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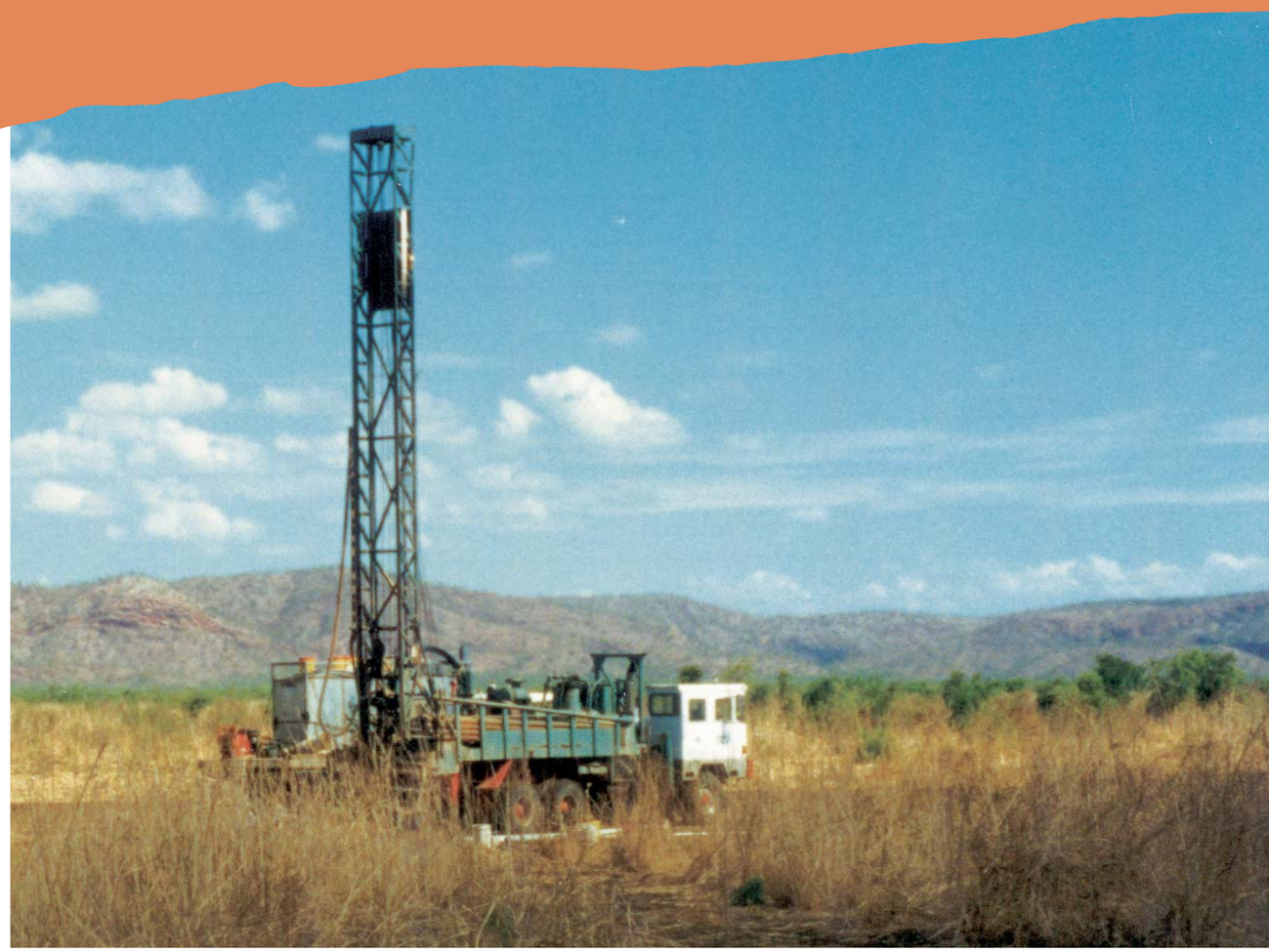

Groundwater investigation program in Western Australia (2005 to 2020)

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GROUNDWATER INVESTIGATION PROGRAM IN WESTERN AUSTRALIA (2005 TO 2020)

by

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Water Resource Division

Department of Environment

DEPARTMENT OF ENVIRONMENT

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Cover photograph:

Drilling on the Weaber Plain near Kununurra, as part of groundwater investigations for the Ord River Irrigation Area.

Contents

Figures

Tables

Executive Summary

An investigation and monitoring bore program is necessary to adequately manage groundwater resources throughout Western Australia, and support the management functions of the Department of Environment. The investigation program is a priority in groundwater management areas where licensed use is close to the allocation limit and where there is insufficient information to manage the resource effectively. This report outlines an investigation program for the next 15 years (2005 to 2020) that will extend throughout Western Australia, but is concentrated in areas of high groundwater use.

Groundwater investigation and monitoring underpins the sustainable management of groundwater resources across the State. The acquisition and interpretation of information for planning and management relies on investigation programs and monitoring for a scientific understanding of the sustainability of groundwater systems. The Department's role can only be maintained if information and assessment strategies/systems are well integrated within projects and with stakeholder information needs and sources.

The main stakeholders that will benefit from the data derived during the investigation program are the Department of Environment for preparation of management plans, local area committees who advise on local groundwater resources management policy, and private self-supply users who require the information to establish groundwater supplies. In addition, the major beneficiaries of the monitoring are the Department, local area management committees, and the public.

The objectives of the groundwater investigation and monitoring program are to define the size and extent of aquifers, determine the magnitude of the groundwater resource in order to manage impacts and consumptive use, as well as monitor water levels and groundwater quality on an ongoing basis. The major outcome will be well-managed groundwater resources with a known minimal or acceptable impact on the environment due to abstraction. Consequently, the benefit to the State is that groundwater abstraction is managed on a sustainable basis.

There are a number of costs and risks if the work outlined in this report is not undertaken, including under-utilisation of the groundwater resources, forgoing economic benefit through hindering State development, or over-utilisation of the resources, which will necessitate reducing licensed groundwater use.

A groundwater investigation program has been defined over a 15 year period between 2005 and 2020. The program has attempted to address both short-term and immediate concerns through to more strategic planning to promote regional development. The focus of the program is to identify areas of increased groundwater usage and/or, where existing groundwater information is insufficient, to allow reassessment of groundwater resources that may be under pressure from natural and/or induced causes.

The first three years of the program are focused on the metropolitan area and horticultural districts (e.g. Gingin and Cowaramup) throughout the Perth Basin. More strategic groundwater investigations are progressively introduced in the fourth year to provide a more balanced, statewide assessment.

The proposed work program will be undertaken through employment of water well drilling contractors with departmental supervision. Staff from the Department of Environment will also be responsible for data analysis, interpretation, and report writing. All information generated from the program will be made available to stakeholders in printed reports, CDs and on the Internet.

1 Introduction

1.1 Agency vision and strategy

The mission statement of the Department of Environment (DoE) puts emphasis on giving the lead to protection and enhancement of the State's natural resources, and the vision statement envisages a healthy environment and sustainable use of natural resources for the benefit of present and future generations. Sustainable groundwater use can only be achieved with an adequate knowledge of the groundwater resources and the ability to adequately monitor changes due to consumptive use. The groundwater investigation and monitoring program is therefore an integral part of the groundwater management undertaken by the Department and is linked to the licensing of private groundwater users.

1.2 Business need

During the two decades to 1990, expenditure on the groundwater investigation/monitoring bore network was at a level of about $2 million (1990$). The Western Australia Water Resources Council recommended in 1992 a base level of investigation at $0.5 million/yr and Treasury granted this level of funding to the former Department of Minerals and Energy in 1993 as the Groundwater Exploration Initiative. With progressive reductions in funding to the Water and Rivers Commission, and the increase in other groundwater management needs, it has not been possible to undertake this activity in recent years.

The statewide groundwater monitoring network, which consists of some 3000 bores to monitor use in proclaimed groundwater areas, has grown by only four new sites in the 1996–2003 period. This has been insufficient to keep up with the large increase in licensed allocations, particularly in the Perth Basin. There are a number of groundwater areas in which allocation limits could currently be unrealistically low owing to lack of investigation data and the inability to monitor water levels. In other groundwater areas, there are impacts on groundwater levels from high levels of abstraction that are not adequately monitored.

A high priority needs to be given to re-establishing the groundwater investigation program in the light of the Auditor General's (2003) report, which found that the Commission did not have the appropriate level of information to manage groundwater resources in some areas. The timing for an enhanced groundwater investigation program is now becoming critical, owing to the large increase in groundwater use in the last decade. There will be an immediate benefit to regional Western Australia from the ability to allocate additional groundwater for consumptive use, particularly for irrigated agriculture, horticulture and viticulture, with a better understanding of regional management responses.

The need for improvements to the monitoring network has become apparent from an analysis of the number of groundwater management areas in which licensed use has reached a high proportion of the allocation limit, but without a corresponding increase in the level of monitoring. The consequences of not proceeding are the under-use and potential over-allocation of groundwater. The credibility of the government as a groundwater manager will also be challenged, as shown by the loss of appeals in cases where it cannot be demonstrated that the Commission's management is

based on sound technical knowledge. Industry groups such as the International Association of Hydrogeologists, representing groundwater consultants, have previously brought this matter to the attention of the State Government.

The base-level program of groundwater investigation recommended by Western Australia Water Resources Council (1991) was to provide a level of knowledge of groundwater resources around the State commensurate with their importance and the stage of development. A minimum knowledge of groundwater resources is required for planning on a regional scale; for example, the water studies for the Goldfields Region. The Association of Mining and Exploration Companies has also prepared a priority list of areas for which further information on groundwater resources is required for planning the future security of supply to the mining industry.

The case of the South West Yarragadee study has illustrated the need to carry out basic investigation well in advance, if planning for large schemes of State importance is to be carried out in a comparatively short time.

The value of water level monitoring data has been demonstrated by the regional-scale groundwater modelling projects carried out for groundwater management in Perth and the South West. In both studies, the groundwater monitoring data were essential for the calibration of the models that will serve to predict groundwater status under future-use scenarios. It is also important for the Department to access high-quality monitoring data to evaluate the condition of the groundwater resources and ensure that future generations have access to potable groundwater supplies.

1.3 Scope and purpose

In order to gain sufficient data for the management of groundwater resources, a well-planned strategy for their assessment is required. This document therefore reviews how groundwater information has been gathered in the past and what has been achieved, and proposes a framework and direction for the development of an effective State groundwater resources investigation program for the future.

The program will focus on resolving short-term and strategic groundwater resource issues, particularly in groundwater subareas at or near full licensed allocation. The recent loss of licence appeals and review of water resource management by the Office of Auditor General (Auditor General of Western Australia, 2003) has highlighted that the Department of Environment requires an integrated groundwater investigation program that complements the water resource management function. This document only addresses the resources, funding and commitments required for reinstating and maintaining a groundwater investigation program that is in keeping with the current level of groundwater use.

2 Importance of groundwater to Western Australia

Water is vitally important for human activities, and for the maintenance of the environment in which all Australians live. It is widely appreciated that Western Australia is the second driest State in the driest continent of the world, yet the availability of water for the wide range of uses to which it is put for domestic, agricultural and industrial use is commonly taken for granted.

Consumers are generally unaware of how small the water resources of the State are in relation to the potential demands that may be placed upon them. The importance of these resources is only highlighted for the wider community when issues arise, such as droughts, that raise community awareness. These are usually temporary occurrences and for most of the time the community takes the availability of water for granted and is generally unaware of the need for careful management of the available resources.

2.1 Distribution

Although groundwater is unevenly distributed in terms of its availability and quality, it has a much wider occurrence over the State than usable surface water. The major fresh groundwater resources occur in the south west of the State, but significant fresh, brackish and saline resources also occur through most of the remainder.

2.2 Storage

The volume of groundwater held in storage is commonly between twenty and several thousand times larger than its mean annual rate of replenishment. In consequence, in many areas there are considerable reserves of groundwater to meet extended drought conditions compared with those provided by surface storages. Similarly, it is possible to draw groundwater from storage with considerable independence from the effects of irregular rainfall. This is a valuable attribute for water resources management, especially in areas of arid climate, such as over the major part of Western Australia. Nevertheless, in the long term, the abstraction of groundwater should not exceed the rate at which it is being replenished, and impacts on the environment must be managed at acceptable levels.

2.3 Development and utilisation

Groundwater resources can readily be developed incrementally to meet growing water supply demands. Thus it is possible to construct wellfields initially to meet the immediate water demands and later extend them as required. Incremental development in this way has a significant financial advantage as it also stages the need for capital expenditure. This contrasts with the development of surface water resources, which generally require major capital expenditure for storage construction, often some years before consumption is likely to reach supply capacity.

Groundwater provides about two-thirds of all water used in the State (WRC, 2000) and is the only available, readily exploitable source of water over about 60% of Western Australia. About 90 rural and mining towns, and numerous Aboriginal communities, rely on groundwater as the main source of public water supply. Groundwater is the principal source of water supply for mining operations, where it is used for mineral processing and dust suppression. It is the source of about 60% of all water used for irrigation, especially in the Carnarvon and Gingin areas, and is also widely utilised for livestock water supplies.

There has been significant increase in groundwater demand with gross groundwater consumption from all sources estimated at 835 GL/yr in 2000 (WRC, 2000) rising from 371 GL/yr in 1983–84 (Fig. 1). It is important to note that groundwater usage greatly exceeds surface water usage, rising from 44% (1983–84) to 67% (2000) of total water consumed. Extensive use is made of groundwater by manufacturing industries and large quantities have been used for major engineering projects such as the construction of roads, railways, pipelines and defence facilities. Groundwater has also been investigated as a potential source of water for aquaculture, for geothermal energy and as a source of salt.

Projections have shown that the reliance on groundwater resources will become greater due to lower rainfall, and that groundwater demand will double between now and 2020. The projections, shown in Figure 1, are considered conservative and growth in groundwater demand may be significantly stronger. This trend is highly significant, particularly in light of the impact of a drying climate on water resources in the South West.

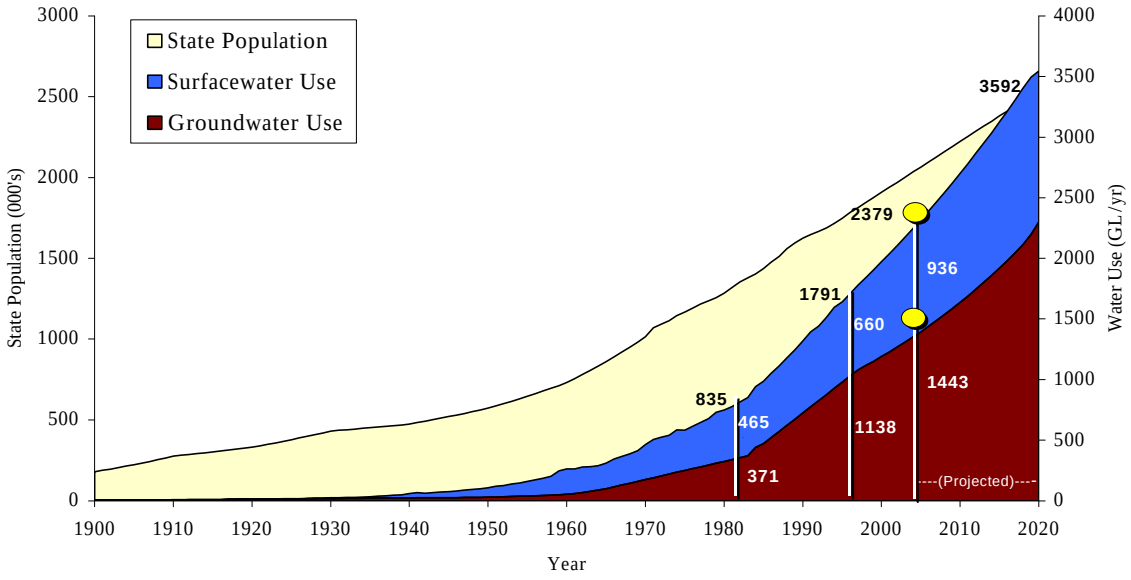

Figure 1. Historical water use and demand projections (*after* WRC, 2000)

2.4 Environmental value

Groundwater at shallow depths, for instance on the Swan Coastal Plain, maintains wetlands and their associated flora and fauna by providing an inflow of water equivalent to two or three times the annual rainfall. In such areas of groundwater discharge, the availability of groundwater through the summer supports plant communities and provides water supplies for the wildlife that

take refuge there. Groundwater also supports native vegetation, particularly trees, in arid areas. Groundwater may also discharge into rivers and streams, and maintain streamflows during dry periods.

2.5 Other values

In addition to providing a source for water supplies, groundwater and the associated aquifers have other intrinsic values and usefulness. Groundwater can be utilised as a source of low-temperature geothermal energy for electricity generation. Dissolved salts within groundwater are an indicator of mineralisation, and can be processed to obtain economic minerals and salt. The flow in groundwater systems may also control the location of oil and uranium mineralisation. Deep aquifers themselves can be used for storing petroleum products, and as sites for chemical or radioactive waste disposal.

3 The continuing need for investigation

Information about the State's groundwater resources is essential for water supply planning, design and operation, and increasingly for effective water, land resource, and environmental management. Groundwater information is required by a wide range of users in all industry sectors, including State, local, and Commonwealth government agencies, consultants, oil and mining companies, drilling contractors, research organisations, land and project developers, educational institutions, and the general public. In the metropolitan area alone there are thousands of enquiries per year for groundwater information.

3.1 Water supply

An understanding of groundwater resources is essential for water supply development and planning to meet the expanding demands of townships, industry, mining operations, farmers and pastoralists. Major new demands for groundwater or the expansion of existing supplies generally require specific investigations to locate sources capable of meeting the target demands in terms of quantity and quality. Such investigations are made more economical and effective where the basic hydrogeological framework has already been established through an appropriate level of groundwater resource assessment.

The Department of Environment requires that proposals for any major water supply development should include a clear demonstration of the availability of water resources, sufficient for the lifetime of the project without deleterious impact on any established water resources development. This is intended to safeguard the State from having to provide additional or alternative supplies if local resources should subsequently prove inadequate.

Consequently, a basic understanding of groundwater resources would enable some developments to proceed and also guide the location of new developments. In areas where no use is currently being made of groundwater resources, the results of groundwater investigations would therefore encourage economic development.

The WA State Water Strategy (Government of Western Australia, 2003) supports a least-cost planning approach to development; however, without adequate information this principle is difficult to support. It is therefore possible that more-costly alternative supplies may be introduced, in advance of what might be considered with properly investigated and costed groundwater supply options.

3.2 Groundwater resources management

Groundwater resources management in Western Australia, except in parts of the Eastern Goldfields, is based upon the concept of 'sustainable yield'. Under this concept, groundwater resources are managed to ensure that they can maintain in perpetuity their capacity to provide a beneficial use, such as water yield, or to meet environmental demands.

The development of the State's groundwater resources has progressed to the point that, in some areas, the available supplies are being utilised at a level close to their sustainable yield. It is essential that these resources are managed to provide water supplies for future generations. Legislation to proclaim groundwater management areas has been available since 1962. Many of the significant water resources of the State are protected by this legislation, and are being actively managed.

The management of water resources is undertaken at various levels. The implementation of effective resource management strategies requires a good understanding of the availability and behaviour of the resource, especially where it is being utilised at a level close to its capacity. Without a knowledge of the resources that is appropriate to the level of management, managers may take an overly conservative approach to water allocation, and this may limit development to below its actual potential.

3.3 Land resources management

It has become increasingly recognised that land resources management requires knowledge of the available water resources. An adequate knowledge of groundwater resources is therefore essential to ensure that land planning is compatible with the availability of groundwater.

In urban developments where water levels are a concern, information is necessary on the temporal variation of these levels and how they are influenced by variations in climate and changes in land use. The occurrence of groundwater close to the ground surface may be of concern, where flooding or waterlogging may occur through a rise in the watertable. Subdivision developments, for example, need to consider drainage in locations where the watertable is at shallow depth.

The problem of land salinisation in farming areas arises from the behaviour of groundwater systems in response to changed land use resulting from clearing. Groundwater resource investigation in such areas may be used to define areas prone to degradation through salinisation. The suitability of uncleared land for farming may be dependent on its proneness or otherwise to salinisation, which may be assessed from knowledge of the character of the groundwater system underlying the land in question.

A particular disadvantage of groundwater in areas subject to direct recharge, such as the Swan Coastal Plain, is the ease with which contamination may occur from fertilisers and other soluble materials. This should be considered in urban planning so that any major areas of groundwater use for public supply are upstream from any such source of contamination, and possible impact on wetlands is minimal.

3.4 Environmental management

Many areas in the State depend on groundwater for maintenance of the natural environment, particularly the wetlands and natural vegetation of the Swan Coastal Plain. Water level and quality are both extremely important parameters in this dependence. If wetlands and natural vegetation are to be protected and not degraded, it is essential that the understanding of these systems and their relationships to groundwater is improved.

With the increasing level of utilisation of groundwater resources, there is a need for a better understanding of the groundwater regimes required to sustain wetlands and their associated ecosystems. Lakes and swamps vary in their susceptibility to changes in watertable levels.

4 Status of groundwater investigation

4.1 Background

Groundwater resource investigation during the 1960s to early 1990s has permitted a qualitative understanding of the groundwater resources throughout most of Western Australia, and quantitative assessment in key areas. However, in the past decade, groundwater resource exploration and assessment programs in the State have been progressively reduced. There has been no groundwater exploration undertaken by government since 2000 and there have been only four new investigation bores drilled in the last eight years.

The level of groundwater investigation and assessment can be illustrated best by the number of metres drilled, rather than dollar expenditure that requires adjustment for inflation. Figure 2 highlights the amount of groundwater investigation drilling undertaken across the State from 1970 till 2004 (this excludes work specifically for metropolitan and country water supply).

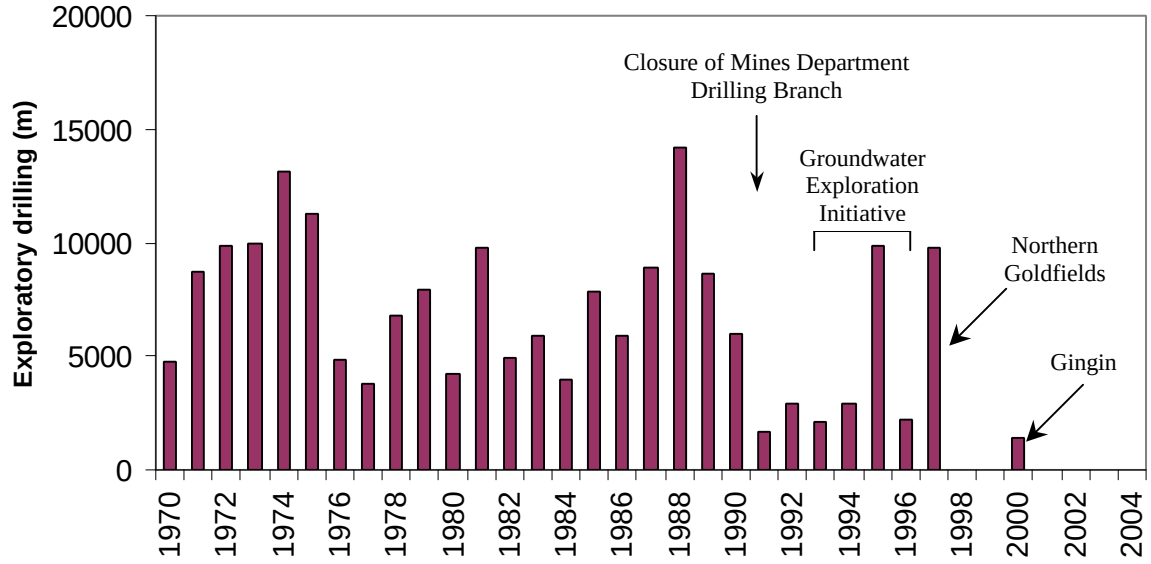

Figure 2. Drilling for groundwater resource assessment (1970 to 2004)

The following points should be noted:

- Until 1986, groundwater assessment in Western Australia was jointly funded by both the Commonwealth and State Governments. The cessation of funding by the Commonwealth resulted in the State Government increasing its contribution to make up the shortfall (WAWRC, 1989)

- The Department of Mines in October 1990 responded to Government budget restraints by suspending funds for exploratory drilling and closing the Drilling Branch (WAWRC, 1991).

- The limited drilling in 1991 and 1992 was funded largely through the disposal and sale of drilling assets.

- Following a recommendation by the Water Resources Council (WAWRC, 1991), special funding of $500 000 per year for groundwater assessment was approved by the incoming State Government in 1993. The investigation program was reinstated for 1993, 1994 and 1995 with the funding transferred from the Department of Minerals and Energy (DME) to the Water and Rivers Commission upon formation of the latter in 1996.

- Since 1996, there has been a significant reduction in the exploration and assessment of groundwater resources throughout the State. The only programs completed were ongoing exploration projects in 1996, drilling in the Northern Goldfields funded by Department of Resource Development during 1997, and the installation of monitoring bores around Gingin in 2000.

The decline in groundwater investigation has coincided with the period in which groundwater abstraction has essentially doubled. There are many groundwater management areas that are now either reaching or at their allocation limit, with these limits determined from the information from investigations undertaken in the 1970s and 1980s. In order for these allocation limits to be modified, it is imperative to gain improved knowledge and understanding of the groundwater resources.

4.2 The process of groundwater assessment

The aim of any groundwater resource assessment should be to have sufficient information to develop and manage groundwater. The amount of information needed, and therefore the degree of assessment, is dependent on the level of use of the resource and the level of management required. If the level of use is low, in relation to the preliminary assessment of sustainable yield, the information required may be of a low order. However, where the proposed abstraction is close to the assessed sustainable yield, an increased level of understanding and ability to monitor the groundwater system is required.

The first priority of an assessment is to achieve an understanding of the geology – to define aquifers and their relationships in three dimensions, which permits the allocation of abstraction to particular aquifers. The second priority is to understand groundwater flow and salinity distribution, as well as quantifying recharge and throughflow, in order to set initial allocation limits. The identification of recharge areas is important, both from the point of view of quantifying recharge, but also with the view to protecting water quality. In a similar way, identifying discharge areas is important for understanding groundwater-dependent ecosystems that may constrain groundwater development. Thirdly, this conceptual understanding of the groundwater environment is compiled into a numerical model, which will enable prediction of future water level changes under different water use scenarios. Ongoing monitoring of groundwater level changes is essential for understanding the impacts of abstraction and for calibration of the model.

There is always an element of uncertainty in geology, and regular review is important for determining where further data need to be collected, and/or how any new data change previous interpretations. The monitoring response, and ability to numerically model this response, will show whether the geological understanding is sufficient for the particular stage of development.

4.2.1 The key stages

There are a number of crucial stages in the design and implementation of a groundwater assessment program. It is important that the desired outcome is clear, so that investigations can be customised and an appropriate methodology can be undertaken. The main components of any groundwater resource assessment program are shown below on Figure 3.

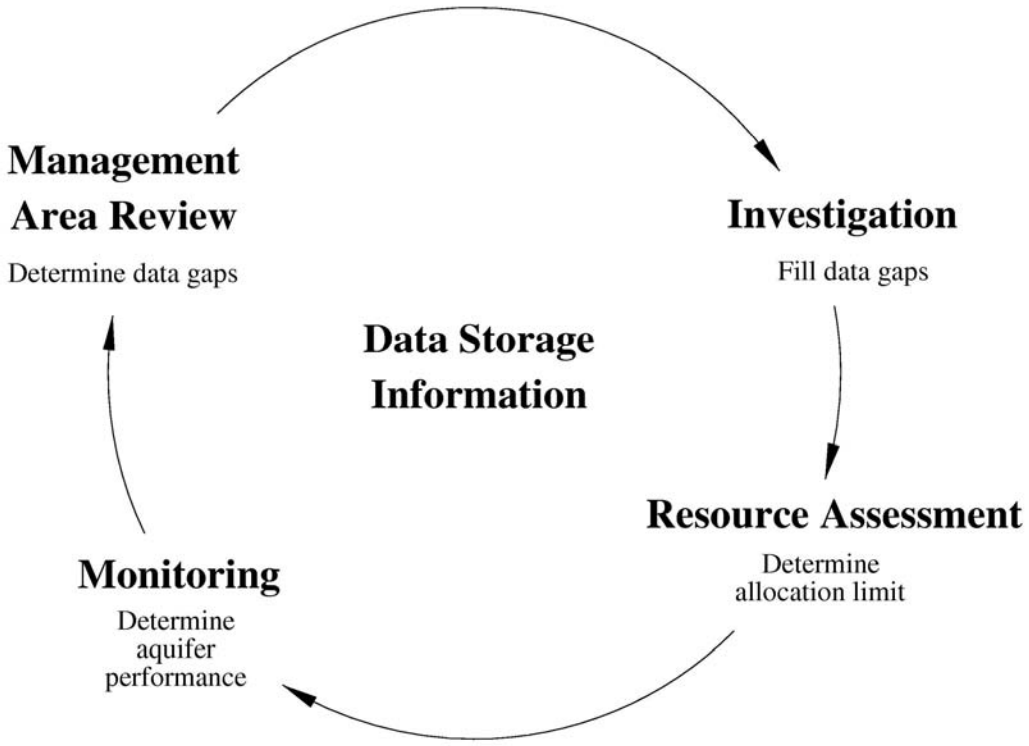

Figure 3. The groundwater resource assessment process

The **planning** stage aims to determine the appropriate level of assessment needed to manage a particular groundwater system, based on the analysis of existing data. Any gaps in the data are identified, and these must be filled through designing an appropriate investigation program and monitoring network.

In the **investigation** stage, the collection of field data is a major task that may entail a census or sampling of existing bores, and exploratory drilling. The basis of any groundwater resource assessment is the drilling of new boreholes to collect sufficient geological information for an improved understanding of the geology, and to fill previously identified information gaps. The drilling also allows completion of cased bores to measure water level and groundwater salinity, and to fulfil the need for appropriate monitoring facilities.

Pumping tests may also be appropriate in investigations, although this is only usually done to assess the potential for wellfield development. The pumping test proves bore yields, and resulting water level changes in observation bores indicate likely impacts of a future borefield. The hydraulic information is invaluable in numerical modelling, and is essential for assessment of a licence application for a borefield.

Quantitative assessment of the groundwater resource may be made on the basis of recharge or throughflow estimation. From these estimates, an initial allocation limit may be determined. Refinement of the allocation limit will be on the basis of monitoring results and groundwater flow

modelling. An allocation database enabling a groundwater use history to be attached to a particular location and depth is essential, in particular for calibrating a groundwater-flow model.

In the **monitoring** stage, there is the ongoing collection of time-series water level and water quality data. Monitoring is the only way to observe and evaluate aquifer performance. In most groundwater systems, it is important to monitor the high and low water levels, for instance four measurements a year (i.e. March, April, September, October) may adequately define the seasonal variation due to natural factors (rainfall recharge) and irrigation season. Aquifers dependent on periodic river flow from infrequent cyclonic storms often require a different strategy, as in the case of Carnarvon. The monitoring may provide baseline data, or show changes due to abstraction or land use change.

An essential part of the groundwater resource assessment process is **data storage, and the synthesis and dissemination of information**, which may be in the form of reports and maps. This information and further investigations undertaken by the private sector assists external proponents in their development of local-scale groundwater models for borefield design. Their outputs may then be fed back into the regional or subregional interpretations, which are maintained and used by the Department.

Review of new information is needed at regular intervals. Monitoring results should be reviewed annually, to gain advance warning of potentially unacceptable impacts, and to ensure that monitoring bores are performing as required. Periodic depth tagging of monitoring bores determines that the bore is open and not blocked, and assists in condition assessment of monitoring bores. New geological information from private bores may change interpretations and may necessitate changes to a groundwater flow model. More detailed subdivision of aquifers may also be appropriate.

Initial allocation limits are based on recharge or throughflow in the aquifer, but ultimately the allocation limit needs to be determined on the basis of acceptable impacts, such as water level change, or vegetation condition. Although the term ‘sustainable yield’ of an aquifer is often used, it is not a single quantity that can be determined in advance. Rather, it is the end point of allocation at which it is felt further allocation would be undesirable. The ‘sustainable yield’ will depend on the distribution of abstraction, and the impacts of that abstraction on water levels, groundwater salinity and groundwater-dependent ecosystems.

The Management Area Review process that is being developed and implemented in the Department will prove useful in identifying groundwater subareas across the State that require additional investigation. These reviews will utilise a variety of monitoring information to determine the hydraulic and environmental performance of any aquifer system. It is possible that the annual reviews will refocus and modify the investigation program by identifying short-term issues in groundwater subareas, such as increasing groundwater demand.

4.2.2 Levels of assessment

The Department of Environment assesses water allocation in relation to demand pressures. The level of utilisation as a proportion of the sustainable yield defines the level at which the groundwater resource unit should be managed. As the use category increases, the management response should be escalated to improve the knowledge and the management of this unit. The levels are based on a relative scale of management from 1 (low level of management) to 4 (high level of management), corresponding to each of the four categories of use listed in Table 1. The

management actions corresponding to each category are quite comprehensive and are provided in Appendix 1.

Table 1. Resource categories according to level of utilisation

Utilisation as % of sustainable yield	0-30%	30-70%	70-100%	>100%
Level of use category	C1	C2	C3	C4
Management response category	R1	R2	R3	R4

Groundwater investigation and assessment is a critical component in the water management process, as highlighted in Appendix 1. It is important to note that if groundwater investigation is insufficient, it will be impossible undertake the other components of water resource management. As a consequence, the level of management (i.e. investigation) response should match increases in utilisation. Thus a groundwater area at a C1 allocation level (0–30% of sustainable yield) should have an R1 level of investigation, whereas an area at C3 (70–100% of sustainable yield) should have an R3 level of investigation. The Divertible Water Allocation Inventory Database (DWAID) assigns the appropriate allocation and investigation level to each groundwater resource unit.

In some cases, the management of the groundwater resource unit can lag behind the desired level of management. These shortfalls in water resource management, referred to as a management gap, can be identified in DWAID by comparing the actual level of management of each groundwater resource unit against the desired level of management defined for each utilisation category. The management gap, as defined below, has been used for identifying groundwater resources units that required further investigation in Section 5.1.

Management gap = actual management response category – utilisation category

In a statewide context, resource assessment may be carried out at different levels ranging through reconnaissance, broad-scale and safe yield (WAWRC, 1991). These have been further defined as levels of management response (R1-R4), broadly related to the level of groundwater allocation used in the National Land and Water Resources Audit (WRC, 2000), and are summarised in Table 2.

Table 2. Actions required in groundwater management response

R1 Reconnaissance Investigation	**R2 Broad Scale Investigation**	**R3 Safe Yield and Environmental Hydrology**	**R4 Impact Assessment**
1 Using hydrogeological mapping and existing drilling information from baseline investigations	3 Major borefields in environmentally sensitive areas	8 Test pumping	11 Groundwater model
2 Regional estimates of recharge based on existing data from baseline investigation programs	4 Move to R3 criteria	9 Recharge measurement	12 Regular/ongoing assessment
	5 Targeted exploratory drilling	10 Groundwater age dating	13 Ecosystems hydrology investigation & modelling
	6 Recharge and throughflow estimates	• Groundwater modelling • Ecosystems hydrology investigation & modelling	
	7 Preliminary assessment of safe yield		

The increasing level of management response from R1 to R4 requires a significant increase in the workload and amount of resources allocated to the assessment process. Below is a summary of the minimum level of understanding that is required at the different levels of assessment.

R1 Outcome:

- A basic knowledge of aquifers, including their approximate extent, thickness and salinity distribution
- Monitoring for baseline water level response

R2 Outcome:

- Detailed knowledge of aquifers in major borefields, supported by monitoring and modelling
- Broad understanding elsewhere
- Monitoring close to major abstraction centres

R3 Outcome:

- Detailed knowledge of aquifers
- Monitoring throughout the area
- Understanding of water balance supported by recharge measurement, age dating etc.
- Determination of Groundwater Dependent Ecosystems
- Regional groundwater model, supported by pumping tests, to predict the effects of increased abstraction

R4 Outcome:

- Detailed understanding of hydrogeology
- Calibrated groundwater model that is able to predict the effects of abstraction
- Intensive water level monitoring, especially in environmentally sensitive areas

5 Identification of groundwater investigation areas

The development of the groundwater investigation program has attempted to address both short-term, immediate concerns and those which require more strategic planning. It is important that groundwater investigation is not solely reactive but has sufficient proactive, strategic focus to encourage broad regional development and to collect baseline data ahead of development. The program has focused on identifying areas of increased groundwater usage and those where existing groundwater information is insufficient for practical reassessment of groundwater resources. In order to achieve this objective, there are four areas of focus in the groundwater investigation: (1) Priority C3/C4 investigations, (2) Metropolitan investigations, (3) Statewide strategic investigation program, and (4) Regional assessments and groundwater dataset provision.

5.1 Priority C3/C4 investigation program

The priority C3/C4 investigation program addresses many of the short-term, reactive issues of the last five years, such as over-allocated groundwater subareas and the loss of appeals. This program is focused on those groundwater subareas throughout the State that are currently at C3 or C4 levels of usage (Table 3).

A methodology was developed to identify areas with high levels of usage, to provide comparison with current resource assessment, and to set priorities for the investigation program. The usage of DWAID has been important for identifying those groundwater resource units at C3 and C4 levels of usage. The complete list of groundwater resource units was extracted from DWAID and sorted into columns that highlighted the allocation limit, the current licensed allocation, and amounts of reserved allocations and new applications. A number of additional columns were introduced to explain how the allocation limit was determined, the resource response category, the management gap, and what further work is required to reduce the gap. A comment column was also included to provide the rationale for selecting groundwater resource units in the proposed investigation program.

The current allocation limits in DWAID have been estimated using four different methods. The most common is an estimation of rainfall recharge with surface area of the aquifer multiplied by a proportion of rainfall that may recharge the groundwater resource unit (i.e. area x rainfall x 10% recharging the aquifer). The allocation limit for some groundwater resource units within confined aquifers has been estimated using groundwater throughflow (i.e. the amount of groundwater moving through the aquifer system). A small number of groundwater resource units have allocation limits determined from groundwater modelling, such as the alluvial aquifer in Carnarvon and parts of the Collie Basin. The final method of determination is the setting of an arbitrary allocation limit, mainly in areas with fractured-rock aquifers, that accommodates groundwater usage in the medium term and reflects the complexity of the aquifer types.

The DWAID data were sorted to identify C3/C4 areas with management gaps of –2 and –3 throughout the State. Each groundwater resource unit was assessed to determine the extent of further investigation or assessment required. Many of the groundwater resource units are, or have been, reassessed as part of the existing work program, either through PRAMS (Perth Regional

Aquifer Modelling System), SWAMS (Southwest Aquifer Modelling System) or individual subarea assessments. A number of groundwater resource units did not warrant further investigation, such as where sufficient monitoring data exist for assessment, or those previously assessed and managed by other parties (Water Corporation, AqWest, etc.).

Groundwater resource units that are at C3/C4 levels of usage and warranted further investigation (either drilling and/or assessment) are summarised in Table 3. Detailed project proposals have been compiled for each investigation in Johnson et al. (2004), including a description of its allocation status, exploration required and cost estimates.

Table 3. Priority C3/C4 investigation areas

Project name	Groundwater area (subarea)	No. of bores required	Drilling (metres)	Staff cost ($ million)	Drilling and ancillary cost ($ million)	Project cost ($ million)
Allanooka Yarragadee	Arrowsmith (Allanooka)	18	6 300	0.48	1.77	2.25
Blackwood Yarragadee	Blackwood (Blackwood River)	20	5 200	0.50	1.11	1.61
Blackwood Lesueur / Leederville	Blackwood (Blackwood River)	8	1 800	0.30	0.46	0.76
Broome	Broome (12 Mile, Coconut Wells and Townsite)	-	-	0.10	-	0.10
Bunbury Yarragadee	Bunbury (Australind, Dardanup, Eaton, Stratham-Gelorup, Sth Bunbury)	4	1 200	0.12	0.28	0.40
Cowaramup Leederville	Busselton–Capel (Cowaramup)	12	1 500	0.20	0.39	0.59
Busselton–Capel Yarragadee	Busselton–Capel (Busselton – Chapman, Elgin – Capel River)	6	1 800	0.12	0.40	0.52
Derby Erskine	Derby (Rural, Derby Townsite)	-	-	0.10	-	0.10
Gingin Yarragadee	Gingin (SA1, SA3, SA5)	11	6 600	0.82	1.43	2.25
Gingin Mirrabooka	Gingin (Red Gully, Eclipse Hill, Gingin Townsite)	12	2 400	0.15	0.59	0.74
Gingin Leederville–Parmelia	Gingin (SA1, SA2, SA3, SA4, SA5 and SA6)	24	9 600	0.82	2.20	3.02
Gingin Superficial	Gingin (Seabird)	10	300	0.05	0.06	0.11
Jurien Leederville–Parmelia	Jurien (Dinner Hill)	10	2 500	0.30	0.59	0.89
Murray Leederville	Murray (Waroona)	20	4 000	0.30	0.94	1.24
Southwest Coastal Leederville	Southwest Coastal (Lake Preston, Myalup, Whitehills)	6	1 800	0.15	0.40	0.55
Southwest Coastal Superficial	Southwest Coastal (Falcon)	-	-	0.10	-	0.10
Total		**161**	**45 000**	**4.61**	**10.62**	**15.23**

5.2 Metropolitan investigation

There is increasing water demand and groundwater abstraction throughout the Perth metropolitan area. The Water Corporation has a number of borefields positioned in various aquifers ranging from the shallow superficial aquifer through to the deep Yarragadee aquifer to meet Perth's potable water requirements. There are large water users on the Gnangara Mound for vegetable production, as well as widespread abstraction by domestic garden bores and some small industry usage.

The groundwater resources in the metropolitan area are now managed, using regional groundwater models such as PRAMS, to assess potential impact from abstraction on water levels, groundwater

salinity and groundwater dependent ecosystems. To achieve this aim, the two main areas of focus in the metropolitan investigation are (1) improving and upgrading the existing monitoring network and (2) undertaking new investigation in areas of poor understanding and/or poor calibration of PRAMS. Table 4 outlines the main projects that warrant further investigation in the metropolitan area.

Table 4. Metropolitan investigation areas

Project name	Type	No. of bores	Drilling (metres)	Staff cost ($ million)	Drilling and ancillary cost ($ million)	Cost ($ million)
Monitoring network – Superficial	Inv. drilling	20	1 000	0.10	0.16	0.26
Monitoring network – Leederville	Inv. drilling	10	5 000	0.35	1.09	1.44
Monitoring network – Yarragadee	Inv. drilling	4	4 000	0.25	0.91	1.16
Deep Yarragadee	Inv. drilling	2	3 000	0.30	0.96	1.26
Serpentine Fault	Inv. drilling / modelling	8	4 000	0.30	0.89	1.19
Kings Park Formation	Inv. drilling / modelling	4	2 400	0.38	0.51	0.89
Gnangara North	Inv. drilling / modelling	31	3 050	0.10	0.60	0.70
Total		**79**	**22 450**	**1.78**	**5.12**	**6.90**

Improvement to monitoring network – There is an ongoing demand for upgrading and improving the monitoring network throughout the metropolitan area. At present, there are many gaps in the existing monitoring network leading to difficulties in groundwater resource management. A recent review of the groundwater monitoring network (Aquaterra, 2004) recommended that an additional 34 bores would be required to improve monitoring of the Superficial, Leederville and Yarragadee Aquifers.

Deep Yarragadee – At present, there is little information on the lower sections of the Yarragadee Aquifer in the metropolitan area. The Water Corporation has been utilising groundwater from the Yarragadee in the northern metropolitan area around Wanneroo. It is recommended that a bore is drilled to the base of the Yarragadee Aquifer (approx. 1500 m in depth), while another bore could be drilled on Rottnest Island to determine water quality (fresh, brackish or saline) and calibrate the western boundary of PRAMS.

Serpentine Fault – A recent drilled bore at Champion Lakes, which encountered quite different hydrogeological conditions from those predicted, highlighted the poor knowledge of the area. Further work is required in the vicinity of the Serpentine Fault, in particular understanding water quality in the Cattamarra Coal Measures and Yarragadee Aquifer. Additional drilling to the west of the Serpentine Fault will determine if the fault acts as a conduit for westward-moving groundwater and, if so, whether fresh water is present beneath the brackish groundwater in the Yarragadee Aquifer.

Kings Park Formation – The extent and hydraulic function of the Kings Park Formation is poorly understood. It is proposed that two drill transects, required to investigate the hydrogeology of the onshore Kings Park Formation, would assist in developing a conceptual understanding of its offshore distribution, connection with underlying aquifers, and the potential risk of saline intrusion.

Gnangara North – There is a poor understanding of the hydrogeology related to the Gingin Brook, particularly in the lower portion west of Brand Highway. A number of drill transects are required to identify the hydraulic connection between the Superficial and Leederville Aquifers, and to ascertain whether the unconfined Leederville Aquifer is a major source of recharge.

5.3 Statewide strategic investigation

This component of the investigation program aims to be proactive and strategic in groundwater resource investigation through the collection of baseline data in areas where little is known, but where there are potential groundwater resources. The strategic program aims to identify areas for new investigation throughout the State (Fig. 4), in particular areas where new information may facilitate State or regional development. Current water demand in many of these areas is low; however, the identification of large, low-salinity groundwater resources may potentially lead to regional expansion.

The investigations will be at a regional scale comprising widely spaced, exploratory drill holes that will provide a broad understanding of aquifer distribution and extent. Most of the investigation sites are located in remote parts of the State. The new data will be important in the completion of regional assessments and in generating groundwater datasets (to be discussed in Section 5.4). The selection of strategic investigation areas is based on the lack of groundwater information and potential for future development. Table 5 outlines the main projects in the strategic investigation and there is further discussion on the objective of each project below.

The following statewide strategic projects have been identified:

- Canning Basin – Investigation drilling will be required in the La Grange–Broome area if the current cotton proposal fails. There is a significant resource of low-salinity groundwater in the desert with potential for large-scale agricultural development. It would be difficult for a private company to investigate due to political constraints.

- Officer Basin – This program will investigate the potential for fresh (potable) groundwater resources along the Great Central Road. New access will assist potential development of groundwater resources in the Gibson and Great Victoria Deserts. The resource could be considered significant, although the water may be fossil or ancient.

- Eucla Basin – Investigate the potential groundwater resource near Lake Boonderoo on the western margin of the Eucla Basin. The resource has been previously mentioned in reports (Goldfields Esperance Water Supply – Water Supply Strategy) as a potential source for Kalgoorlie. The area is unexplored and investigation is required to determine whether there is groundwater resource potential or not.

- Murchison Palaeochannels – Investigate the possible presence of Tertiary palaeochannels in the Murchison River Catchment, and the potential for water resource development. It is possible that there are low-salinity groundwater resources in palaeochannels up-gradient of salt lakes, and this may have implications for understanding salinity of the Murchison River and associated alluvial aquifers.

ID	Project name
1	Canning Basin
2	Officer Basin
3	Eucla Basin
4	Murchison Palaeochannels
5	Eastern Carnarvon Basin
6	Northern Canning Basin
7	Bonaparte Basin
8	Northern Perth Basin - Ajana
9	Western Carnarvon Basin

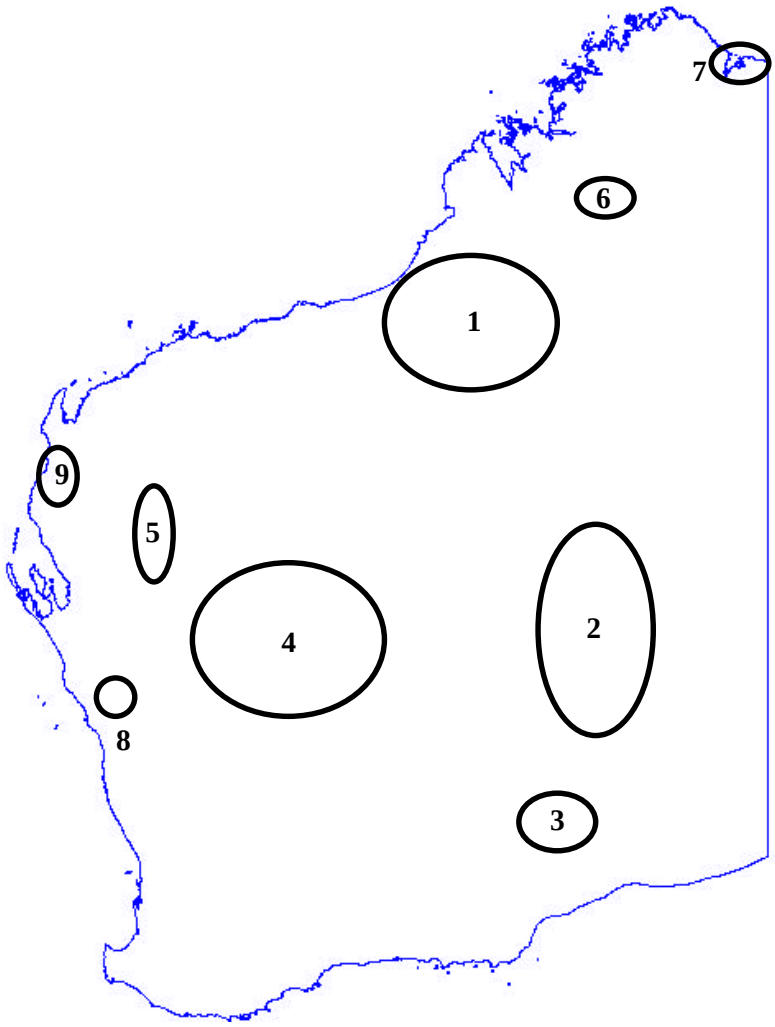

Figure 4. Location map showing strategic investigation programs

Table 5. Statewide strategic investigation areas

Project	No. of bores	Drilling (m)	Staff costs ($ million)	Drilling and ancillary costs ($ million)	Cost ($ million)
Canning Basin	6	3 000	0.15	0.70	0.85
Officer Basin	8	1 500	0.15	0.35	0.50
Eucla Basin	4	1 000	0.10	0.15	0.25
Murchison Palaeochannels	50	3 000	0.30	0.70	1.00
Carnarvon Basin – Birdrong Sandstone	4	500	0.08	0.12	0.20
Northern Canning Basin	6	2 500	0.18	0.64	0.82
Bonaparte Basin	2	500	0.08	0.12	0.20
Northern Perth Basin – Ajana	4	500	0.10	0.15	0.25
Carnarvon Basin – alluvium	50	1 250	0.15	0.30	0.45
Total	**134**	**13 750**	**1.29**	**3.23**	**4.52**

- Carnarvon Basin – Investigate low-salinity groundwater resources in the Birdrong Sandstone. It is possible that there is low-salinity groundwater along the eastern margin, which may prove a useful resource in areas of very low rainfall.

- Northern Canning Basin – Investigate and obtain some baseline data on the potential groundwater resources in the Palaeozoic aquifers along the northern margin of the Fitzroy Trough. There are few existing data but there are likely to be significant fresh groundwater resources.

- Bonaparte Basin – Drill a number of bores to assess the potential groundwater resource in the Permian sandstone on the coast, north of Kununurra. There are likely to be significant fresh groundwater resources near the coast and extending eastward into the Northern Territory. It will be important to review bore information for the Northern Territory.

- Northern Perth Basin – Ajana – Investigation drilling of the Tumblagooda Sandstone, east of the Northampton Complex, to assess the groundwater resources potential. The resources are poorly understood but it is likely that groundwater will be brackish. The area, which is agricultural, has a potential demand for groundwater supply from the aquifer.

- Carnarvon Basin alluvium – Assess the potential for groundwater resources associated with the Yanarie, Lyndon and Minilya Rivers. The investigation will require an EM (electromagnetic) survey for site selection, to be followed by a shallow drilling program.

5.4 Regional assessment and groundwater dataset provision

There is a requirement to provide regional assessments of groundwater resources and interpreted groundwater datasets to the Department, industry and public. The program aims to synthesise regional groundwater information via the preparation of GIS layers and datasets, which will have the added advantage of improving data quality stored in the Water Information (WIN) database.

There is an ongoing need for the synthesising of all groundwater information throughout the Perth Basin, as per GSWA Bulletin 142 for the Metropolitan Region by Davidson (1995). Another component of the program is to recommence the systematic hydrogeological mapping of the State, using a GIS format rather than paper-based maps.

The reports will detail the basic information obtained from investigation projects, groundwater licence data and other sources of information. The main beneficiaries will be mining companies, farmers and other industries requiring information on groundwater resources to assist them in their water supply developments. The reports will also provide a documented record that would be available for re-interpretation as regional understanding changes.

Hydrogeological maps and geographic information datasets synthesising data from existing bores, investigation projects, infrastructure, cultural features and water-dependent environmental features need to be produced. Hydrogeological maps at 1:250 000 scale have been produced for the Goldfields, Albany-Esperance, and Broome-Derby areas. It may be appropriate to compile maps at 1:100 000 scale for the Perth Basin and other areas of intensive groundwater abstraction, with maps at 1:250 000 scale sufficient for areas with large, low-salinity groundwater resources and for existing and prospective mining areas and farming regions. These maps will provide the base for a

new State Hydrogeological Map depicting the location of groundwater resources and where they are currently being developed.

The hydrogeological mapping would be carried out in parallel with investigation projects described above and underpin the preparation of management plans (refer Section 6). The use of the latest geographic information system and computer-aided drafting techniques will enable the mapping to be done efficiently

The main areas, shown on Figure 5, that have been identified for regional assessment and groundwater dataset provision are:

- Perth Basin ($500 000) – Prepare reports on the northern and southern Perth Basin to complement GSWA Bulletin 142 (Davidson, 1995), or complete a basin-wide publication that incorporates the metropolitan area.

- Goldfields ($350 000) – Complete hydrogeological maps for the Wiluna, Edjudina, Menzies, Lake Johnston and Norseman 1:250 000 sheets to finalise coverage of the Goldfields Region.

- Murchison ($350 000) – Prepare regional maps and description of the Murchison Region to encompass mining areas from Yalgoo to Meekatharra. This regional mapping program must be linked to drilling of the palaeochannels in the Murchison area, as outlined in the strategic drilling program.

- Musgraves ($75 000) – Report on groundwater prospects for newly emerging nickel provinces.

- Pilbara ($400 000) – Mapping and description of the Pilbara Craton and Pilbara coast.

- Eucla ($100 000) – Compilation of data, mapping and publication of report. This regional assessment must be linked to the drilling on the western margin of the Eucla Basin, as outlined in the strategic drilling program.

ID	Regional assessment areas
1	Perth Basin
2	Goldfields
3	Murchison
4	Musgraves
5	Pilbara
6	Eucla

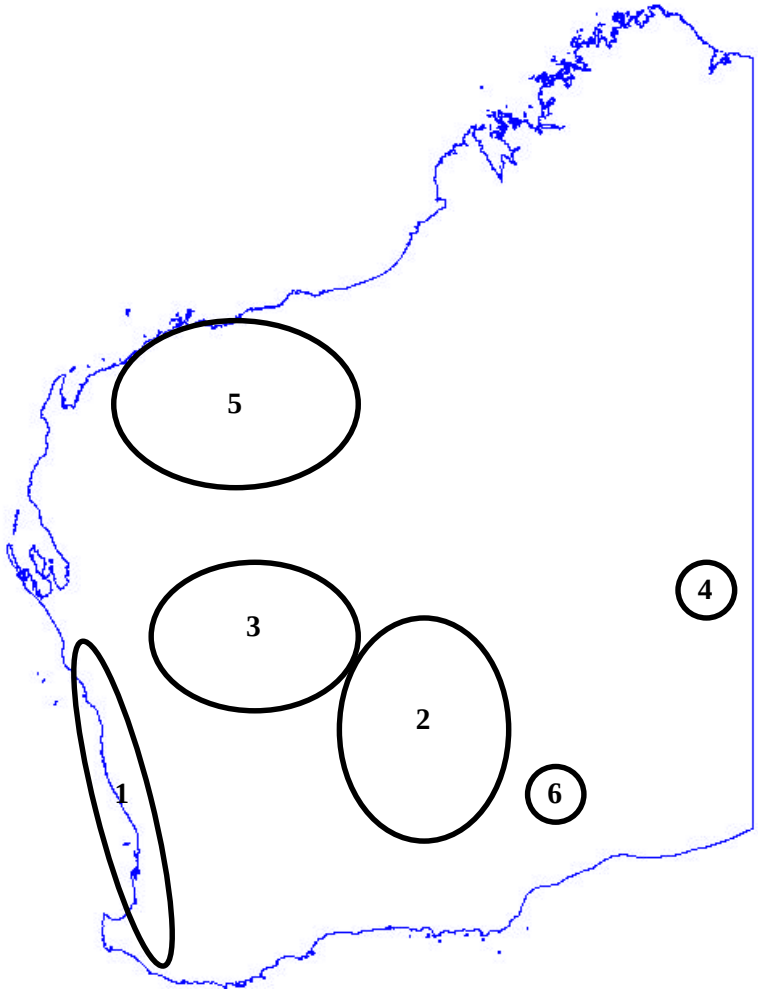

Figure 5. Location map showing regional assessment areas

6 The investigation program

6.1 Program costs and benefits

A rigorous financial analysis of the value to the State of the current groundwater use has yet to be carried out, and the value of groundwater has not yet become apparent through trading of water entitlements. However, the value of additional groundwater allocated with the additional investigation and monitoring bores will far outweigh the capital cost of the monitoring infrastructure.

The progressive shift in water entitlements to higher value uses, and the ability to manage water resources on the basis of a share of the available resources, requires adequate knowledge of the resources. This knowledge can only be acquired through groundwater investigations and assessment. Unquantifiable benefits are as follows:

- better data will enable the agency to achieve its vision of sustainable use of natural resources;
- better groundwater management will assist the water utilities and other natural resource management agencies;
- on a statewide basis, the main effect will be in areas where groundwater is used from regional (sedimentary) aquifers. This applies primarily to the Perth Basin, between Geraldton and Augusta, but also to the regional centres of Albany, Esperance, Carnarvon, Broome and Derby;
- most of the economy of Western Australia is underpinned by the availability of groundwater resources for domestic, agricultural, industry, and mining sector use;
- the social implications of improved groundwater management are security of supply and long-term sustainability; and
- the benefits of improved groundwater management and efficient use of the State's groundwater resources will be distributed across the community primarily through the economic activity of the agricultural and mining sectors.

An important benefit of the reinstating of the groundwater investigation will be the rebuilding and retention of intellectual property in the Department. Since the formation of the Water and Rivers Commission, a number of hydrogeologists have sought other employment, resulting in a loss of intellectual property. It is necessary for the Department of Environment to have groundwater professionals contributing to its water management process and the investigation process would be an ideal training ground for rebuilding hydrogeological expertise within government.

6.2 Funding

The investigation program has been costed over a 15 year period with appropriate funding levels to ensure adequate staff and resources to undertake the proposed work. The program has been designed to ensure a constant split between funding used by the Department and that for external purposes. Over the 15 years, the investigation program has a total envisaged expenditure of $28.4 million, which comprises $9.4 million for Departmental purposes (one-third of total expenditure) and $19 million for external contractors (the remaining two-thirds). This funding split is similar to that of the previous investigation program within the former Department of Minerals and Energy.

Table 6 shows the allocation of funding across the broad categories of salaries, ancillary and drilling costs for each investigation project. The salary component will used by the Department of Environment for salaries and supplementary support in data collection and storage. The ancillary component will fund various external contractors that will support the program through the undertaking of groundwater sampling, geophysical surveys (surface or downhole) and/or palynological studies. The drilling estimates will cover external drilling contractors to undertake the drilling and installation of the new monitoring bores.

In recent times, there has been much discussion on the funding of groundwater management in the State. There have been proposals to raise finance from water resource management fees (bore licensing) and to put the onus on new groundwater licensees to provide funding for the monitoring bore network. However, Cabinet has decided not to implement water resource management charges. It is considered that the preferred option is central funding, as had been done before 1996, and as specifically recommended by the Water Resources Council (1991).

The estimated number and aggregate depth of bores required, as part of the investigation program, are given in Table 6. The actual number of bores and depths drilled will vary in practice, depending on the hydrogeological conditions encountered. Nonetheless, the estimates are useful in providing a basis for determining the cost and time needed to complete the proposed investigation program.

6.3 Timing

The investigation program has been designed over a 15 year period from 2005 to 2020, although it is considered that additional investigations will be continually required beyond 2020. The timeline has been developed through consultation with staff from Allocation Branch who are responsible for water resource planning. The consultation attempted to prioritise projects that are of short-term importance (e.g. Metropolitan – Gnangara, and SW Yarragadee) and those projects that are more strategic for regional development (e.g. Cowaramup and Allanooka). As a result, the investigation program will complement the current and future management of the State's groundwater resources. The selection of projects has also considered water resource planning commitments by the State Government, as part of the National Competition Council requirements.

Table 6. Project details for the investigation program

Project name	Type of investigation	No. of bores	Metres drilled	Salaries $	Ancillary $	Drilling $	Project cost ($)
Monitoring network - Superficial	Metro	20	1,000	100,000	24,100	133,800	257,900
Gingin Superficial	C3/C4	10	300	50,000	18,100	39,200	107,300
Monitoring network - Yarragadee	Metro	4	4,000	250,000	60,700	805,000	1,115,700
Gnangara North	Metro	31	3,050	100,000	75,900	528,400	704,300
Deep Yarragadee	Metro	2	3,000	300,000	59,900	896,300	1,256,200
Cowaramup Leederville	C3/C4	12	1,500	200,000	52,100	339,200	591,300
Monitoring network - Leederville	Metro	10	5,000	350,000	84,600	1,010,300	1,444,900
Eucla Basin	Statewide	4	1,000	100,000	50,000	100,000	250,000
Gingin Mirrabooka	C3/C4	12	2,400	150,000	78,000	516,100	744,100
Allanooka Yarragadee	C3/C4	18	6,300	475,000	105,800	1,665,300	2,246,100
Kings Park Formation	Metro	4	2,400	375,000	66,300	457,600	898,900
Murray Leederville	C3/C4	20	4,000	300,000	87,800	848,600	1,236,400
Gingin Leederville	C3/C4	24	9,600	825,000	229,500	1,964,100	3,018,600
Gingin Yarragadee	C3/C4	11	6,600	825,000	164,800	1,264,600	2,254,400
Blackwood Lesueur / Leederville	C3/C4	8	1,800	300,000	69,200	391,500	760,700
Blackwood Yarragadee South	C3/C4	20	5,200	500,000	96,300	1,015,500	1,611,800
Serpentine Fault	Metro	8	4,000	300,000	77,100	809,700	1,186,800
Murchison Palaeochannels	Statewide	50	3,000	300,000	100,000	600,000	1,000,000
Bunbury Yarragadee	C3/C4	4	1,200	125,000	30,300	246,200	401,500
Busselton–Capel Yarragadee	C3/C4	6	1,800	125,000	36,000	362,300	523,300
Northern Perth Basin - Ajana	Statewide	4	500	100,000	50,000	100,000	250,000
Jurien Leederville-Parmelia	C3/C4	10	2,500	300,000	75,500	517,300	892,800
Carnarvon Basin - Birdrong	Statewide	4	500	75,000	25,000	100,000	200,000
Officer Basin	Statewide	8	1,500	150,000	50,000	300,000	500,000
Carnarvon Basin - alluvium	Statewide	50	1,250	150,000	50,000	250,000	450,000
Southwest Coastal Leederville	C3/C4	6	1,800	150,000	39,600	362,400	552,000
Southwest Coastal Superficial	C3/C4	-	-	70,000	70,000	70,000	100,000
Canning Basin	Statewide	6	3,000	150,000	100,000	600,000	850,000
North Canning Basin	Statewide	6	2,500	175,000	75,000	575,000	825,000
Broome	C3/C4	-	-	100,000	0	0	100,000
Derby	C3/C4	-	-	100,000	0	0	100,000
Bonaparte Basin	Statewide	2	500	75,000	25,000	100,000	200,000
Regional Assessment							
Perth Basin	Reg. Ass.			500,000	0	0	500,000
Goldfields	Reg. Ass.			350,000	0	0	350,000
Murchison	Reg. Ass.			350,000	0	0	350,000
Musgraves	Reg. Ass.			75,000	0	0	75,000
Pilbara	Reg. Ass.			400,000	0	0	400,000
Eucla Basin	Reg. Ass.			100,000	0	0	100,000
Totals		**374**	**81,200**	**9,420,000**	**2,126,600**	**16,968,400**	**28,405,000**

The lack of groundwater investigation in the past decade has seen the State fall behind in its water resource management, and there is a backlog of investigations required to catch up with current water resource allocations. There are a number of groundwater investigations that warrant a high priority, particularly in groundwater subareas with rapidly increasing demand, licence allocations at sustainable limits, and community concern related to environmental impacts from abstraction.

Table 7 shows the timeline and related annual expenditure for the investigation program. Most of the projects in the first three years are focused on the metropolitan area and horticultural districts (e.g. Gingin and Cowaramup) throughout the Perth Basin. The strategic groundwater investigations are progressively introduced in the fourth year to provide a more balanced, statewide assessment. The undertaking of the regional assessment program will be dependent of the completion of the strategic investigations, and as such are timed to either coincide or closely follow the completion of drilling.

6.4 Resources

6.4.1 Staff levels

In order to complete the investigation program, it is necessary that there be adequate staff available with the appropriate skills. The investigation program will require the employment of six new staff including a supervising hydrogeologist (Level 7), three hydrogeologists (Level 2/4), a groundwater modeller (Level 6) and a drilling supervisor (Level 5). To ensure adequate staff training and planning of the program, it is anticipated that it will take one year to reach the full staffing levels.

The recruitment of appropriately skilled staff has been identified as a possible constraint on the rapid implementation of the investigation program. The recent increase in mining and economic development throughout the State has resulted in a shortage of hydrogeological expertise with many groundwater consultants actively recruiting from overseas. The shortage of hydrogeologists is a major problem for the water industry, and this has been discussed previously with the Minister for Environment through the International Association of Hydrogeologists.

Personnel are required to possess knowledge of drilling methods and the ability to write specifications, approve and supervise contracts, and possess hydrogeological skills to collect and interpret the hydrogeological data. These skills are currently held within the Department and can be passed on with the appropriate training. The drilling of new bores and addition to the network was previously standard procedure, and no major change is needed to either working practices or existing systems. Accountability will be with the Manager, Hydrology and Water Resources Branch.

6.4.2 Internal support

The investigation program will also require computing support to assist in data handling, storage and processing. All information that is generated from the program will be entered and stored in the WIN database. Cost estimates related to this function have been incorporated into the project budget.

Table 7. Cost schedule for the investigation program

Project name	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Project
	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	Cost
Monitoring network - Superficial	257,900															257,900
Gingin Superficial	107,300															107,300
Monitoring network - Yarragadee		1,115,700														1,115,700
Gnangara North		352,100	352,200													704,300
Deep Yarragadee			601,800	654,400												1,256,200
Cowaramup Leederville		301,100	290,200													591,300
Monitoring network - Leederville			751,200	693,700												1,444,900
Eucla Basin	250,000															250,000
Gingin Mirrabooka						380,800	363,300									744,100
Allanooka Yarragadee				748,600	1,497,500											2,246,100
Kings Park Formation					463,200	435,700										898,900
Murray Leederville						1,236,400										1,236,400
Gingin Leederville							965,000	1,026,800	1,026,800							3,018,600
Gingin Yarragadee							757,200	749,800	747,400							2,254,400
Blackwood Lesueur / Leederville										381,600	379,100					760,700
Blackwood Yarragadee Sth										800,900	810,900					1,611,800
Serpentine Fault										597,200	589,600					1,186,800
Murchison Palaeochannels												550,000	450,000			1,000,000
Bunbury Yarragadee												401,500				401,500
Busselton-Capel Yarragadee													523,300			523,300
Northern Perth Basin - Ajana												250,000				250,000
Jurien Leederville-Parmelia													450,600	442,200		892,800
Carnarvon Basin - Birdrong												100,000	100,000			200,000
Officer Basin														300,000	200,000	500,000
Carnarvon Basin - alluvium														225,000	225,000	450,000
Southwest Coastal Leederville														278,500	273,500	552,000
Southwest Coastal Superficial															100,000	100,000
Canning Basin												425,000	425,000			850,000
North Canning Basin															825,000	825,000
Broome														100,000		100,000
Derby															100,000	100,000
Bonaparte Basin															200,000	200,000
Perth Basin	200,000	300,000														500,000
Goldfields										175,000	175,000					350,000
Murchison														300,000	50,000	350,000
Musgraves												75,000				75,000
Pilbara												100,000		300,000		400,000
Eucla Basin	100,000															100,000
Annual totals	**915,200**	**2,068,900**	**1,995,400**	**2,096,700**	**1,960,700**	**2,052,900**	**2,085,500**	**1,776,600**	**1,774,200**	**1,954,700**	**1,954,600**	**1,901,500**	**1,948,900**	**1,945,700**	**1,973,500**	**28,405,000**
Cumulative totals	**915,200**	**2,984,100**	**4,979,500**	**7,076,200**	**9,036,900**	**11,089,800**	**13,175,300**	**14,951,900**	**16,726,100**	**18,680,800**	**20,635,400**	**22,536,900**	**24,485,800**	**26,431,500**	**28,405,000**	

6.4.3 External contractors

The drilling and installation of new monitoring bores will be achieved by competitive tendering in accordance with established procedures. Each project will be implemented by firstly planning on a project basis in which the geographical area, depth of drilling and type of bore construction are suitable for a single contract. Authority would be sought from the relevant landowner or agency and the necessary heritage clearance sought for drilling. Department personnel would supervise specialist drilling contractors.

A number of other contractors would be required on occasions as part of the investigation program. There may be need for geophysical contractors to undertake surface-based geophysical surveying to refine drilling targets, as well as downhole geophysical logging to determine the vertical change in lithology and groundwater salinity. Other contractors will be required to undertake isotopic dating of water samples and age dating of sediments via palynological analysis.

6.5 Program outputs and outcomes

Information from the program projects will be in the form of hydrogeological reports on groundwater resources, and the monitoring program will generate individual bore hydrographs (water levels) which are valuable to other groundwater users. The monitoring data will assist the Department in its obligation to manage groundwater in a sustainable manner under statutory allocation plans. The additional data will result in improved decisions on allocation limits, granting of individual licences, and allowance of groundwater trades. Benefits from improved data should result in reduced costs associated with appeals against licence decisions, since with better data those decisions will be defensible.

Most of the monitoring bores are needed in the Perth Basin where there is 749 GL/yr of groundwater use (1999 figures). A nominal value of 10c/kL placed on that usage is $75 million/yr, not accounting for the economic activity generated by that groundwater use. The benefits in sustaining or increasing that level of use outweigh the costs of the monitoring network. Risks are involved with land access, drilling safety, and integrity of the completed bores. Those risks are known and can be adequately identified and managed.

6.6 Stakeholder awareness

Responsibility for the planning and implementation of the groundwater investigation program will rest with the Department of Environment. The investigation will be undertaken in regular consultation (e.g. March of each year) with various government and industry stakeholders to ensure the relevance of the program to the State's need. The main stakeholders are the Water Allocation Branch and regional offices in the Department of Environment, Water Corporation, Department of Industry and Resources, Mining and Water Liaison Committee (Chamber of Mines and Association of Mining Exploration Companies) and the International Association of Hydrogeologists. Regional NRM groups should be encouraged to identify with investigations and monitoring activities that will support the objectives of regional programs.

7 Conclusions

A groundwater resource investigation program in Western Australia is required; because of the variable distribution and quality of the State's water resources: to expedite planning; to encourage industrial and agricultural development; and to allow effective and sustainable environmental and water resource management.

Groundwater investigation and monitoring underpins the sustainable management of groundwater resources across the State. The acquisition and interpretation of information for planning and management relies on investigation programs and monitoring for a scientific understanding of the sustainability of groundwater systems. The Department's role in sustainability assessment can only be maintained if information and strategies/systems are well integrated within projects and with stakeholder information needs and sources.

A groundwater investigation program has been formalised over a 15 year period from 2005 until 2020. The program has attempted to address short-term, immediate concerns through to more strategic planning to promote regional development. The focus of the program has been to identify areas of increased groundwater usage, and/or those where existing groundwater information is currently too poor to permit reassessment of groundwater resources.

The first three years of the program, determined through consultation, is focused on the metropolitan area and horticultural districts (e.g. Gingin and Cowaramup) throughout the Perth Basin. The strategic groundwater investigations are progressively introduced in the fourth year to provide a more balanced, statewide assessment.

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Appendix 1 — Management response actions for each category

Response Criteria

1. Resource Investigation and Monitoring							
Groundwater				Surface Water			
1.1. Resource Investigation (for establishment of allocations)				**1.1. Resource Investigation (for establishment of allocations)**			
R1 Reconnaissance Investigation	**R2 Broad Scale Investigation**	**R3 Safe Yield and Environmental Hydrology**	**R4 Impact Assessment**	**R1 Reconnaissance & Desktop Yield Studies**	**R2 Broad Scale Investigation**	**R3 Detailed Invest. and Environmental Hydrology**	**R4 Impact Assessment**
Using hydrogeological mapping and existing drilling information from baseline investigations Regional estimates of recharge based on existing data from baseline investigation programs	Major borefields in environmentally sensitive areas to R3 criteria Other borefields and self supply -Targeted exploratory drilling - Recharge and throughflow estimates - Preliminary assessment of safe yield	Test pumping Recharge measurement Groundwater age dating Groundwater modelling Ecosystems hydrology Investigation & modelling	Groundwater model Regular/ongoing assessment Ecosystems hydrology investigation & modelling	Simple water balance and assessment based on regional stream gauging & relationships Usually based on - Storage assessments from available topographical maps - Divertible yields based on regional storage yield data or annual flow duration data	Catchment-wide hydrological studies to support yield estimates and estimation of downstream effects For major developments - Use R3 criteria For medium-sized developments - Divertible yield estimates from site specific studies - Standard simulation models using at least 30 years of extended flows For development via numerous small dams or diversions - Divertible yields based on R1 level data and monthly or other low flow estimation techniques	Detailed hydrological studies to support yield estimates and ecological studies For medium to large developments - Full scale field investigations - Accurate streamflow data and stochastic flow generation - Operationally realistic simulation models for yield assessment - Ecosystems hydrology investigation & modelling For developments via numerous small dams or diversions - Divertible yields based on monthly or seasonal low flow data extended to at least 30 years - Hydrological assessment of effects on ecosystems	Detailed hydrological studies to support impact assessment and revision of allocations - Full scale field investigations - Accurate streamflow data and stochastic flow generation - Operationally realistic simulation models for yield assessment - Ecosystems hydrology investigation & modelling - Problem specific investigation and modelling relating to environmental and resource recovery
1.2. Water Resource Monitoring (for investigating and managing allocations)				**1.2. Water Resource Monitoring (for investigations and managing allocations)**			
R1 Broad Surveillance	**R2 Main Parameters**	**R3 Comprehensive**	**R4 Recovery**	**R1 Broad Surveillance**	**R2 Main Parameters**	**R3 Comprehensive**	**R4 Recovery**
Drilling and monitoring programs of low spatial and temporal intensity Pump testing and related studies to support preliminary assessment of sustainable yields	Drilling and monitoring programs of medium spatial and temporal intensity Monitoring to support data requirements of simple models.	Drilling and monitoring programs of high spatial and temporal intensity Expanded monitoring criteria Support data requirements for comprehensive review of sustainable yield	Very high spatial and temporal intensity Monitoring to support impact assessment and resource recovery	Periodic reconnaissance surveys Spot measurements and use of regional data Operation of a long-term baseline hydrological network	Where large dams are likely - Major dams to R3 criteria Small to medium dams or small diversions - Refinement of hydrology to update yield estimates - Initiate baseline flow and biological monitoring of ecosystems - Operation of a hydrological network with full range of catchment types and sizes, supplemented by spot measurements	Refine observations and models for more precise review of yield and for resolving user disputes Monitor potential environmental impacts identified in impact assessments Specifically monitor downstream impacts on water quantity & quality Hydrological network complemented with special purpose stations and spot investigations as required	Refine observations and models for more precise reviews of yield recovery options and key impact areas Monitor key impacts of over-use and benefits of recovery Ensure appropriate response to monitoring Hydrological network complemented with special purpose stations and specific investigations

Response Criteria (cont..)

2. Allocation Planning & Sustainable Limits							
Groundwater				Surface Water			
2.1. Allocation Planning [1]				**2.1. Allocation Planning[1]**			
R1 General Guidelines	**R2 Broad Scale Plans**	**R3 Comprehensive Sub- Regional and Management Area Plans**	**R4 Recovery**	**R1 General Guidelines**	**R2 Broad Scale or Regional Plans**	**R3 Comprehensive Subregional and Management Area Plans**	**R4 Recovery**
Allocations defined through regulation of use - no formal management area planning Beneficial values for major groundwater resources for the region may be defined in regional plans	Existing Plans - Large scale in nature with broad subarea definition written within last 10 years Future plans - Prepared in consultation with Local Water Resource Committees or other apt consultation processes referred to EPA and advice or requirements included - Progression to finer definition of subareas and R3 considerations as demand increases	Comprehensive subregional plans (defining management areas in their fuller context) *OR* Management Area Plans Plans written or reviewed within the last 5 years New plans prepared in consultation with Local Water Resource Committees or other apt consultation processes EPA formal assessment and clearance	Detailed subarea management plans written or reviewed within the last 5 years New plans prepared in consultation with Local Water Resource Committees and/or local community EPA assessment Strategy planning giving reductions of use to sustainable levels Annual review of reduction strategy	Allocation decisions defined through regulation of use (3.1) - no formal management area planning Beneficial values of major surface water resources may be defined in regional plans	Broad or regional scale management plan written or renewed within last 10 yrs Future plans prepared in consultation with Local Water Resource Committees or other apt consultation processes referred to EPA and advice or requirements included	Comprehensive subregional plans (defining management areas in their fuller context) *OR* Management Area Plans written or reviewed within the last 5 years New plans prepared in consultation with Local Water Resource Committees or other apt consultation processes EPA formal assessment and clearance Required for all proposed large dams	Detailed subarea management plans written or reviewed within the last 5 years New plans prepared in consultation with Local Water Resource Committees and/or local community EPA assessment Strategy planning giving reductions of use to sustainable levels Annual review of reduction strategy
2.2. Sustainable Limits (Basis)				**2.2. Sustainable Limits**			
R1 Conservative Reconnaissance Limits	**R2 Preliminary Sustainable Limits**	**R3 Formal EWRs & EWPs**	**R4 Recovery Targets**	**R1 Conservative Reconnaissance Limits**	**R2 Preliminary Sustainable Limits**	**R3 Formal EWRs & EWPs**	**R4 Recovery Targets**
Allocation limit based on conservative estimates of rainfall recharge Conservative yields include notional allowance for EWPs	Sustainable yield estimates with consideration of preliminary EWRs and EWPs[2]	Specific EWR and EWP studies carried out to set sustainable limits into allocation plans EPA approval of EWRs and EWPs	Reassess EWPs to ensure EWRs are met in accordance with reduction strategy Manage to EWRs and EWPs set.	Notional EWPs adopted when major resource inventories compiled Sustainable yields based on R1 divertible yields reduced by notional EWPs and broad sustainability criteria	Sustainable yields are limited by preliminary EWRs & EWPs Specific sustainability criteria set Preliminary environmental allocations to meet criteria Preliminary sustainable yields based on preliminary environmental allocations and EWPs	Specific EWR and EWP studies carried out prior to preparation of allocation plans EPA approval of EWRs and EWPs Required for all proposed large dams	Reassess EWPs to ensure EWRs are met in accordance with reduction strategy Manage to EWRs and EWPs set

[1] The table defines the appropriate planning response at the management area scale. Regional Planning is additional to the planning defined in this table. Regional Plans are being progressively developed in key areas of the State to define beneficial uses and show the wider context of water resource management objectives. They address major surface and groundwater resources across large regions and therefore span many management areas or river basins.

[2] EWR is Ecological Water Requirements and EWP is Environmental Water Provision.

Response Criteria (cont..)

2. Allocation Planning & Sustainable Limits Contd.							
Groundwater				Surface Water			
2.3. Preparation for Trading				2.3. Preparation for Trading			
R1 User Awareness	**R2 Identify Demand for Market**	**R3 Program of TWE Implementation**	**R4 TWE Program Effective**	**R1 User Awareness**	**R2 Identify Demand for Market**	**R3 Program of TWE Implementation**	**R4 TWE Program Effective**
Awareness of trading concepts	Identification of whether the area will need TWEs implemented for effective resource management	Set up processes (licensing triggers) and timelines to implement TWEs, to accord with demand Set apt market rules Actively communicate with users on TWEs How and when trading is to start to be included in Allocation Plans (2.1)	TWE program and market rules meeting market demand Mechanism set for recovering over-allocation	Awareness of trading concepts	Identification of whether the area will need TWEs implemented for effective resource management	Set up processes (licensing triggers) and timelines to implement TWEs, to accord with demand Set apt market rules Active communication with users on TWEs How and when trading is to start to be included in Allocation Plans (2.1)	TWE program and market rules meeting market demand Mechanism set for recovering over-allocation

Response Criteria (cont..)

3. Management of Use							
Groundwater				Surface Water			
3.1. Regulation of Use				**3.1. Regulation of Use**			
R1 Guidelines and General By-laws	**R2 Licensing and Local By-law Controls**	**R3 Active Licensed Management**	**R4 Market Regulation**	**R1 Guidelines and General By-laws**	**R2 Licensing and Local By-law Controls**	**R3 Active Licensed Management**	**R4 Recovery under Market Regulation**
Guidelines for managing disputes in unproclaimed areas By-laws to exempt licensing in proclaimed areas where regulation unnecessary	Local by-laws to control use OR licensing controls introduced (consistent with 2.1 , 2.2 and 3.2) Routine scrutiny of licence applications Standard licence conditions adopted initially, strengthened as demand and use increases and plans updated	Close scrutiny of new licence applications Review of licensed quantity & conditions at time of renewal Reporting of use specified in licence conditions Licensing triggers activated to prepare for and start trading (see 2.3 & 3.3)	Through trading in licensed use Market rules to reduce diversions to sustainable levels	Guidelines for managing disputes in unproclaimed areas By-laws to exempt licensing in proclaimed areas where regulation unnecessary	Local by-laws to control use during drought and low flows in place where past disputes have occurred Licensing controls introduced (consistent with 2.1 , 2.2 and 3.2) Standard licence conditions adopted initially, strengthened as demand and use increases and plans updated	Close scrutiny of new licence applications Review of licensed quantity & conditions at time of renewal Reporting of use specified in licence conditions Licensing triggers activated to prepare for and start trading (see 2.3 & 3.3)	Through trading in licensed use Market rules to reduce diversions to sustainable levels
3.2. Community Involvement in Management				**3.2. Community Involvement in Management**			
R1 General User Education	**R2 Progression to Active Involvement**	**R3 Active Involvement**	**R4 Active Involvement in Recovery**	**R1 General User Education**	**R2 Progression to Active Involvement**	**R3 Active Involvement**	**R4 Active Involvement in Recovery**
No active community involvement required General education	General education on water management. Awareness of advisory committee roles and responsibilities Consultative formation of committee, or other apt involvement, as demand increases	Community based committee actively involved in policy recommendations Community consultation in policy decisions on public water systems	Community based committee actively managing resources in partnership with WRC and stakeholder groups Community consultation in policy decisions on public water systems	No active community involvement required General education	Where large dams are likely - apply R3 criteria Numerous small diversions or small to medium sized dams are likely General education on water management. Awareness of advisory committee roles and responsibilities Consultative formation of committee, or other apt involvement, as demand increases	Community based committee actively involved in policy recommendations Community consultation in policy decisions on public water systems	Community based committee actively managing resources in partnership with WRC and stakeholder groups Community consultation in policy decisions on public water systems

Response Criteria (cont..)

3. Management of Use							
Groundwater				Surface Water			
3.3. Implementation of Trading				**3.3. Implementation of Trading**			
R1 Trading Inappropriate	**R2 Trading Normally Inappropriate**	**R3 Pre- Market Reviews and Commencement** Carry out planned pre-market reassessments prior to trade starting Commence market trading when adopted licensing triggers are reached	**R4 Functioning Market under Appropriate Rules** TWEs operational unless found inappropriate in sub-allocation planning Market rules for recovering over-allocation in place after consultative process	**R1 Trading Inappropriate**	**R2 Trading Normally Inappropriate**	**R3 Pre Market Reviews and Commencement** Carry out planned pre-market reassessments prior to trade starting Commence market trading when adopted licensing triggers are reached	**R4 Functioning Market under Appropriate Rules** TWEs operational unless found inappropriate in sub-allocation planning Market rules for recovering over-allocation in place after consultative process
3.4. Water Use Monitoring				**3.4. Water Use Monitoring**			
R1 Estimated Resource Use Use based on licensed allocations Metering on bores with large abstractions	**R2 Empirical Surveillance** Survey planned prior to category 3 Estimated use from surveillance compared to licensed allocations Metering on bores with large abstractions	**R3 Survey and Metering** Survey completed within the last 2 to 3 years Reporting use & metering abstractions as specified in plan(2.1) or licence conditions (3.1) Procedures to manage non-conforming use	**R4 General Metering** Survey completed within the last year Metering abstraction Knowledge of draw from bores with domestic or stock exemptions Procedures to manage non-conforming use	**R1 Estimated Resource Use** Licensed areas -Use assumed same as licensed allocations. Unlicensed Areas - Primarily based on infrequent resource inventories (Water Audit) -Supported by records of stream disputes	**R2 Empirical Surveillance** Major Dams - Apply R3 criteria Small diversions or small to medium sized dams - Survey planned prior to category 3 - Estimated use from surveillance compared to licensed allocations - Frequency of stream disputes - Metering on large diversions	**R3 Survey and Metering** Major Dams - Metering diversions Small diversions or small to medium sized dams - Survey completed within the last 2 to 3 years - Reporting use & metering diversions as specified in plan(2.1) or licence conditions (3.1) - Procedures to manage non-conforming use	**R4 General Metering** Survey completed within the last year Metering diversions Knowledge of draw from riparian users and exemptions Procedures to manage non-conforming use
3.5 Effort in Water Use Efficiency				**3.5 Effort in Water Use Efficiency**			
R1 Awareness Awareness of 'best practice'	**R2 Informed Users** Awareness of 'best practice' Developing an understanding of efficiency and accountability in water use	**R3 Analysis and Use of Efficiency Options** Awareness of 'best practice' Monitoring (as above) Analysis of the appropriateness of once-through efficiency measures e.g. resource substitution, wastewater re-use. Implementation where appropriate.	**R4 Active Programs including Audits** Awareness of 'best practice' Monitoring as above (large licences) Full water audit highly desirable	**R1 Awareness** Awareness of 'best practice'	**R2 Informed Users** Awareness of 'best practice' Developing an understanding of efficiency and accountability in water use	**R3 Analysis and Use of Efficiency Options** Awareness of 'best practice' Monitoring (as above) Analysis of the appropriateness of once-through efficiency measures e.g. resource substitution, wastewater re-use. Implementation where appropriate.	**R4 Active Programs including Audits** Awareness of 'best practice' Monitoring as above (large licences) Full water audit highly desirable

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