they applied for water later on. This was seen as especially problematic for the study area due to the pressure increasing urbanisation was placing on water demand (development and human consumption) in the northern suburbs and beyond. The interviewee proposed that the WRC consider reducing some of the existing allocations and reallocating the water to others in the same area.

Rather than allocating water on a 'first come, first served' basis some interviewees indicated that the length of tenure in an area or the value of the activity supported by the water should be considered.

A couple of interviewees believed that over allocation had already occurred in some areas. It was suggested that a solution would be to reduce the existing water allocations equally across all users. They stated that "if everyone has to take their medicine, they should all take equal amounts". Another interviewee contended that it was politically untenable to consider taking water back from existing licensees.

One interviewee identified that before allocation could occur a cap based on sustainable yield would need to be set and adjusted annually based on yearly rainfall. The price would need to be adjusted based on the annually defined yield, e.g., cost more when less water is available. Adjustments would also need to be made to allocations, i.e., less water would mean proportionate redistribution of the available water. This approach was complimented by the idea that no future water users should be able to apply for a license, unless the license is for trading water between current users.

A number of other issues related to allocation, including water trading, water re-use and quantities of water being consumed, are discussed in other sections of this report.

3.3.2 Natural environment as a water user

In discussions of how water might be allocated among uses, the majority of those interviewed viewed the natural environment as a water user. However, some individuals viewed the natural environment (i.e., ecological values) as different from other types of water users. Rather than being another water user, one person viewed the natural environment as the source from which other users drew their water.

It was clear that the vast majority of interviewees valued the role of the natural environment in relation to the Gnangara groundwater system. The lakes, wetlands, and the Yanchep National Park cave system were the most commonly cited groundwater dependent environmental features. With respect to the value of the natural environment, some individuals emphasised its intrinsic value but more commonly the ecological functions (e.g. water purification) and/or anthropogenic (human) uses were raised during the interviews.

The declining water level in lakes and wetlands was often flagged in terms of the negative effects on aesthetic values (i.e., negative visual impact) and recreational use. For example, a few individuals recalled a time when Lake Gnangara was an enjoyable place to visit on a weekend or afternoon to engage in water skiing or other water-based recreational activities. They described the current condition of the lake as "little more than a salt flat". This change was attributed to a decline in groundwater levels. Existing recreational uses such as racing four wheel drives and motorbikes on the dry lake bed were seen as contributing to the spread of dieback, degrading fringing vegetation and making the area more prone to fires.

Several individuals commented on tree deaths within *Banskia* woodlands, specifically in areas surrounding bores owned by the Water Corporation. These impacts were attributed to over abstraction for public water supply.

In discussions about the future of the pine plantations, some interviewees discussed the potential impact of thinning or clearing the pines on the breeding habitat of Carnaby's Black-Cockatoo (see 3.5.2). While the cockatoos were viewed as part of the 'natural' environment, the pine plantations were typically seen as part of the man-made environment.

Discussions of allocating water among the various water users revealed a tension between a desire for conservation of the natural environment (e.g., retention of ecological values) and meeting the needs of other water users (e.g., horticulture, public water supply). The majority of interviewees stated that in some situations other water users may take priority over the environment as a water user. This would apply in cases where meeting the groundwater needs of the natural environment would result in detrimental effects on human uses (e.g., horticulture).

The background information provided prior to the interviews (Appendix D) noted that water levels in a number of the wetlands, lakes and caves were being artificially maintained by agencies such as the DoE, CALM and the Water Corporation pumping water into them. Several interviewees had previously been unaware that water was being pumped into particular areas and that this had been occurring for a number of years. This practice was often viewed as unsustainable in the long term, but acceptable by most in the short term, at least until a better scientific understanding of the system was attained.

Of those who were prompted to choose an outcome, at least half indicated that if ecological features could not be maintained 'naturally' in the longer term, then they should no longer be augmented.

Some interviewees questioned whether the benefits of augmentation were sufficiently large enough to warrant the negative socio-economic impacts. They noted that water assigned to augmentation would not be available for other uses.

A few interviewees made specific reference to the cave systems. They placed a different or higher value on the caves than on the wetlands and lakes. They saw the caves as a unique ecosystem and in need of indefinite supplementation. Maintaining the cave ecosystem via water augmentation was compared to a zoo by one interviewee where the augmentation of the cave system was warranted for the preservation of threatened and endangered species and for general public education.

3.3.3 Water trading

The interviews revealed that only a small proportion of interviewees were either aware of water trading as a concept or saw its potential relevance in managing the Gnangara groundwater resources. Further, many of those who had heard of water trading had limited knowledge of the existing WRC policies related to water trading (i.e., *Transferable Water Entitlements for Western Australia - Statewide Policy No.6*) or unused licensed water entitlements (i.e., *Management of Unused Licensed Water Entitlements - Statewide Policy No.11*) .

Although interviewees were not asked a specific question regarding water trading, several individuals raised the issue during their interviews. Each supported water trading programmes in which those licensed users not fully using their allocation could sell their excess water to the highest bidder.

Those supporting water trading believed that by giving groundwater a market value it would be more respected as a resource by users. This was contrasted with current water use practices that were viewed as less than optimal and not consistent with good resource management.

For a couple of interviewees the concept of water trading was connected to the notion of water ownership, in that water was traded from one owner to the next. From this perspective, water was treated not only as a commodity to be bought and sold but as a property right. This view conflicts with current water policy which treats water as a common property resource and thus a licensed allocation is not attached to an individual property right.

One interviewee expressed concern that water trading in fully allocated areas could result in windfall profits for those individuals who had been fortunate enough to get their licence applications in early with the WRC (i.e., the first come first served principle). The interviewee was concerned that those holding water licences would become wealthy through the sale of their much sought after water allocations. This was viewed as inequitable. It was recommended that for water trading to be equitable in such situations, pre-existing water allocations would need to be reviewed and water redistributed amongst users within the area before trading could continue.

3.4 Demand management

The majority of those interviewed saw reducing the demand for water as a key component of the groundwater resource management equation. The most commonly raised forms of demand management were water use efficiency, water pricing and water reuse.

3.4.1 Water use efficiency

The majority of the interviewees advocated working towards greater water use efficiency through water wise programs. Each category of water user was seen as being able to incorporate additional water wise techniques. For example, the manner in which local governments watered their public open spaces and sports grounds was often cited. It was suggested that they modify the quantity and time of day they water. Another example applicable for builders was using water sensitive design in new developments and offering native vegetation landscaping packages.

Horticulturalists were viewed as another sector that could improve its water use efficiency. Many believed that substantial water savings could be made if water use practices were changed within the industry. One horticulturalist noted the substantial water savings he had achieved as a result of water use efficiency research. Not all horticulturalists agreed that substantial savings were possible, believing instead that many operations, especially the larger ones, had already adopted water use efficient practices and technologies.

However, the horticulturalists were happy to review their practices if supported by government in terms of research and financing. Education was identified by horticulturalists and others as central to better water use efficiency. Several horticulturalists identified the Water Wise on the Farm programme (co-sponsored by the Department of Agriculture and the DoE) as a recent water use efficiency initiative. There was a perceived need for even greater government support and longer term security (see section 3.5.3) for horticulturalists in their efforts to become more water efficient.

3.4.2 Future Residential Development

Urbanisation continues to extend northward in the study area. A number of interviewees, including some land developers, identified the need for water sensitive urban design (WSUD) as a water saving mechanism in future subdivisions. This included the use of native vegetation for landscaping, household water saving measures (e.g., rainwater tanks), use of recycled water in water features (e.g., ponds), and stormwater drainage systems. Some interviewees viewed best management practices (BMPs) for channelling stormwater as a way to protect ground and surface water from surface runoff , which could potentially contain pollutants(e.g., oil from paved surfaces). Recycling of stormwater was raised as a potential management option.

Several of those interviewed from the land development sector emphasised the need for water resource planning to acknowledge the current shifts in development trends. New residential developments are replacing the traditional quarter-acre block with smaller residential lots including less private garden space but larger public open spaces.

3.4.3 Water pricing

The cost of water was raised by several interviewees. Several individuals commented that the problem was not the availability of water because sources such as the desalination of seawater meant a limitless resource. Rather, the problem was the cost of making the water available for consumers.

Others viewed water pricing as a potential means of curbing water demand. Several interviewees advocated setting a quantity of water to meet a household's basic domestic needs and charging this at a certain rate. Any volume of water used above this basic amount should be priced at a significantly higher rate. This was viewed as an equitable approach as low income households would be able to affordably meet their basic domestic uses.

Others advocated a system in which the rate paid for water reflected the value society placed on the use of that water. Uses that were highly valued would be less expensive than those considered less valuable to society.

Several individuals argued that water is at present severely under priced. An industrial consumer of water drew a parallel between the price charged for water and the price charged for phone usage. The interviewee noted that the monthly phone bill was often many times more expensive than the monthly water bill. It was stated that since both services are essential by today's standards, their prices should be more comparable.

3.4.4 Water reuse

Close to half of the interviewees identified a need to recycle waste water. Waste water was seen as a valuable but untapped resource. Some were perplexed as to why such a valuable resource has remained unutilised.

The majority of those who identified waste water reuse as an option did not explore the types of water (e.g., industrial, agricultural, household, stormwater) to be recycled. Similarly potential barriers to waste water reuse were raised by only one interviewee who questioned the potential health implications of using recycled waste water on irrigated crops. In terms of potential reuse applications, several were proposed: outdoor household use (e.g. gardens and lawns), industrial reuse, and groundwater recharge (pumping recycled water back into the aquifer).

An interviewee from the industry sector believed that many industrial users of water were interested in having access to the wastewater. In industrial clusters, not all water users may want to recycle. The industries interested in recycling would like to have access to this stream of waste water. The water would be reused within their industrial production processes.

Through the media, a few individuals had heard of managed aquifer recharge via the use of waste water. Treated waste water would be re-injected into the groundwater system as a means of increasing the rate of recharge. Those who discussed the aquifer recharge process viewed it positively.

The EPA (2005) recently released a discussion paper on this topic titled *Managed Aquifer Recharge Using Treated Wastewater on the Swan Coastal Plain*. It explores potential applications of managed aquifer recharge using recycled waste water, including: preventing salt water intrusion; irrigation in horticultural areas; restoring groundwater levels; integrated water management in new residential areas; and to increase drinking water supplies.

3.5 Management Options

During the interviews, a number of potential management measures were put forward as components of a groundwater management plan.

3.5.1 Environmental features

A number of ecosystems (e.g., caves, wetlands and lakes) in the study area are dependent on groundwater for their survival. As discussed earlier (see 3.3.2), many did not advocate a long term continuation of the current practice of supplementing groundwater dependent ecosystems negatively impacted by over abstraction.

Two alternative approaches were suggested. The first was to reduce groundwater abstraction (either public or private supply) in the areas immediately surrounding the groundwater dependent ecosystems. This was viewed as providing the opportunity for natural water levels to return in these areas.

The second approach was to allow the wetlands and lakes to dry out with the hope that rainfall would increase over the long-term. Some interviewees questioned whether continuation of the current augmentation practices was sustainable in the context of a drying climate.

Several interviewees indicated that if groundwater dependent ecosystems were to have a future then land use practices in their vicinity needed to be compatible and not impose additional stresses on these features.

3.5.2 Pine plantations

Almost half of the interviewees viewed the pine plantations as a significant user of water but a low priority water user. Thinning or clearing the pine plantations was proposed to provide additional groundwater recharge and thereby increase groundwater levels. Many felt that significant gains in recharge could be attained in this manner. However a few interviewees believed the groundwater gains might not be as great as some hope it to be.

Some interviewees noted that the magnitude of potential gains in recharge would be influenced by the choice of land use that replaced the pine plantations. Several future land uses were proposed for the area currently covered by pine plantations. These included: a continuation of pine plantations, revegetation using native plants, clearing the pines to use the land for recreation, urbanisation, or some combination of these. Development of a dedicated horticultural precinct in an area currently occupied by pines was an option particularly popular with those from the Wanneroo area. It was seen as a means of providing a secure future for horticulture in the region.

Only a few individuals commented on whether or not the endangered Carnaby's Black-Cockatoo, who feed on the pine plantations, would be negatively impacted by thinning or clearing activities. Those who believed the cockatoos may be negatively impacted noted that it was not just the loss of habitat due to clearing the pine plantations that was a concern. It was the cumulative impact of plantation clearing plus the additional loss of habitat due to the increasing urbanisation on the Swan Coastal Plain.

3.5.3 Horticulturalists

As a group, the horticulturalists interviewed were concerned about the future of their industry. Both issues of land security (i.e., effects of urban sprawl) and groundwater availability were threatening the longer term viability of the horticulture industry in the Wanneroo area.

In addition to water, horticulturalists needed additional land for expansion and crop rotation. It was pointed out that both land and water security issues must to be resolved for the horticulture industry, as well as the viticulture industry, to be sustainable in the study area.

As a solution to these concerns some pointed to a land use proposal to establish a new horticulture precinct where one of the pine plantations currently exists (see 3.5.2). The potential use of recycled water from nearby urban development to supply the proposed precinct with water was raised by several interviewees.

While some horticulturalists were somewhat optimistic regarding the future of horticulture in the region, others had a bleak outlook fearing that no matter the steps taken to increase groundwater recharge, the industry eventually would be squeezed out due to encroaching urbanization.

During the interviews, horticulturalists were often asked to consider a hypothetical scenario in which horticulture was considered no longer compatible with other land and water uses in the area. Under such a scenario, the horticulturalists indicated that some individuals would simply leave the industry at that point while others would look to relocate their operations. Gingin was the area seen as the most likely for relocation. However, a couple of individuals familiar with the Gingin area believed it had neither the land nor the water resources available to support additional horticulture.

One person explained that if society determined that horticulture was incompatible with environmental objectives for the area, then horticulturalists should not be the only ones to pay for maintaining a common good (i.e., the natural environment). In these circumstances, regardless of whether horticulturalists left the industry or relocated, compensation by government was viewed as warranted by a number of interviewees.

Among the non-horticulturalists, many advocated maintaining the horticulture industry in the Wanneroo area. Some saw value in preserving 'small business' interests. Horticultural operations were seen by many outside the industry as small businesses although as several horticulturalists noted many are multi-million dollar operations. Others pointed to the Wanneroo horticulture industry's contribution to Perth's food supply, referring to it as the 'salad bowl' of the State. In addition, locally produced food was viewed by some as more desirable than reliance on imported food.

As noted in Section 3.4.1, some of those interviewed believed the existing horticultural operations could be made more water efficient.

3.5.4 Private unlicensed bores

More than half of those interviewed raised the issue of private unlicensed bores (e.g., backyard bores used for watering lawns, small vegetable patches and flower gardens). A number of individuals commented that the current rules for unlicensed private bore owners did little to encourage water efficiency and were inequitable when compared with the rules that applied to consumers on the Integrated Water Supply System (public water supply). Several suggested that unlicensed private bore users should pay for their water.

Restricting the frequency and time of day bores could be used was raised by some as a way of making the system more equitable and water efficient. Currently those on public water supply can use their sprinklers only on their two allocated watering days, either once in the morning before 9am or in the evening after 6pm. However, bore owners can water lawns and gardens any day but only after 6pm and before 9am. Examples of private bore owners watering in the middle of the day were commonly cited as an example of inequity. Many of these interviewees appeared to be unaware that bore owners are restricted concerning the time of day watering is permitted.

Of those who raised the issue of private unlicensed bores, the majority identified a need for bores to be metered. This was often identified as a priority item in the resource management planning process. Metering was viewed as laying a foundation for allocation planning because it would contribute to a more accurate picture of resource use.

Several interviewees identified a conflict between the incentives being provided for sinking bores and the decreasing water levels found in the study area.

Others, including some individuals without private bores, were hesitant to recommend metering. They viewed the cost of meters as too high when compared with the gains in groundwater recharge from limiting unlicensed bore use.

3.5.5 Water Corporation

A number of individuals gave examples of over abstraction by the Water Corporation that had resulted in incidents of *Banksia* dying in proximity to some public water supply bores. It was advocated that the Water Corporation take greater care and make any needed adjustments to its operating practices to avoid any reoccurrences. Some noted that the Water Corporation had already made some modification to its pumping regimes in response to the 1991 incidence of drawdown effects on groundwater dependent vegetation.

Other than encouraging greater water use efficiency on the part of the Water Corporation's consumers, little specific comment was made regarding the volume of water allocated to public water supply. Although a few individuals advocated greater government investment in finding alternative sources of water for public supply, this was typically not raised in the context of reducing the volume of water the Water Corporation is allocated from the Gnangara groundwater resources. However, one interviewee did identify the need to develop new sources to stop the Water Corporation from 'falling back' on the Gnangara groundwater resources during this increasingly dry period.

3.6 Community Involvement

The vast majority of interviewees supported the involvement of key stakeholders and the wider community in the groundwater planning process for Gnangara. However, many distinguished between involvement by the key stakeholders (both government and non-government) on the one hand and the general public on the other hand.

3.6.1 General public

Those who commented on the role of the general public in subsequent stages of the planning process typically envisioned a less active role for the wider community than key stakeholders. This view reflected a variety of perceptions about the general public including: they are not interested in the issues, 'they do not want to get involved in the issues', they have less to offer the planning process because they are not 'large' water users, and 'they do not understand or recognise the problem'. The role of the general public was viewed as that of a receiver of information with the hope that they would apply the information and appropriately modify their attitudes and/or behaviours.

Several interviewees noted a need to ensure individuals were water wise in their daily activities (e.g., use water wise shower heads, observe watering restrictions). Some acknowledged ongoing community education efforts (e.g., water wise commercials run by the Water Corporation) but saw room for expansion of such programs.

Several individuals identified additional water wise measures, including a move away from English style gardens towards gardens using native vegetation. This would require that suitable information about native gardens was available as well as local nurseries having stocks of native vegetation available for consumers to purchase.

The majority of interviewees advocated providing information to raise awareness of the challenges facing the Gnangara groundwater resources (e.g., its status, its causes and what this means for the general public). It was felt that the general public was not aware of the problems facing resource managers, nor had they been given reasons why they should be concerned.

It was important that whatever information was disseminated in the community be truthful and unbiased. Some felt that government had not done a good job in this respect. Past efforts received criticism for not accurately depicting situations or not providing enough information to allow the public to make informed choices. Some accused the government of providing the community with only the information they wanted the public to have rather than the whole 'truth'. One interviewee contended that only minimal information had been released about the quantities of groundwater used and how water abstraction was impacting the environment (e.g., ecosystem functioning and biodiversity loss).

3.6.2 Key stakeholders

The majority of stakeholders interviewed wanted to be engaged in the planning process. This meant not simply receiving information from agencies informing them what the agencies planned to do. They sought higher levels of involvement that extended beyond information and education.

Very few interviewees favoured the creation of additional committees as a means to engage stakeholders. Committees were described as diversions or roadblocks rather than as forums for meaningful contributions. Many spoke of their past experiences with committees and how they were often ineffective and frustrating. Criticisms of how committees functioned included: lack of power, lack of government support, lack of strong leadership and lack of a clear agenda. One person commented that "committees typically work well for the first four to five meetings but after that they became a time for gossiping."

Some favoured holding community meetings in local areas with clear agendas instead of establishing a committee. These meetings were seen as a means of ensuring that all voices were heard and discussed in the community. This was viewed as a more transparent approach and one that accommodated many more voices than the limited number allowed in a committee. They were also seen to provide a wide audience for mass dissemination of information.

When encouraged to identify additional means of engaging stakeholders or the general public in the planning process, few additional ideas emerged. This may reflect a lack of awareness about the number and variety of techniques that could be used to meet their community involvement objectives.

4.0 Conclusions

A number of key messages emerged from the interviews. There was consensus among those interviewed that the Gnangara groundwater resources are under pressure and need to be effectively managed.

The number of competing uses, the high demand for water and the absence of a full understanding of current use were seen as adding to the complexity of sustainable resource management. These factors made both protection of the resource and the allocation of water a challenge for resource managers. Yet, the majority of interviewees were adamant that these factors could not be used as an excuse for inaction.

The DoE's intention to develop a groundwater management plan for the resource was viewed favourably. But the majority of those interviewed believed that such a plan would need to involve multiple government agencies.

A common view was that multiple government agencies had contributed to creating the current problem and as such the solutions would need to draw on the skills and powers of many of the agencies involved in land use planning and water resource management. A whole of government approach was viewed as desirable but many interviewees were aware that interagency coordination and political will were key determinants of success or failure.

Concern was expressed that not enough is known about how much groundwater is actually being abstracted by licensed and unlicensed private bores. The new metering program was viewed as a positive step although some complained that the process for installing meters had already taken too long.

There was agreement that groundwater levels were dropping but not all understood that this was happening to varying degrees across the resources. The drop in water levels was largely attributed to over abstraction for public and private supply. The declining annual rainfall levels were viewed by most as only a secondary factor affecting groundwater levels. The pine plantations were viewed by many as a major water user but they were not viewed as a component of the natural environment.

Allocating groundwater among the competing users was viewed as an important but difficult task. Done poorly, it could result in inequitable and negative outcomes for groundwater users. A tension was seen to exist between the desire to conserve ecological values and also meet the needs of other water users (e.g., horticulture and public water supply). Under certain conditions, many stakeholders were willing to have other water users take priority over the environment with respect to water allocation.

Several individuals advocated water trading whereby licensed users could sell their excess water to the highest bidder. Many of those who had heard of water trading had limited knowledge of the existing DoE policies related to water trading or cases of water trading that have occurred in WA. The view of some that a water entitlement is similar to a property right is inconsistent with state policy which treats water as a common good. Overall, only a small proportion of interviewees raised water trading as an option. This may in part reflect a lack of awareness of water trading as a concept that is already in use in WA albeit on a small scale.

Thinning or clearing the pine plantations was frequently suggested in the hope that significant gains in recharge could be attained in this manner. However, a few interviewees believed the groundwater gains might not be as great as others were anticipating.

Improved demand management was seen as a means of reducing the pressure on the groundwater resources. More efficient water use, effective water pricing and greater wastewater reuse were the most commonly identified demand management measures. The ideas put forward by interviewees were very similar to those raised by the public during the drafting of the State Water Conservation Strategy.

Many of those outside the horticulture industry believed that significant gains in water use efficiency could be achieved by the industry. Unlicensed private bores were also viewed by some as an inefficient water use. Some perceived current rules for unlicensed private bores as not only inefficient but inequitable when compared with the rules for consumers on the public water supply system.

Wastewater was seen as a valuable but unutilised resource. The potential to recharge aquifers using wastewater was raised by only a small number of interviewees. However, those who advocated its use did not identify any barriers to successful implementation.

Many from within and outside the industry would like to see horticulture have a sustainable future in the Wanneroo area. However, issues of land security and groundwater availability appear to be threatening its long term viability in the Wanneroo area. Some pointed to a land use proposal to establish a new horticulture precinct where one of the pine plantations currently exists as a solution.

While some horticulturalists were somewhat optimistic about the future of horticulture in the area, others had a bleak outlook fearing the industry would eventually be squeezed out. If that occurred some horticulturalists would leave the industry while others might relocate to an area such as Gingin, provided suitable land and water is available which may not be the case. If horticulturalists were forced by government decisions to either retire or relocate, a number of the interviewees expected that the horticulturalists would receive fair compensation in return.

There was broad support for the involvement of key stakeholders and the wider community in planning the future for the Gnangara groundwater resources. The wider community was generally viewed as taking a less active role than that played by key stakeholders in the planning process. The primary role of the community was seen to be that of information receiver with education the community involvement objective. It was important that any information provided to the community be complete, truthful and unbiased. There was a common perception that the community was not aware of the problems facing the groundwater resources, nor had they been given reasons to be concerned about how it will be managed in the future.

The key stakeholders sought higher levels of involvement that extended beyond information and education. Few favoured the creation of more committees which were characterised as diversionary, ineffective and frustrating for participants. Rather, processes that allowed more voices to be heard in a transparent fashion were advocated (e.g., public meetings). It appeared that beyond committees and public meetings, many stakeholders were unaware of the variety of techniques that could be used to meet their public involvement objectives.

Appendices

Appendix A: List of Interviewees

Interviewee	Affiliation
Mike Allen	Department of Planning and Infrastructure
Russell Anderson	Horticulturalist
Trina Anderson	City of Swan
Lex Bastian	WA Speleological Group
Sue Bathols	Lake Gnangara Conservation and Community Group
Frank Battini	Consultant
Eugene Bouwhuis	Department of Industry and Resources
David Bright	Wildflower Society, Northern Suburbs Group
Alan Brown	Department of Defence
Gavin Butcher	Forest Products Commission
Leon Cazirri	Horticulturalist
Jane Chambers	Murdoch University
David Charles	TiWest Joint Venture
Daniel Chatley	Landcorp
Vivian Chung	University of Western Australia
Allan Crawford	City of Swan
Frank Cvitan	City of Wanneroo
David Davies	City of Joondalup Residents Forum
Owen Donovan	Department of Conservation and Land Management
James Duggie	WWF
Simon Fraser	Shire of Gingin
Mike Freeman	Department of Industry and Resources
Ray Froend	Edith Cowan University
Alex Gardner	University of Western Australia
Peter Gell	Department of Defence
Ross George	Department of Agriculture
Graham Gibbs	ET and GE Gibbs Coogee Springs
Dianne Guise	MLA, Wanneroo Electorate
John Hackett	Landcorp
Rosanna Hindmarsh	Ellen-Brockman Catchment Group
Sue Hurt	Swan Groundwater Advisory Council
Ivan Ivankovic	Strawberry Growers Association/Horticulturalist
Philip Jennings	Wetlands Conservation Society, WA
Jon Kaub	Conservation Council WA
Kerry Langlands	Strawberry Fields
Gary Lawther	LWP Property Group
David Lewis	Landcorp
Michael Martin	Water Corporation
Leonnie McMahon	Birds Australia Ltd
Andy McMillan	WA Farmers Federation
Joe Miotti	Water Corporation
Andrew Moore	Department of Planning and Infrastructure
Danny Murphy	LWP Property Group
Lyndon Mutter	Department of Conservation and Land Management
Brock Nanovich	Horticulturalist
Mick Nanovich	Horticulturalist
Jason Neave	Horticulturalist
John Neave	Horticulturalist

Interviewee	Affiliation
Andrew O'Farrell	City of Joondalup
Dale Park	WA Farmers Federation
Russel Perry	Capricorn Village Joint Venture
Dale Putland	City of Swan
Nicole Roach	Yellongona Catchment Group Coordinator
Peter Ruscoe	Turf Grass Association of WA
Clayton Sanders	Department of Conservation and Land Management
Jackie Sinclair	Naturalists Club – Northern Districts[1]
Jim Sweetman	City of Swan
Linda Taman	Swan Catchment Centre/North East Catchment Committee
Phil Thompson	City of Wanneroo
Lloyd Townley	Consultant
Nick Trandos	Horticulturalist
Jim Turley	Vegetable Growers Association
Giz Watson	MLC, North Metropolitan Electorate
Ray Wills	WA Chamber of Commerce and Industry
Nevin Wittber	Forest Products Commission
Paul Woodcock	Botanic Golf Gardens
Eric Wright	Department of Agriculture
Renata Zelinova	Quinns Rocks Environment Group

[1] Interview included: Jeph Sinclair, Willard Libby, Alan Notley, Johanna Notley, Mary Hackett, Heather Ramdohr, Harold Bennetts, Robert Willis, and Marlene Madden from the Naturalist Club – Northern Districts.

Appendix B: Interview Guide

Themes (and Possible Questions):

Theme A: The planning challenge and key issues/concerns surrounding the future of the Gnangara groundwater resources

- What is your understanding of the condition of the groundwater resources? Do you think there is a problem?

- What has created the problem?

- From your group's/organization's perspective, what are the key issues or concerns?

- Are there additional issues and concerns held by other stakeholders or sections of the community?

Theme B: Allocation of Gnangara groundwater resources

- A key part of managing a water resource is determining which users will be given access to the resource and how much water they will be allowed to use. This includes both human uses such as public water supply, irrigation, and recreation, as well as environmental uses such as lakes and wetlands.

  Would you like to see any changes in how the groundwater is allocated to various human and environmental uses? [Note: May need to explain concept of allocation depending upon the stakeholder]

- Do you think priority should be given to some users or uses over others? Explore (include human versus ecological uses).

- How would you like to see the water resources allocated? What process do you think should be used to allocate the water resources?

Theme C: Actions needed to ensure a sustainable future for the Gnangara groundwater resources.

- A goal of the planning process is to ensure that the Gnangara groundwater resources are managed in such a way that they will be both ecologically and socio-economically sustainable. "Sustainability" has become a planning buzzword. What does this term mean to you in the context of Gnangara?

- Are there any decisions or actions that could be taken to help make the Gnangara groundwater resources more sustainable? [If the person focuses only on alternative sources such as desalination or Kimberley water then follow up and ask about measures that could be applied specifically to the Gnangara area.]

- Have you heard of any other possible actions to manage the groundwater? If yes, what do you think of those ideas?

- What advice would you offer the Department of the Environment as it develops a management plan for Gnangara's groundwater?

- At the end of the day, what recommendations do you think will be in the DoE's management plan for Gnangara?

Theme D: Public involvement in the planning process for Gnangara

[Possible preamble: Public involvement is one of those terms that can mean a lot of different things. Involvement can take many forms ranging from simply receiving a newsletter in the mail or accessing a website through to hands on involvement by participating in a series of workshops. Not all groups want to participate in the same manner or on similar issues.**]**

- From your group's perspective, what type(s) of involvement would your group like to have in this planning process?

- What sort of involvement would you/or your group be willing to undertake as part of the planning process?

- Are there some key questions that you would like to see answered during the planning process?

- Have you or your group worked with the Department of the Environment or the Water and Rivers Commission on water resource issues in the past? Was this a positive or negative experience? [If no experience with DoE or WRC then ask about land use or other planning initiatives especially in that geographic area]

- What advice do you have for the Department of the Environment as far as public involvement on this (or any) project is concerned?

Appendix C: Introduction Letter

Dear XXXX

Thank you for agreeing to meet to discuss the future of the Gnangara groundwater resource. As we discussed, the Department of Environment has commenced preparation of a Water Resource Management Plan for this valuable natural resource.

At this early stage in the planning process we are meeting with a range of key stakeholders, such as you, to gain a better understanding of the views held in the community. This will help the DoE in its efforts to plan a future for this groundwater resource that is ecologically, socially and economically sustainable.

As agreed, I will be meeting with you on XX (date) at XX (time), at XX (location).

During the interview, the following topics will be explored:

- The current condition and uses of the groundwater resource;

- Possible changes to the current use(s) of the groundwater resources;

- Ways of managing the groundwater resource to ensure a sustainable future; and

- Roles for stakeholders, including yourself and others who may share your interests, in the development of the Gnangara Groundwater Management Plan.

Once the interviews are complete, you and the other interview participants will receive a draft summary report of the interview findings for your review. A final report will be made publicly available.

Please note that the summary report will not permit association of any individual's identity with specific responses or findings. With your permission, your name and affiliation will appear in a participants list as an appendix.

The attached materials provide some general background information on the Gnangara groundwater resource and the challenges we face in managing it now and in the future.

If you have any questions or concerns please do not hesitate to contact me on XXXX or a/h on XXXX.

I look forward to meeting you.

Yours sincerely,

Appendix D: Background Information

A Sustainable Future for the Gnangara Groundwater System

Introduction
Our State's environment, economic livelihood and the community's lifestyle, health, food production and industry depend on the availability of affordable good quality fresh water. The most valuable and largest source of such water in the Perth region is the Gnangara groundwater resource. With its large volume of easily accessible fresh groundwater, this resource has for many years supported a variety of ecological, social and economic uses.

The groundwater resource extends for approximately 2,200 km^2 over the Swan Coastal Plain between Perth and Gingin. Land use in the northern portion of the Gnangara groundwater resources are dominated by pine plantations, National Park, Crown land, nature reserves, and dryland pasture. The southern portion of the Mound is largely urbanized with irrigated horticulture prominent in the Wanneroo and West Swan districts.

The groundwater resource consists of a system of three layered aquifers (i.e., the Superficial, Leederville and Yarragadee aquifers). Most lakes and wetlands in the region are surface expressions of the aquifer closest to the surface (i.e., the Superficial aquifer). Many of the significant environmental features are dependent on accessing the shallow groundwater of the Superficial Aquifer for their survival.

This includes around 200 groundwater-fed wetlands and other groundwater-dependent ecosystems including Banksia woodlands and the cave pool fauna of Yanchep National Park. These ecological features in turn support a number of social (e.g., Aboriginal cultural sites, aesthetic features; recreation), and economic (e.g., bee keeping; tourism) values.

As Perth's population has grown, so too has the demand for water and with it the importance of the Gnangara groundwater resource for public water supply. In the early 1990s, approximately 40 per cent of Perth's public supply was met by Gnangara groundwater. Today, this has increased to over 60 per cent as surface water supplies in the Darling Range have decreased due to reduced annual rainfall and run off.

Private groundwater users also rely on the Gnangara groundwater system for agricultural, recreational and domestic uses. Horticulturists and private garden bore owners are the largest private users of groundwater from this region. Irrigation of ovals, parks and golf courses is secondary to these users. Other private bores are used for household, stock, industry and services.

Most private abstractions continue to come from the Superficial aquifer. In recent years, abstractions for public water supply have progressively shifted from the superficial aquifer to the deeper confined Leederville and Yarragadee aquifers. In part this is an effort to reduce impacts on the natural environment.

Increased demand, less water
In recent years less water has been entering the groundwater system than was predicted when resource management decisions were made several decades ago. This is due to declining annual rainfall in the Perth region for the past 30 years. If or when past higher

rainfall levels will return is unknown. During this time period the demand for water has continued to grow.

The combination of low rainfall and increasing demand has resulted in a situation that is no longer ecologically or socio-economically sustainable. Simply put, more groundwater is leaving the Gnangara system to meet our demands than is being replaced by rainfall.

As a result, the water level has dropped significantly in some areas. In those locations, ecosystems dependent on the shallow groundwater have shown signs of significant stress (e.g. dying native vegetation and wetlands and caves drying up for longer periods). Under the powers of the *Environmental Protection Act 1986,* specific groundwater requirements were set in the 1980s to protect highly valued groundwater dependent ecosystems (e.g., wetlands, caves). These management objectives are currently not being met in a number of locations due to the lowering of the water table.

The current situation threatens not only the ecological but also the many social and economic uses supported by the Gnangara groundwater resource. The immediate task is deciding how to return the Gnangara groundwater system to a condition of sustainability. This would allow the many environmental, social, economic and cultural values of the groundwater resource to be maintained for present and future generations.

While it might be tempting to gamble that former higher rainfall will eventually return, based on current climate change science, this may not occur. In planning the future of the Mound, resource managers must include scenarios in which rainfall levels in the near future (the next 10-20 years) or longer term do not increase significantly, if at all. Failure to consider such scenarios in planning the future of our water resources could prove costly and disruptive.

While more action is needed, the State Government has already taken a number of steps to address problems created by declining water tables in some areas. When groundwater monitoring revealed declining water levels, the Water Corporation in consultation with the Department of Environment shut down or significantly reduced abstraction from 40 bores in sensitive environmental areas.

The Department of Environment and the Water Corporation also commenced artificially maintaining water levels in some lakes, wetlands and caves to maintain their ecological values. CALM has also been pumping groundwater into a number of caves in Yanchep National Park in an attempt to protect threatened aquatic fauna living in cave pools.

While somewhat successful in maintaining water levels and environmental values, these actions have carried a financial cost in the millions of dollars and have increased the need to develop public water supply sources in other areas. Maintaining these levels is not a long-term solution if the water table continues to drop.

In an effort to reduce water demand, the Department of Environment and the Department of Agriculture are co-sponsoring the *Water Wise on the Farm* program to promote greater horticultural water use efficiency in the Wanneroo area. In addition, water restrictions limiting household sprinkler use to two days per week have been in effect across Perth's public water supply system since the summer of 2000-01.

Planning for the Future

Future resource management decisions need to draw upon good science but we do not yet have a full understanding of how the Gnangara groundwater system functions and its relationship to groundwater-dependent ecosystems. Currently a research program involving multiple State Government agencies and the CSIRO is exploring how the Superficial aquifer and deeper confined aquifers (i.e., Leederville and Yarragadee aquifers) work as a system. Scientific investigations, including computer modelling, are assessing the impact of abstracting groundwater from the deeper aquifers on near-surface shallow water levels.

Despite these efforts, more needs to be done if the groundwater resource is to be managed in a sustainable fashion. Planning a sustainable future for the Gnangara groundwater is not an easy task. There are no quick fixes readily at hand. The community is likely to balk at any efforts to further reduce demand through more stringent water restrictions on sprinkler use. The development of alternative water supply sources (e.g., seawater desalination, groundwater from the Southwest Yarragadee, water from the Fitzroy River) has recently garnered considerable media attention as a possible solution. However, even if alternative sources were implemented in the near future, the Gnangara groundwater system would remain a highly valued resource for public water supply and local private use. Gnangara groundwater will remain a far more affordable source of high quality fresh water as demand for public water supply continues to increase due to population growth.

Achieving the best balance among the community's social, economic and environmental aspirations for the Gnangara groundwater resource will likely require some difficult choices on the part of resource managers, the Government and the community. Allocating water to maintain or expand one type of use would likely mean less water would be available for other uses. We need to make wise choices that are fair to those affected and which minimise negative impacts and maximise benefits.

The following questions illustrate the complexity and magnitude of the planning challenge we face:

- Should groundwater be reassigned from public water supply in order to support environmental features?
- How can water security be achieved for the local horticultural industry?
- Should private garden bores be licensed to encourage water efficiency?
- Should the pine plantations be selectively cleared so as to reduce their water uptake near wetlands and caves?
- Should native vegetation be managed by more frequent controlled burning to enhance groundwater recharge?
- What role could wastewater reuse play in stabilising water levels?
- How should the prospect of climate change be factored into our water resource planning?

These are just a few of the questions that need to be answered.

The Department of Environment is responsible for managing and allocating groundwater for public and private use. The Department is currently developing the first comprehensive management plan for the Gnangara groundwater resource. The plan will establish how much water can be abstracted from the various aquifers while still achieving ecological sustainability. It will describe how water will be allocated to users and the measures needed to manage the groundwater resource responsibly into the future.

But successfully resolving the many issues and competing uses of the Gnangara groundwater resource is beyond the mandate or ability of any single state government agency. A holistic and whole of Government approach is needed. To that end, the Department of Environment is working with other State Government agencies with an interest in the future of the Gnangara groundwater resource. This includes the Water Corporation (public water supply), the Department of Planning and Infrastructure (land use), CALM (biodiversity), the Health Department (wastewater reuse), the Department of Agriculture (horticulture and other agricultural uses) and the Forest Products Commission (pine plantations).

The outcomes of the Gnangara groundwater planning process will directly or indirectly affect many in the community. If we are to be successful in outlining a sustainable future for this valuable groundwater resource, the planning process needs to extend beyond state government agencies. It requires not only State and Local Governments, but communities, environmental groups, and industry working together to set priorities and develop strategies to ensure the sustainable management of the resource.

Appendix 6 – Current and Future Ecological Condition

Zone	Current Conditions				Regional Water Table Decline (2015)				Risk Of Impact		Consequences of Impact* - 8 Year Climate Trend	Consequences of Impact* - 28 Year Climate Trend
					8 Year Climate Trend		28 Year Climate Trend		8 Year Climate Trend	28 Year Climate Trend		
	Site	Previously stated values	Retained Values	Ecological Impact	Magnitude of Predicted Drawdown (m)	Rate of Predicted Drawdown (m/year)	Magnitude of Predicted Drawdown (m)	Rate of Predicted Drawdown (m/year)				
Wetlands												
Lexia	**GNM17A (Lexia 94)**	• Undisturbed by typical impacts. • Supports diverse vegetation. • Significant fauna habitat.	• Supports diverse vegetation.	Water level declines have coincided with some decline in the condition of fringing vegetation and the drying and thinning of wetland shrubs and emergent macrophytes across the wetland basin. Declining water levels have been associated with a reduction in faunal habitat area and drying of rich organic sediments.	2	0.2	1	0.1	severe	severe	The magnitude and rate of drawdown exceeds that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a severe level of possible impact. Drying and thinning of vegetation is likely to continue across the basin with further decline in fringing tree and shrub species and faunal habitat area.	The magnitude and rate of drawdown exceeds that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a severe level of possible impact. Drying and thinning of vegetation is likely to continue across the basin with further decline in fringing tree and shrub species and faunal habitat area.
	GNM16 (Lexia 86)	• Undisturbed by typical impacts. • Supports diverse vegetation. • Significant fauna habitat.	• Supports diverse vegetation.	Water level declines have coincided with decline in health, patch deaths and encroachment of fringing vegetation into the basin and the contraction of *Baumea articulata*. Sediments have also dried and vertebrate species become less prevalent.	2	0.2	0.1	0.01	severe	significant	The magnitude and rate of drawdown exceeds that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a severe level of possible impact. The decline in health and encroachment of fringing vegetation into the basin is likely to continue. Vertebrate species may continue to become less prevalent.	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. The decline in health and encroachment of fringing vegetation into the basin is likely to continue. Vertebrate species may continue to become less prevalent.
	GNM15 (Lexia 186)	• Undisturbed by typical impacts. • Supports diverse vegetation. • Significant fauna habitat.		Water level declines have coincided with some decline in the condition of fringing vegetation and encroachment into the basin and the contraction of *B. articulata*. There has also been drying of organic rich sediments and low macroinvertebrate family richness.	2	0.2	1	0.1	severe	severe	The magnitude and rate of drawdown exceeds that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a severe level of possible impact. The decline in health and encroachment of fringing vegetation into the basin is likely to continue. Organic sediments are likely to continue to dry, and macroinvertebrate family richness may decline further.	The magnitude and rate of drawdown exceeds that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a severe level of possible impact. The decline in health and encroachment of fringing vegetation into the basin is likely to continue. Organic sediments are likely to continue to dry, and macroinvertebrate family richness may decline further.
	EPP 173/ GNM14SG	• Unique hydrology. • High vertebrate and macroinvertebrate species richness. Contains most northern population of Black-stripe minnow (Galaxiella nigrostriata).	• Unique hydrology. • High vertebrate and macroinvertebrate species richness.	Water level declines have coincided with some decline in the condition of fringing vegetation, reduced water quality and drying of organic sediments. There has also been the possible decline in Black-stripe minnow.	1	0.1	0.1	0.01	severe	significant	The magnitude and rate of drawdown exceeds that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a severe level of possible impact. Reduction in flows from the springs due to groundwater drawdown will also likely influence the hydrologic regime of EPP173. If the springs stopped flowing, then the depth and duration of inundation in winter and the soil moisture profile in summer all could be affected. It is likely that lower surface water levels will impact on the breeding capabilities of the Black-striped Minnow and other vertebrate species. Emergent vegetation may also contract into the basin with further decline in the condition of fringing species.	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. . Reduction in flows from the springs due to groundwater drawdown will also likely influence the hydrologic regime of EPP173. If the springs stopped flowing, then the depth and duration of inundation in winter and the soil moisture profile in summer all could be affected. It is likely that lower surface water levels will impact on the breeding capabilities of the Black-striped Minnow and other vertebrate species. Emergent vegetation may also contract into the basin with further decline in the condition of fringing species.
	Dampland 78 / GNM31	• Supports swamp vegetation.		Water level declines have coincided with some decline in the condition and density of fringing vegetation and wetland shrubs. There has also been encroachment of fringing vegetation into the basin and the contraction of *B. articulata*.	2	0.2	0.1	0.01	significant	moderate	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. In light of previous changes in ecological condition, the impact is 1ikely to be severe, with loss of some mature *Melaleuca preissiana* and increased thinning in the understorey. The decline in health and encroachment of fringing vegetation into the basin is likely to continue.	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a moderate level of possible impact. In light of previous changes in ecological condition, the impact may be significant, with loss of some mature *Melaleuca preissiana* and increased thinning in the understorey. The decline in health and encroachment of fringing vegetation into the basin may continue.
	Edgecombe (B10)	• High conservation value due to mosaic of habitats likely to support diverse fauna populations.	• High conservation values due to mosaic of habitats likely to support diverse fauna populations.	Water level declines have coincided with a decline in faunal diversity and habitat condition.	0.1	0.01	0	0	significant	significant	The magnitude and rate of drawdown exceeds that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. Declines in faunal diversity and habitat condition may continue.	Although water levels are predicted to rise the wetland remains at significant risk of impact due to historic changes and conservation values. However, it is likely that vegetation will continue to re-establish and increased surface water levels by 2015 may restore faunal diversity.
	Egerton (B25) (Wetland)	• Supports significant club moss and liverwort species. • Supports pristine fringing vegetation. • High conservation value as invertebrate habitat.	• Supports significant club moss and liverwort species. • Supports pristine fringing vegetation. • High conservation value as invertebrate habitat.	There has been no recorded change in the ecological condition of the site over this time period.	1	0.1	0	0	severe	moderate	The magnitude and rate of drawdown exceeds that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a severe level of possible impact. There is likely to be a decline in the ecological condition of Egerton Seepage.	Although water levels are predicted to rise the wetland remains at moderate risk of impact due to historic changes and conservation values.
Mirrabooka	**Gnangara Lake**	• Low value due to poor water quality, especially high pH.	• Low value due to poor water quality, especially high pH.	Water level declines have coincided with low pH and evidence of eutrophication, low macroinvertebrate family richness and reduced inundation of littoral and fringing vegetation (Benier and Horwitz 2003).	2	0.2	0	0	significant	non significant	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. Low pH, eutrophication, low macroinvertebrate family richness and reduced inundation of littoral and fringing vegetation, are likely to continue.	Although water levels are predicted to rise, the combination of historic changes and conservation values represents a non significant risk of impact.

Zone	Current Conditions				Regional Water Table Decline (2015)				Risk Of Impact		Consequences of Impact* - 8 Year Climate Trend	Consequences of Impact* - 28 Year Climate Trend
					8 Year Climate Trend		28 Year Climate Trend		8 Year Climate Trend	28 Year Climate Trend		
	Wetland	Previously stated values	Retained Values	Ecological Impact	Magnitude of Predicted Drawdown (m)	Rate of Predicted Drawdown (m/year)	Magnitude of Predicted Drawdown (m)	Rate of Predicted Drawdown (m/year)				
North Wanneroo	**Nowergup (Wetland)**	• As a permanent deep-water wetland acts as a major drought refuge for waterbirds. • Supports dependent invertebrates and fish species (one native, Swan River Goby; & one exotic, Mosquitofish). • Large areas of sedges minimise impact of nutrient enrichment on aquatic fauna.	• As a permanent deep-water wetland acts as a major drought refuge for waterbirds • Supports fish species and other dependent vertebrate species. • Significant for aquatic macroinvertebrates.	Despite artificial maintenance the health of *Eucalyptus rudis* and *Melaleuca rhaphiophylla* has declined significantly in recent years, *B. articulata* has been thinning and *Typha orientalis* and other exotics have been encroaching into the basin. Water quality changes include increase in pH range, decreased conductivity, nutrient levels and chlorophyll-a values, mostly attributable to supplementation of water levels using fresh water from Leederville aquifer. There has also been a slight decline in summer macroinvertebrate family richness.	2	0.2	1	0.1	severe	severe	The magnitude and rate of drawdown exceeds that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a severe level of possible impact. Drawdown predicted on both sides of the lake over each time period combined with historic changes and conservation values represent a severe level of possible impact. Unless artificial maintenance is successful is retaining adequate surface water level the predicted declines are likely to result in further encroachment of *T. orientalis* across the basin, loss of *B. articulata* from the wetland fringes and continued decline in the condition of *M. rhaphiophylla* and *E. rudis*. Recruitment of exotics and tree species across the basin is also possible. In addition, water quality and macroinvertebrate family richness is likely to decline further.	The magnitude and rate of drawdown exceeds that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a severe level of possible impact. Drawdown predicted on both sides of the lake over each time period combined with historic changes and conservation values represent a severe level of possible impact. Unless artificial maintenance is successful is retaining adequate surface water level the predicted declines are likely to result in further encroachment of *T. orientalis* across the basin, loss of *B. articulata* from the wetland fringes and continued decline in the condition of *M. rhaphiophylla* and *E. rudis*. Recruitment of exotics and tree species across the basin is also possible. In addition, water quality and macroinvertebrate family richness is likely to decline further.
Perth Metro/Coastal	**Goollelal (Wetland)**	• Waterbird habitat and drought refuge. • Supports good populations of native fish species (Swan River Goby & Western Pygmy Perch).	• Permanent water provides waterbird habitat and drought refuge. • Supports good populations of native fish species	The hydrographs for the staff gauge and monitoring bore at Lake Goollelal indicates that minimum surface water level declined 0.06 m from 1995 to 2003 following a long-term trend of increasing water levels. This has lead to increased inundation of fringing trees and some decline in the condition of *E. rudis* and *M. rhaphiophylla*, and contraction of *B. articulata* bands away from the wetland basin. There is also evidence of increased eutrophication, and a relatively low macroinvertebrate family richness. There has also been some invasion of exotic plant and fish species.	3	0.3	1	0.1	significant	significant	Although Lake Goollelal has experienced increasing water levels in the past, the magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. However, other than increased invasion of exotics, it is likely that the condition of wetland vegetation may improve. In contrast, water quality and macroinvertebrate family richness is likely to decline significantly.	Although Lake Goollelal has experienced increasing water levels in the past, the magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. However, other than increased invasion of exotics, it is likely that the condition of wetland vegetation may improve. In contrast, water quality and macroinvertebrate family richness is likely to decline significantly.
	Joondalup (Wetland)	• Waterbird habitat. • Diverse range of macrophytes.	• Waterbird habitat. • Diverse range of macrophytes. • Supports aquatic macroinvertebrates and vertebrates.	Water level declines and fires have coincided with some decline in the condition of fringing vegetation and encroachment of *T. orientalis* into the southern reaches of the basin. Sediments have dried and contributed to wind-throw of some mature *M. rhaphiophylla.* Water quality has also been impacted, with high nutrients, high chlorophyll a and low DO recorded during summer. Poor water quality (high nutrients, chlorophyll a, low dissolved O2) has also been recorded in summer.	2	0.2	1	0.1	severe	severe	The magnitude and rate of drawdown exceeds that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a severe level of possible impact. The surface water component of the wetland is likely to dry completely unless perching occurs resulting in the loss of habitat. There is also likely to be further encroachment of *T. orientalis* and *B. articulata*, increased wind throw of trees, loss of fringing vegetation condition and possible recruitment of exotics and native species across the basin, along with declines in water quality.	The magnitude and rate of drawdown exceeds that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a severe level of possible impact. The surface water component of the wetland is likely to dry completely unless perching occurs resulting in the loss of habitat. There is also likely to be further encroachment of *T. orientalis* and *B. articulata*, increased wind throw of trees, loss of fringing vegetation condition and possible recruitment of exotics and native species across the basin, along with declines in water quality.
Southern Wanneroo	**Mariginiup**	• Rich aquatic fauna (fish species – one native, Swan River Goby; & one exotic, Mosquitofish). • Wading bird habitat. • Good water quality.	• Wading bird habitat. • Rich aquatic fauna (under threat from acidification).	Water level declines, fire, physical disturbances and exotics have resulted in a decline in the condition of fringing *E. rudis,* encroachment of *T. orientalis* into the basin and a decline in flora species richness. Sediments have also dried and water quality has been impacted through increasing acidification.	4	0.4	3	0.3	significant	significant	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. The decline in health and encroachment of fringing vegetation into the basin is likely to continue. Organic sediments are likely to continue to dry, and acidification may increase.	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. The decline in health and encroachment of fringing vegetation into the basin is likely to continue. Organic sediments are likely to continue to dry, and acidification may increase.
	Lake Jandabup	• Most diverse sedge and macrophyte vegetation of all Bassendean dune wetlands, including unusual species. • Supports wide range of waterbirds, especially waders. • Extremely good water quality with low nutrients.	• Most diverse sedge and macrophyte vegetation of all Bassendean dune wetlands – not known if 'unusual species' persist. • Supports wide range of waterbirds, especially waders. • Supports significant macroinvertebrate species.	Prior to augmentation sedge species had encroached into the wetland basin, flora species richness had declined, and low pH had led to local extinctions of highly sensitive macroinvertebrate taxa. While the majority of declines in ecological condition have been arrested through artificial maintenance, the condition of fringing vegetation has continued to decline.	3	0.3	1	0.1	significant	significant	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. Unless artificial maintenance is continued and retains adequate surface water level the predicted declines are likely to result in further encroachment of sedges across the basin, and continued decline in the condition of fringing. Recruitment of exotics across the basin is also possible. Water quality issues are also likely to resurface under a drier regime.	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. Unless artificial maintenance is continued and retains adequate surface water level the predicted declines are likely to result in further encroachment of sedges across the basin, and continued decline in the condition of fringing. Recruitment of exotics across the basin is also possible. Water quality issues are also likely to resurface under a drier regime.
Yanchep	**Loch McNess (wetland)**	• Undisturbed wetland. • Unusual hydrologic regime. • Rich aquatic fauna. • Vegetation largely intact, provides range of habitat types. • Supports good populations of water-birds and acts as drought refuge. • Excellent water quality.	• Vegetation largely intact, provides range of habitat types. • Undisturbed wetland. • Unusual hydrologic regime. • Supports good populations of waterbirds and acts as drought refuge. • Excellent water quality. • Rich aquatic fauna	Although the water dependent biota of the Lake appear to be in excellent condition there has been some evidence of declining water quality in the past.	2	0.2	1	0.1	severe	severe	The magnitude and rate of drawdown exceeds that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a severe level of possible impact. Groundwater level decline may impact on surface water levels and result in Loch McNess becoming a seasonally inundated sumpland or at worst, a seasonally waterlogged dampland. This may result in the loss of habitat for aquatic fauna. Groundwater decline of this magnitude is also likely to lead to significant losses of *M. rhaphiophylla*, *B. littoralis* and *B. articulata*.	The magnitude and rate of drawdown exceeds that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a severe level of possible impact. Groundwater level decline may impact on surface water levels and result in Loch McNess becoming a seasonally inundated sumpland or at worst, a seasonally waterlogged dampland. This may result in the loss of habitat for aquatic fauna. Groundwater decline of this magnitude is also likely to lead to significant losses of *M. rhaphiophylla*, *B. littoralis* and *B. articulata*.

Zone	Current Conditions				Regional Water Table Decline (2015)				Risk Of Impact		Consequences of Impact* - 8 Year Climate Trend	Consequences of Impact* - 28 Year Climate Trend
					8 Year Climate Trend		28 Year Climate Trend		8 Year Climate Trend	28 Year Climate Trend		
					Magnitude of Predicted Drawdown (m)	Rate of Predicted Drawdown (m/year)	Magnitude of Predicted Drawdown (m)	Rate of Predicted Drawdown (m/year)				
	Yonderup (Wetland)	Previously stated values • High ecological values due to undisturbed nature. • Rich invertebrate fauna. • Excellent water quality. Undisturbed hydrologic regime and lack of seasonal variation.	Retained Values • Undisturbed hydrologic regime and lack of seasonal variation - declining water levels. • High ecological values due to undisturbed nature. • Rich invertebrate fauna. • Excellent water quality.	Current Ecological Impact Water level declines have coincided with increased invasion of wetland basin and surrounds by exotic flora, some health decline in fringing *M. rhaphiophylla* since 1997, and some signs of declining water levels and drying of organic rich sediments.	1	0.1	1	0.1	severe	severe	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a severe level of possible impact. Groundwater level decline may impact on surface water levels and result in Lake Yonderup becoming a seasonally inundated sumpland or at worst, a seasonally waterlogged dampland. This may result in the loss of habitat for aquatic fauna. Fringing and emergent vegetation may be lost, in particularly *Banksia littoralis*, which responds quickly to water level decline and *M. rhaphiophylla*, *B. articulata* and *T. orientalis* may encroach into the basin, reducing the area of open water and impacted on habitat and feeding grounds of vertebrates and waterbirds.	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a severe level of possible impact. Groundwater level decline may impact on surface water levels and result in Lake Yonderup becoming a seasonally inundated sumpland or at worst, a seasonally waterlogged dampland. This may result in the loss of habitat for aquatic fauna. Fringing and emergent vegetation may be lost, in particularly *Banksia littoralis*, which responds quickly to water level decline and *M. rhaphiophylla*, *B. articulata* and *T. orientalis* may encroach into the basin, reducing the area of open water and impacted on habitat and feeding grounds of vertebrates and waterbirds.
	Wilgarup Lake (Wetland)	Previously stated values • One of few remaining undisturbed wetlands within the region. • Rich and unusual vegetation. • Likely to support diverse fauna.	Retained Values • One of few remaining undisturbed wetlands within the region • Rich and unusual vegetation.	Ecological Impact Water level declines have coincided with severe declines in the ecological condition of the wetland, including the widespread loss of *M. rhaphiophylla* saplings and some mature trees, deaths of mature *B. littoralis*, thinning of *B. articulata* and the invasion of exotic species. No surface water has been recorded at Lake Wilgarup since 1998 resulting in the loss of macroinvertebrates and drying of organic rich sediments. Surface water was recorded in winters from 1993-98 the lake bed has remained dry since that time.	1	0.1	1	0.1	severe	severe	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a severe level of possible impact. Drawdown will further exacerbate the declining condition of this wetland. Total loss of tree seedlings and emergent macrophytes should be expected along with continued decline in the vigour of mature trees. However, terrestrialisation is unlikely to occur for some time due to the dense nature of litter across the wetland basin.	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a severe level of possible impact. Drawdown will further exacerbate the declining condition of this wetland. Total loss of tree seedlings and emergent macrophytes should be expected along with continued decline in the vigour of mature trees. However, terrestrialisation is unlikely to occur for some time due to the dense nature of litter across the wetland basin.
	Pipidinny Swamp	Previously stated values • Waterbird habitat	Retained Values • Waterbird habitat	Ecological Impact There has been an increase in the conductibility of the ponds in recent years suggesting the possibility of salt water intrusion associated with surrounding groundwater decline. There has been on-going invasion of wetland by exotic flora.	1	0.1	1	0.1	significant	significant	The magnitude and rate of drawdown exceeds that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. Groundwater level decline may impact on surface water levels and result in Pipidinny Swamp becoming a seasonally inundated sumpland or at worst, a seasonally waterlogged dampland. This may result in the loss of habitat for aquatic fauna. The sedge species that constitute the TEC at this site may decline in density and condition along with fringing *M. rhaphiophylla*.	The magnitude and rate of drawdown exceeds that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. Groundwater level decline may impact on surface water levels and result in Pipidinny Swamp becoming a seasonally inundated sumpland or at worst, a seasonally waterlogged dampland. This may result in the loss of habitat for aquatic fauna. The sedge species that constitute the TEC at this site may decline in density and condition along with fringing *M. rhaphiophylla*.
Terrestrial												
Mirrabooka	**MM16**	Previously stated values • Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater.	Retained Values • Banksia woodland <8m depth to groundwater (3-6m). • Selected to represent water levels over area of undisturbed phreatophtyic vegetation.	Ecological Impact There appears to have been no associated change in ecological condition at this site.	2	0.2	0	0	significant	non significant	The magnitude and rate of drawdown exceeds that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. This may result in changes in the distribution of some species and encroachment of more drought tolerant species.	Due to increases in groundwater levels, historic changes, high conservation values and current depth to groundwater the risk of impact is not significant.
	MM18	Previously stated values • Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater.	Retained Values • Banksia woodland <8m depth to groundwater (3-6m). • Selected to represent water levels over area of undisturbed phreatophtyic vegetation. Whiteman Transect • Representative of terrestrial vegetation in the area with respect to; • Vegetation structure • Vegetation composition • Fauna habitat.	Ecological Impact Water level declines have coincided with some decline in condition of *M. preissiana* and *B. ilicifolila*, and in the abundance of *Pericalymma elipticum* since 1999.	0	0	0	0	moderate	moderate	Although an increase in groundwater levels should not impact on vegetation the area remains at moderate risk due to historic changes, high conservation values and current depth to groundwater.	Although an increase in groundwater levels should not impact on vegetation the area remains at moderate risk due to historic changes, high conservation values and current depth to groundwater.
	MM49B	Previously stated values • Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater.	Retained Values • Banksia woodland <8m depth to groundwater (3-6m).	Ecological Impact Vegetation area largely cleared for recreation.	0	0	0	0	non significant	non significant	Due to increases in groundwater levels, historic changes, high conservation values and current depth to groundwater the risk of impact is not significant.	Due to increases in groundwater levels, historic changes, high conservation values and current depth to groundwater the risk of impact is not significant.
	MM53	Previously stated values • Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater.	Retained Values • Banksia woodland <8m depth to groundwater (3-6m). • Selected to represent water levels over area of undisturbed phreatophtyic vegetation.	Ecological Impact Although this appeared to have little impact there was some decline in vegetation condition during summer 2003/04.	0	0	0	0	non significant	non significant	Due to increases in groundwater levels, historic changes, high conservation values and current depth to groundwater the risk of impact is not significant.	Due to increases in groundwater levels, historic changes, high conservation values and current depth to groundwater the risk of impact is not significant.

Zone	Current Conditions				Regional Water Table Decline (2015)				Risk Of Impact		Consequences of Impact* - 8 Year Climate Trend	Consequences of Impact* - 28 Year Climate Trend
					8 Year Climate Trend		28 Year Climate Trend		8 Year Climate Trend	28 Year Climate Trend		
					Magnitude of Predicted Drawdown (m)	Rate of Predicted Drawdown (m/year)	Magnitude of Predicted Drawdown (m)	Rate of Predicted Drawdown (m/year)				
	MM55B	Previously stated values • Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater.	Retained Values • Melaleuca woodland <8m depth to groundwater (0-3m).	Ecological Impact There has been no change in ecological condition at this site. However, as much of the surrounding area has been cleared for grazing the conservation value of the site is moderate.	0.1	0.01	0	0	moderate	non significant	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a moderate level of possible impact. This may result in changing distribution of *M. preissiana* and wetland shrubs in the vicinity	Due to increases in groundwater levels, historic changes, high conservation values and current depth to groundwater the risk of impact is not significant.
	MM59B	Previously stated values • Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater.	Retained Values • Banksia woodland <8m depth to groundwater (3-6m).	Current Ecological Impact A number of dead and stressed *Banksias* were noted in the area in 2003.	1	0.1	0	0	significant	moderate	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. This may result in changes in the distribution of some species and encroachment of more drought tolerant species.	Although an increase in groundwater levels should not impact on vegetation the area remains at moderate risk due to historic changes, high conservation values and current depth to groundwater.
Lexia	**NR6C**	Previously stated values • Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater.	Retained Values • Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater (3-6m).	Current Ecological Impact Declining water levels have coincided with decreased vegetation density between 1988 and 2000.	2	0.2	0	0	significant	moderate	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. This is likely to result in deaths of mature *Banksias*, further declines in vegetation density, thinning of the understorey, and encroachment of more drought tolerant species.	Although an increase in groundwater levels should not impact on vegetation the area remains at moderate risk due to historic changes, high conservation values and current depth to groundwater.
Pinjar	**PM6**	Previously stated values • Selected to represent water levels over area of undisturbed phreatophtyic vegetation • Banksia woodland <8m depth to groundwater.	Retained Values • Selected to represent water levels over area of undisturbed phreatophtyic vegetation – some decline in vegetation condition. P50 transect • Representative of terrestrial vegetation in the area with respect to; - Vegetation structure - Vegetation composition - Fauna habitat.	Current Ecological Impact Declining water levels have coincided with significant health declines in *Banksia*, and decreased understorey density.								
	PM7	Previously stated values • Selected to represent water levels over area of undisturbed phreatophtyic vegetation • Banksia woodland <8m depth to groundwater.	Retained Values • Selected to represent water levels over area of undisturbed phreatophtyic vegetation.	Ecological Impact Declining water levels have coincided with decreased vegetation density between 1988-2000.								
	PM9	Previously stated values • Selected to represent water levels over area of undisturbed phreatophtyic vegetation • Banksia woodland <8m depth to groundwater.	Retained Values • Banksia woodland <8m depth to groundwater (6-10m).	Ecological Impact Declining water levels have coincided with significant declines in understorey density and deaths of individual Banksias in the area.	4	0.4	2	0.2	moderate	moderate	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a moderate level of possible impact. This could result in further loss of *Banksia* and encroachment of more drought tolerant species.	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a moderate level of possible impact. This could result in further loss of *Banksia* and encroachment of more drought tolerant species.
	PM24	Previously stated values WAWA (1995) • Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • <8m to groundwater.	Retained Values • Depth to groundwater <8.0m (0-3m)	Ecological Impact While there has been no water level associated change in ecological condition, vegetation in much of the lake heavily modified through agriculture, with little undisturbed vegetation remaining.	2	0.2	0.1	0.01	severe	significant	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a severe level of possible impact This may result in the contraction of sedge species and terrestrialisation of the wetland basin.	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact This may result in the contraction of sedge species and terrestrialisation of the wetland basin. However, the saplings establishing in the area should persist.
	PM25	Previously stated values • Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • <8m to groundwater.	Retained Values •Depth to groundwater <8.0m (3-6m)	Ecological Impact Vegetation in much of the lake heavily modified through agriculture, with little undisturbed vegetation remaining.								
Southern Wanneroo	**MT31/MT3S**	Previously stated values • Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater.	Retained Values • Banksia woodland <8m depth to groundwater (6-10m). • Selected to represent groundwater levels over area of undisturbed phreatophtyic vegetation. Jandabup transect • Representative of terrestrial vegetation in the area with respect to; - Vegetation structure - Vegetation composition - Fauna habitat.	Ecological Impact Water level decline has coincided with some decline in tree condition and abundance of understorey species since 1993.	2	0.2	0.1	0.01	moderate	non significant	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a moderate level of possible impact. This may result in the further decline in tree condition, loss of some individual *Banksia* and encroachment of more drought tolerant species.	The magnitude and rate of drawdown combined with historic changes, high conservation values and current depth to groundwater, represents a non significant risk of impact.

Zone	Current Conditions				Regional Water Table Decline (2015)				Risk Of Impact		Consequences of Impact* - 8 Year Climate Trend	Consequences of Impact* - 28 Year Climate Trend
					8 Year Climate Trend		28 Year Climate Trend		8 Year Climate Trend	28 Year Climate Trend		
	Site	Previously stated values	Retained Values	Ecological Impact	Magnitude of Predicted Drawdown (m)	Rate of Predicted Drawdown (m/year)	Magnitude of Predicted Drawdown (m)	Rate of Predicted Drawdown (m/year)				
	JB5	• Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater.	• Banksia woodland <8m depth to groundwater (3-6m)	Ecological Impact Water level declines have coincided with some decline in *Banksia* health. This site is also invaded by weeds.	2	0.2	1	0.1	significant	moderate	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. *Banksia* health is likely to continue to decline.	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a moderate level of possible impact. There may be some further decline in *Banksia* health.
Lexia	**NR11C**	• Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater.	• Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater (3-6m).	Ecological Impact Water level decline has coincided with a decrease in vegetation density.	2	0.2	2	0.2	significant	significant	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. This is likely to result in deaths of mature *Banksia*, thinning of the understorey and encroachment of more xeric species.	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. This is likely to result in deaths of mature *Banksia*, thinning of the understorey and encroachment of more xeric species.
	MM12	WRC (1997) • Established to ensure comprehensive representation of native vegetation areas which are susceptible to drawdown. • Banksia woodland <8m depth to groundwater.	• Selected to represent water levels over area of undisturbed phreatophtyic vegetation • Banksia woodland <8m depth to groundwater (3-6m).	Current Ecological Impact Water level decline coincides with some declines in condition and density of *Banksia* woodland at this site.	1	0.1	0	0	significant	moderate	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. This may result in spot deaths of mature *Banksia* and declines in vegetation density	Although an increase in groundwater levels should not impact on vegetation the area remains at moderate risk due to historic changes, high conservation values and current depth to groundwater. This may result in spot deaths of mature Banksia and declines in vegetation density.
	L30C	• Established to ensure comprehensive representation of native vegetation areas which are susceptible to drawdown. • Banksia woodland <8m depth to groundwater.	• Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater (3-6m).	Current Ecological Impact Water level decline coincides with some decreased vegetation density.	3	0.3	0.1	0.01	significant	moderate	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. This is likely to result in further declines in vegetation density due to spot deaths and vegetation condition decline.	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a moderate level of possible impact. This may result in further declines in vegetation density due to spot deaths and vegetation condition decline.
	L110C	• Established to ensure comprehensive representation of native vegetation areas which are susceptible to drawdown. • Banksia woodland <8m depth to groundwater.	• Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to (6-10m).	Current Ecological Impact Water level declines have coincided with decreased vegetation density due to spot deaths in mature *Banksia attenuata*.	3	0.3	0.1	0.01	moderate	non significant	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a moderate level of possible impact. This may result in some decline in vegetation density and condition.	The magnitude and rate of drawdown combined with historic changes, high conservation values and current depth to groundwater, represents a non significant risk of impact. However there may still be some decline in vegetation density and condition.
	L220C	• Established to ensure comprehensive representation of native vegetation areas which are susceptible to drawdown. • Banksia woodland <8m depth to groundwater.	• Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater (3-6m).	Current Ecological Impact Despite water level declines, there appears to have been no associated change in ecological condition at this site.	2	0.2	0.1	0.01	significant	moderate	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. This may result in some decline in vegetation condition.	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a moderate level of possible impact. This may result in some decline in vegetation condition.
	WM1	WAWA (1995) • Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater.	• Retained Values • Banksia woodland <8m depth to groundwater (3-6m).	Current Ecological Impact Water level declines have coincided with thinning in the understorey and some *Banksia* deaths.	3	0.3	1	0.1	significant	significant	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. This is likely to result in further decline in *Banksia* woodland condition.	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. This is likely to result in further decline in *Banksia* woodland condition.
	WM2	• Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater.	• Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater (3-6m).	Current Ecological Impact Water level declines have coincided with decreased vegetation density.	4	0.4	2	0.2	significant	significant	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. This is likely to result in deaths of mature *Banksias,* thinning of the understorey and encroachment of more drought tolerant species.	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. This is likely to result in deaths of mature *Banksias,* thinning of the understorey and encroachment of more drought tolerant species.
	WM6	• Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater.	• Banksia woodland <8m depth to groundwater (6-10m).	Current Ecological Impact Water level declines have coincided with decline in condition of vegetation. There is also clearing to the south.	1	0.1	0	0	non significant	non significant	The magnitude and rate of drawdown combined with historic changes, high conservation values and current depth to groundwater, represents a non significant risk of impact.	Due to increases in groundwater levels, historic changes, high conservation values and current depth to groundwater the risk of impact is not significant.

Zone	Current Conditions			Regional Water Table Decline (2015)				Risk Of Impact		Consequences of Impact* - 8 Year Climate Trend	Consequences of Impact* - 28 Year Climate Trend
				8 Year Climate Trend		28 Year Climate Trend		8 Year Climate Trend	28 Year Climate Trend		
				Magnitude of Predicted Drawdown (m)	Rate of Predicted Drawdown (m/year)	Magnitude of Predicted Drawdown (m)	Rate of Predicted Drawdown (m/year)				
	WM8			4	0.4	2	0.2	significant	significant	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. This is likely to result in deaths of mature *Banksias,* thinning of the understorey and encroachment of more drought tolerant species.	The magnitude and rate of drawdown may exceed that required to maintain a low risk of impact. This combined with historic changes and conservation values represents a significant level of possible impact. This is likely to result in deaths of mature *Banksias,* thinning of the understorey and encroachment of more drought tolerant species.
	Previously stated values • Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater.	Retained Values • Retained Values • Selected to represent water levels over area of undisturbed phreatophtyic vegetation. • Banksia woodland <8m depth to groundwater (3-6m).	Current Ecological Impact Water level declines have coincided with decreased vegetation density.								

*** See Appendices Wetland and Terrestrial for possible responses to drawdown in the key elements of wetland and terrestrial ecosystems for 4 degrees of risk of impact (adapted from Environmental Protection Authority, 2000) (Froend et al. 2004).**
Froend et al (2004) was used in putting together this table

Appendix 7 – IOCI – Notes on Changed Climate in Western Australia – Number 2

How has our Rainfall Changed? - The South West

Indian Ocean Climate Initiative
www.ioci.org.au
Informed Adaptation

This series outlines observed changes which have occurred in various aspects of Western Australian climate in recent decades.

Summary

Winter rainfall in the south west of Western Australia was once considered the most consistent and reliable anywhere in Australia. However, around the mid 1970s there was a shift to consistently drier winter conditions, which have continued to this day. This change occurred simultaneously with a change in the global atmospheric circulation. It is likely that both natural variability and the enhanced greenhouse effect have played a role. There have been strong impacts on surface and ground water supplies, on natural ecosystems and agriculture. Simulations of future climate with enhanced greenhouse gases show a similar pattern of drier conditions for the south west. Continuing research by IOCI is further building our understanding of what caused the rainfall changes and what we may expect in the future. Further details: 'Climate variability and change in south west Western Australia', IOCI 2002.
www.ioci.org.au

Seasonal Rainfall

The annual rainfall in the south west of Western Australia has declined by about 10% since the mid 1970s. Rainfall in the south west is strongly dominated by winter rainfall. Figure 1 shows the mean monthly rainfall averaged over the region southwest of the diagonal line in Figure 4. The monthly totals for the early period (1925-1975) are shown in dark blue while the later period (1976-2003) is shown in light blue. The annual rainfall decline in the later period was due mostly to a decrease in autumn and early winter. There has been little change in rainfall totals in late winter and spring, with a slight increase in summer.

An Abrupt Change

The decline in early winter rainfall is evident when the total May to July rainfall is plotted for each year since 1925 (Figure 2). The linear rainfall trend from 1925 to 2003 was downward and statistically significant at the 99% level. However the decline was more of a sharp drop than a gradual decline, as illustrated by the dark blue lines of average rainfall in Figure 2. The mean May – July rainfall for 1925-1975 was 323 mm, while for 1976-2003 it was 276 mm - a 15% drop. In the 28 years since 1976 there has been a notable absence of wet years with only eight years when the May – July rainfall was greater than the 1925-1975 mean. This is a significant factor in the strong impact on the water sector.

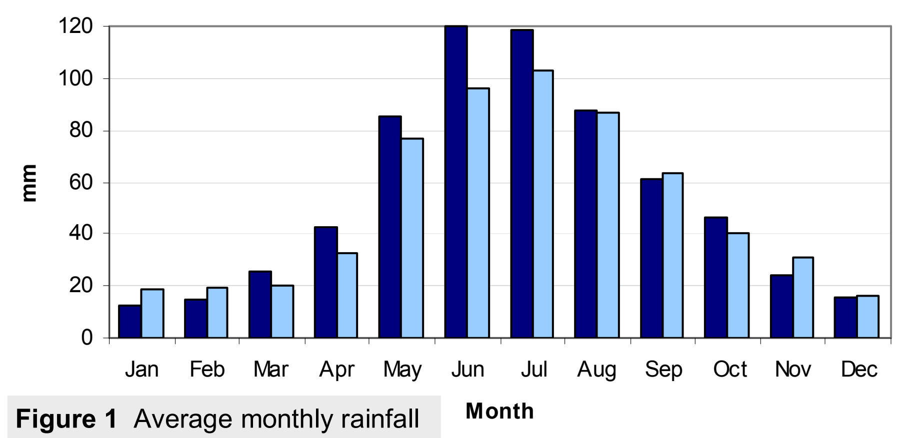


Figure 1 Average monthly rainfall for the south west. (The area south west of the line in Figure 4)

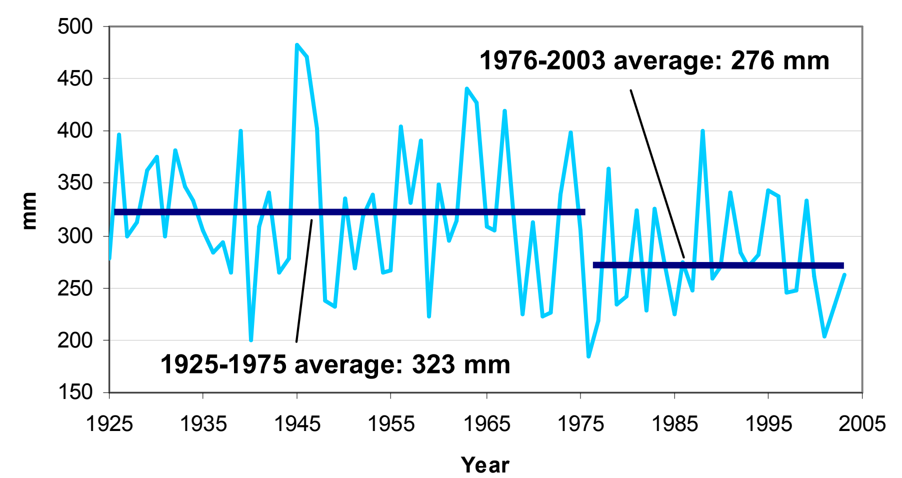


Figure 2 May - July rainfall totals averaged over the south west

Changes Across the Region

The total rainfall for May – July is shown by isohyets (lines of equal rainfall amount) in Figure 3. The south west coast receives the largest amount of rainfall, while it is drier inland and to the north. The westward shift in the isohyets in the later period is striking.

Figure 4 shows the percentage change in May - July rainfall from the earlier to later periods across the region. Areas in red indicate a decline in rainfall since 1975, while areas in blue indicate an increase in rainfall. The percentage change is less meaningful in regions where the total rainfall is low.

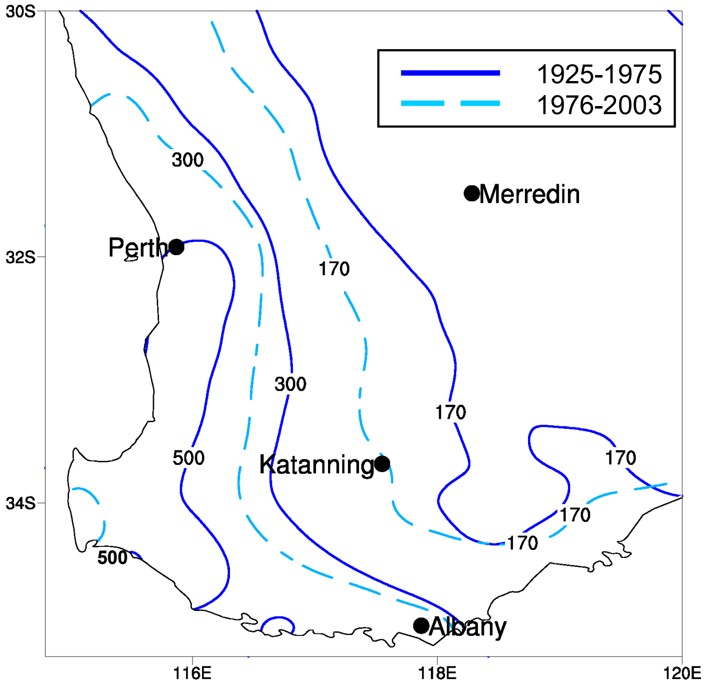


Figure 3 Isohyets of May-July rainfall totals in mm

Isohyets are lines of equal rainfall amount

What Caused the Changes?

The sharp drop in rainfall occurred at the same time as a global change in the atmospheric circulation. Both natural variability and the enhanced greenhouse effect ("global warming") are thought to have played a role in these broad scale changes.

Local factors such as land-use change may also have played a role in the rainfall decline, but this is likely to be secondary compared with the larger scale atmospheric changes.

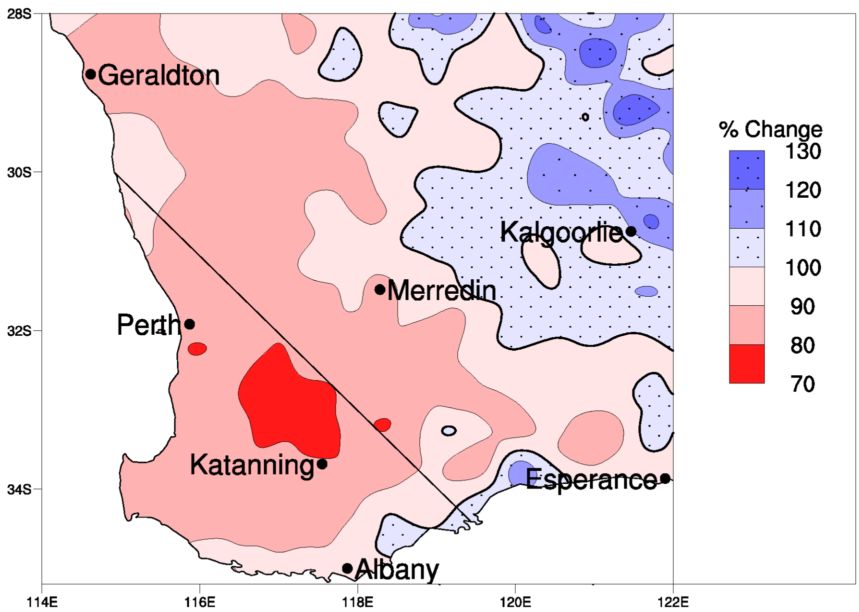


Figure 4 Average May-July rainfall for the period 1976-2003 as a percentage of the May-July rainfall for the 1925-1975 period. Red indicates a decline in rainfall in the later period, blue an increase. The area to the south west of the diagonal line is averaged to produce the values in Figures 1 and 2

What are the Implications?

South west Western Australia is reliant on good winter rains. The rainfall drop has led to a stream flow reduction of about 40%, a large decrease relative to the rainfall decline. This disparity is due to the lack of surplus water from very wet years. The resulting decrease in surface and ground water availability has severely reduced regional water resources and is forcing major enhancement of water systems. Some ecosystems such as wetlands and woodlands are under pressure. Agriculture has also been impacted, as it is dependent on autumn rainfall for crop and pasture establishment.

What Can We Say About the Future?

Projections for the future, with increasing greenhouse gas concentrations, suggest that a decline in rainfall may occur over the south west. The observed decline was most likely linked to both enhanced greenhouse gases and natural variability. Further research by IOCI is building our understanding of the drivers that led to the major circulation shift in the 1970s and how these drivers will change in the future.