Water Authority
of Western Australia

Supply Options for Western Australia's Long-term Water Requirements

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Report No. WP 52
July 1988

Water Authority
of Western Australia

WATER RESOURCES DIRECTORATE
Water Resources Planning Branch

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1. SUMMARY AND CONCLUSIONS

Regional water resource utilisation

The State was divided into 10 regions and long-term population, water demand and climate change scenarios were developed to evaluate likely demands on available regional water resources. The study was based on a stabilised State population of 3.1 million people by 2050.

Under most scenarios, the only region with deficit water resources was 'Perth-Mandurah'. 'Goldfields' and 'Central West & East' regions could have supply problems under high demand scenarios, but these scenarios are unlikely.

'Kimberley' and 'South West' regions have large surplus water resources under all scenarios.

The combined available water resources of the south-west corner of the State are more than enough to meet its long-term water needs under allmost all scenarios.

Perth water supply options

Total demand (public and private) in Perth and the Goldfields and Agricultural Water Supply (G&AWS) scheme is likely to double from the current level of about 400 million m^3/yr to between 700 and 1000 million m^3/yr by the middle of next century. This would mean an excess demand of between 100 and 530 million m^3/yr on the region's available potable water resources of about 600 million m^3/yr. The moderate regional scenario envisaged a supply deficit of about 300 million m^3/yr by the year 2050.

To meet this deficit, fourteen options were evaluated:

* seven alternative options within the Perth-Mandurah region (brackish water, forest thinning, reuse of wastewater, excess drainage water, rainwater tanks, groundwater manipulation, and groundwater recharge);

* four inter-regional transfers (from South West, Central West & East, Kimberleys and Pilbara);

* three other source options (seawater desalination, tankering, and icebergs).

The South West supply option dominates because of its relatively large volumes and low cost. The two other major options are water from the Kimberleys and seawater desalination.

The supply volumes, capital costs and the per kilolitre costs of the 3 major options to supply 300 mcm/y to Perth-Mandurah are:

South West	730-920 million m^3/y	$1 260M	$0.53/kL
Desalination	>500 " "	$2 180M	$1.95/kL
Kimberley	870 " "	$9 580M	$5.35/kL

For the 'low' demand scenario the additional supply requirement of about 100 million m^3/yr could be met from within the region or small transfers of water from adjacent regions, particularly the South West.

For 'moderate' demand the additional 300 million m^3/yr would require some transfers of water from adjacent regions, particularly the South West.

For 'high' demand the additional 530 million m^3/yr would require substantial transfers, particularly from the South West, and may require some seawater desalination.

Goldfields water supply options

Eight major supply options were evaluated to meet the assumed urban and private industrial demands of the Goldfields:

- *Existing G&AWS scheme
- *Additional Perth supply
- *Local saline groundwater
- *Regional potable groundwater
- *Esperance seawater supply
- *Moore River basin supply
- *South-west supply
- *Kimberley supply

Under the 'medium' demand scenario there are no long-term supply problems for the region. The existing Goldfields supply scheme has the capacity to meet the long-term reticulation system demands of the Goldfields. Local hypersaline groundwater (currently about $0.30/m^3) will remain the cheapest source of water for private industrial demand until the middle of next century, when the cost of continuing to go further afield for more groundwater will exceed that of providing seawater from Esperance (at $1.70/m^3).

The 'high' demand scenario would cause a significant increase in the cost of water for urban and private industrial use.

Initially local hypersaline groundwater would provide the least expensive supply source for both uses. Desalination of the groundwater to meet the excess urban demand would cost at least $2.30/m^3. The cost of the hypersaline groundwater for private industrial demand would increase steadily from the current cost of about $0.30/m^3 as water close to Kalgoorlie is exhausted.

After about 2015 diversion of local groundwater would become more expensive than developing a seawater supply scheme from Esperance at $1.30/m^3$. A difficult choice would then be required between a seawater pipeline from Esperance (with lower industrial water costs) and a freshwater pipeline from the Moore River basin (with lower urban water costs). The overall cost of water from the seawater pipeline supply is lower despite its desalinated water cost of about $3.10/m^3$.

2. INTRODUCTION

Most Western Australians live and work in the south-west of the State. Water plays a central role in creating and maintaining a relaxed and prosperous life-style. Although the water resources within this corner of the State are substantial, they are not limitless, and our use of them is considerable and growing. Water resources within the Perth-Bunbury sub-region may be fully committed within the next 30 to 40 years.

There seems to be general agreement now amongst scientists that a gradual shift to a drier climate in the south-west will occur over the next 30 to 50 years due to the Greenhouse effect.

The Water Authority is actively committed to a Water Conservation programme to encourage efficient water use and this is receiving strong support in the community.

However, discussion of climate change, the current drought, and promotion of efficient water use have caused some concern in the community about long-term planning for water supply development.

The Minister for Water Resources asked the Western Australian Water Resources Council (WAWRC), and the Water Authority to look at options for the south-west corner of the State beyond the next 30 or 40 years to determine how its growing water requirements can continue to be met in the future. The Minister had previously requested the Kimberley Regional Development Advisory Committee (KRDAC) to investigate the potential of transferring water south from the Kimberleys. This initiative was extended to involve the Water Resources Council and the Kimberley Committee in joint action on a widened brief with technical support from the Water Authority.

A preliminary report was prepared by consultants Binnie & Partners and Wilson Sayer Core for KRDAC on the cost and potential benefits of transferring water south from the Kimberleys (Binnie, 1988a).

The draft working report presented here has been prepared by the Water Authority for the WAWRC to:

* review the ability of regional water resources to meet long-term regional water demands and identify regions with significant deficit or surplus water resources (see sections 3, 4 and 5);

* review the long-term supply options available for regions with potential deficit water resources (see sections 6 and 7);

The WAWRC will prepare a final report for the Minister for Water Resources which takes account of the results of this draft working report and the Kimberley study.

Some qualifications need to be understood in reading this report. The report primarily addresses water supply issues; water conservation and water allocation issues, although touched on briefly, are dealt with elsewhere. For such a long-range study it is not possible to determine reliable predictions of regional population, climate change and demand figures, hence the values presented are based on a range of 'scenarios' which should cover the likely long term outcomes. Finally, since the report seeks to provide an overview of the State's long-term regional water resource utilisation levels, it does not address potential intra regional water transfer problems. Some regions may have adequate water resources, but water transfer costs could be high.

3. STATE PERSPECTIVES

3.1 Regions

Western Australia has been divided for the purposes of this report into ten regions recognised by the Department of Regional Development (1984) - Perth-Mandurah, South-West, Central West and East, Central South, Great Southern, Goldfields-Esperance, Geraldton Mid-West, Gascoyne, Pilbara and Kimberley.

Mandurah and Pinjarra have been included with Perth to form the 'Perth-Mandurah' region. This reflects the actual water supply situation, where Mandurah and Pinjarra are connected to the metropolitan water supply (MWS) system, and adjacent catchment areas provide supply sources for the MWS.

A report by the Western Australian Water Resources Council (WAWRC, 1986) provides the basic water resource and water use data for this study. The 44 water resource basins used in the report were grouped to approximate the Department for Regional Development regions (Figures 1 and 2). The population and water demand data are therefore not exactly those of the regions but this approximation will not detract from the regional perspectives gained on current and future water utilisation.

3.2 Population scenarios

Two population scenarios - 'moderate' and 'high' - were selected for the study. A 'moderate' scenario is based on advice from the State Planning Commission (Correspondence, pers. comm.) that the population of the State is likely to stabilise at between 3.0 and 3.6 million by middle or late next century. An intermediate value of 3.1 million by about the year 2050 was chosen.

The SPC also provided regional population projections to 2011. These were used as a basis for apportioning the State population of 3.1 million by 2050 amongst the ten regions used in the study (Figure 3). The regional values for 2050 are very approximate, but provide a reasonable basis for a 'moderate' population scenario for the purposes of the study.

The second scenario was developed to examine the effects of possible 'high' population growth in each region due to either a State population of more than 3.1 million people, or an unusually high proportion of growth in the region. The South-West is predicted to be the fastest growing region with a growth of 2.7 times its 1984 population under the 'moderate' scenario. This factor was applied to other regions to calculate 'high' scenario values, while a factor of 3.5 times the 1984 population was applied to the South-West. The Pilbara and Kimberley regions were also assigned a 'high' growth factor of 3.5 as regions of possible high growth.

3.3 Climate scenarios

The potential impact of the 'greenhouse effect' on the State's climate by the middle of next century cannot be ignored. The indications are that the south-western portion of the State will become drier (Chittleborough, 1985).

Hence three climate scenarios were developed to examine the effects of possible climate change on regional water resource utilisation in the southern regions. The assumed effects of 'zero' (C0), 'moderate' (C1) and 'high' (C2) climate change scenarios on mean rainfall and yields of surface water and groundwater are summarised in the table below and illustrated in Figure 4.

No climate changes were considered for northern regions of the Gascoyne, Pilbara and Kimberleys. These are expected to experience a more variable climate, with extremes of wet and dry periods, but with no change in average conditions (Chittleborough, 1985).

CLIMATE SCENARIO	REDUCTION IN CURRENT MEAN RAINFALL		REDUCTION IN WATER YIELDS			
			SURFACE		GROUNDWATER	
	1988	2040	1988	2040	1988	2040
C0	5%	5%	10%	10%	0%	0%
C1	5%	10%	10%	20%	0%	10%
C2	5%	20%	10%	40%	0%	20%

TABLE 1: CLIMATE CHANGE SCENARIOS

3.4 Energy scenarios

Two energy scenarios were selected. One assumes current direct energy costs and the other that energy costs will approximately double by the middle of next century. This 'future' energy cost scenario was used to examine the relative sensitivity of various water supply options to variations in direct energy costs. It was based on a recent study by the Chevron Corporation (1987) of the future world energy outlook and could be considered a 'moderate' estimate.

4. REGIONAL WATER DEMAND

Three demand scenarios were selected: 'high', 'medium' and 'low'. The 'high' and 'medium' estimates were a simple calculation of water demand in 2050 by the 'high' and 'moderate' populations at 1984 per capita water usage values (WAWRC, 1986). The 'low' demand scenario was based on a 25% reduction in the 'medium' demands by the middle of next century.

There were three exceptions to this procedure. The public water demands for Perth were based on the preliminary results of a recent revision of the Source Development Plan for Perth (Mauger, 1987). The public supply irrigation demand in the South-West was kept constant at the 1984 value (i.e. no increase was anticipated). Finally, the Goldfields industrial demands were based on a recent draft report prepared for the Department of Resource Development (BHP Eng., 1988).

The 'medium' demand scenario assumes no significant changes in the per capita water use patterns of 1984 or any new future water users consuming a disproportionate amount of water. The 'high' demand scenario takes into account the possibilities of additional demand due to a higher population factor, increased per capita demand and new industries.

The 'low' demand scenario was developed to examine the effect of significant reductions in per capita demand on regional water resource utilisation. An active water conservation programme and a steady increase in the unit cost of water as available water resources become fully committed could lead to such a reduction in per capita demand in the long term.

5. REGIONAL WATER RESOURCE UTILISATION

5.1 Approach

The water resource inventory figures adopted for this study were based on those of the WAWRC (1986) report. However, the groundwater resources of the Perth Sedimentary Basin between Cervantes and Augusta were revised in accordance with a recent review by the Geological Survey of W.A. (WAWRC, 1988b).

For each region the 'divertible', 'potable' component of the total water resource was considered. 'Divertible' water resources are those able to be extracted on a sustained basis at rates capable of serving urban, irrigation, industrial or extensive stock uses. 'Potable' water resources are those with salinity levels below 1000 mg/L TSS (i.e. 'fresh' or 'marginal').

The divertible, potable component of each region was further reduced by an allocation to the environment for instream uses. This allocation for the Perth to Bunbury area was based on the recently published Perth-Bunbury Study (WAWRC, 1988a). For other regions a notional allocation of 20% of the surface water component was made to the environment. Since groundwater yield values are based on 'throughflow' with the environment as a constraint, no further reduction in groundwater yields was required.

The effects of the climate change scenarios were then imposed on the yields of the available water resources for each region.

The level of utilisation of the available water resources of each region was determined by comparing the 'high', 'medium' and 'low' demand scenarios with water resources under the three climate scenarios. For simplicity three regional scenarios ('low', 'moderate' and 'extreme'), which represented combinations of the water demand and climate change scenarios, were selected as follows:

Regional Scenario		Demand Scenario		Climate Scenario	
'low'	=	'low'	+	'moderate'	(C1)
'moderate'	=	'medium'	+	'moderate'	(C1)
'extreme'	=	'high'	+	'high'	(C2)

The regional water utilisation pictures presented here do not generally address the issue of intra regional water transfers. Thus although a region may have adequate water resources to meet all of its future needs, the supply sources may be located far from the centres of demand and transferring the water within the region may be very expensive.

Nevertheless, these reviews provide an important overview on a regional scale of the ability of the State's water resources to meet the water demands of the 21st century and highlight the regions with significant supply deficits and surpluses.

5.2 Regional reviews

The regions have been arranged in order of most severely affected to least affected.

5.2.1 Perth-Mandurah region

Perth-Mandurah is the most critical of the regions. It is likely to face a significant deficit of available regional water resources against water demand by the middle of next century even under a 'moderate' regional scenario (Figure 5).

The region has an estimated 624 x 10^6 m^3/yr of potable water available of which about 57% is groundwater. The overall water quality is good, with nearly 90% of the water being fresh (of less than 500 mg/L TSS).

Current utilisation of the available water resources is nearly 68%. The 'moderate' regional scenario would cause utilisation to rise to nearly 150%, i.e. a total demand of approximately 880 x 10^6 m^3/yr, which would exceed the available supply by nearly 300 x 10^6 m^3/yr. Excess demand would rise to more than 500 x 10^6 m^3/yr under the 'extreme' regional scenario. Reductions in per capita consumption ('low' regional scenario) would have a significant effect on the excess demand, cutting it to less than 100 x 10^6 m^3/yr (i.e. 116% of the region's available resources). These effects are illustrated in Figure 5.

Total demand on the region's water resources includes an amount exported to meet the public supply needs of the Central W & E and Goldfields-Esperance regions via the Goldfields and Agricultural Water Supply Scheme (G&AWS). This inter-regional transfer currently amounts to about 11% of the public supply demand on the region's resources.

There are significant additional quantities of brackish water in the Murray and Avon Rivers that could be utilised (about 270 x 10^6 m^3/yr), but use of these is constrained by social and environmental considerations (Section 6.2.1).

5.2.2 Goldfields-Esperance region

The severe lack of available potable water resources in this dry region is highlighted by ongoing dependence on water imported from the Perth-Mandurah region. The region has theoretically enough divertible potable groundwater to meet its current needs. However, the sources are small and very widely scattered and not suitable for harnessing in a reticulated supply scheme for Kalgoorlie. For all practical purposes, the Goldfields public supply demand is continually in excess of the region's available water resources. Esperance is more fortunate, with small but adequate potable groundwater sources to meet its needs.

Figure 6 shows the demands on the region's resources under the three demand scenarios. Public supply demand below 17×10^6 m^3/yr has been excluded as this is a load on Perth-Mandurah resources.

The 'medium' demand scenario for the Goldfields is based on the recent survey by BHP Eng. (1988) of current and anticipated short-term future industrial demands. The anticipated increase in public supply demand for potable water is small and can be met by the G&AWS scheme. A significant increase in private industrial water demand is expected which further development of the significant saline paleochannel resources in the vicinity should meet.

The 'high' demand scenario for the Goldfields predicts significant increases in potable and saline water demand of approximately 20×10^6 m^3/yr and 60×10^6 m^3/yr respectively. This would require sizeable new supply sources and transfer systems to deliver water into the region, and unit cost would be high (Section 7). Perth-Mandurah region would be unable to provide these additional sources because of its own likely supply deficit.

5.2.3 Central South region

As for the Goldfields, Central South region has such limited potable water resources that it is dependent on importing water. Water is transferred from Wellington Dam in the South-West region via the Great Southern Towns Water Supply (GSTWS) scheme, supplemented by some local sources.

Under the 'medium' demand scenario there would be negligible increase to the small (4 x 10^6 m^3/yr) demand of the region. The 'high' regional scenario predicts an increase in demand to 11 x 10^6 m^3/yr, which would require major upgrading of the GSTWS scheme, but have minimal impact on the water resources of the South-West region.

5.2.4 Central West & East region

The overall available water resources of this region of approximately 300 x 10^6 m^3/yr appear at face value more than adequate to meet its future demand. However, there are two distinct water demand areas within the region and the water supply situation of each is different.

The traditional demand centres are located inland in the farming communities of the wheatbelt. Here local water supply sources are negligible and, like the Goldfields and Central South, the communities are dependent on importing about 12 x 10^6 m^3/yr of water via the G&AWS scheme. Demand increases under the 'moderate' regional scenario could be easily met by the existing G&AWS scheme and would make negligible difference to the supply situation in the Perth-Mandurah region. However, an increase of approximately 20 x 10^6 m^3/yr under the 'extreme' demand scenario would require significant upgrading of the G&AWS system and would adversely affect the long-term supply of the Perth-Mandurah region.

New water demand centres have emerged recently on the coastal plain area of the Moore River basin. Restricted expansion of horticultural activity in the Perth-Mandurah region due to a lack of available groundwater has led to rapid growth in water demand between Gingin and Moore River. Groundwater on the coastal plain area of the Moore River basin contributes 303 x 10^6 m^3/yr of the region's 314 10^6 m^3/yr total available water resources, but the water quality is not high, with some 85% being marginal (of 500 to 1000 mg/L TSS). The fresher water is generally located in the southern portion of the basin.

This coastal plain groundwater resource is located in the Gingin and Arrowsmith Groundwater Areas (GWA) which require licensing of private groundwater extraction. Based on the current licensing arrangements in the Gingin GWA a total limit of 148 x 10^6 m^3/yr of the 303 x 10^6 m^3/yr coastal plain groundwater resource is assumed to be allocated to private use under the 'medium' demand scenario. Under 'moderate' climate change, this would represent about 56% of the available groundwater on the coastal plain by the middle of next century.

Under the 'high' demand scenario it was assumed that growth in private irrigation demand would be more rapid and the total allocation limits lifted to allow the full development of the groundwater resource by private irrigators. If this occurred in conjunction with the severe climate change scenario (C2), utilisation would rise to 130%, i.e. over commitment of the groundwater resources.

Thus the 'moderate' regional scenario does not pose supply problems for either area, but the 'extreme' scenario would, particularly for the wheatbelt.

Figure 8 shows the demands on the region's resources.

5.2.5 Gascoyne region

The water resources of the Gascoyne region, although relatively small, appear to be adequate to meet its long-term water needs.

The groundwater contribution of 37 x 10^6 m^3/yr makes up most of the 49 x 10^6 m^3/yr of the region's available water resources. The water quality is not as good as that of most other regions, with less than a quarter of the available potable water being fresh (of less than 500 mg/L TSS).

Climate change is not expected to affect average conditions in this region. Under the 'medium' demand scenario, the current level of utilisation of the available water resources of 20% would rise to about 43% by the middle of next century. Utilisation levels for the 'high' and 'low' demand scenarios would be 55% and 33% respectively (Figure 9).

Regional water resources are more than adequate to meet these demands but many of the sources are some distance from the major demand centre at Carnarvon. Supplying its long-term needs will be costly.

5.2.6 South-West region

The water resources of the South-West region appear to be more than adequate to meet its long-term needs.

Surface water makes up about 70% of the region's available water resources of 1400 x 10^6 m^3/yr. The quality of the water is good, with nearly 70% being fresh.

Under the 'moderate' regional scenario the current level of utilisation of the available water resources of about 18% would rise to nearly 40% by the middle of next century. Utilisation would rise to nearly 65% under the 'extreme' regional scenario, and to less than 30% under a 'low' scenario (Figure 10).

The groundwater resources of the coastal plain between Waroona and Capel will play a key role in the development of the South-West Region, and are likely to be fully committed by the middle of next century.

The region has two other additional and potentially significant water resources. The deep confined aquifers of the Perth Sedimentary Basin, which extend as far south as Augusta, contain several hundred million cubic metres of potable water in storage. The second potential resource is 420 x 10^6 m^3/yr of divertible brackish water, principally of the Blackwood River. Development of this resource may well be constrained by environmental and social considerations.

The South-West region exports water to the Central South region from Wellington Dam via the GSTWS scheme. However, the 4 x 10^6 m^3/yr currently transferred is comparatively small and even an 'extreme' regional scenario for Central South would have little impact on the overall resources of the South-West.

5.2.7 Great Southern region

The 73 x 10^6 m^3/yr of available potable water is more than adequate to meet the likely long-term water needs of the Great Southern region. This is despite the fact that most of the region's divertible water resources have become brackish or saline through previous catchment clearing practices.

Surface water makes up nearly 80% of the available potable water. The water quality is reasonable with some 40% being in the fresh range. The region has a significant additional resource of about 250 x 10^6 m^3/yr of divertible brackish water.

The current level of utilisation of some 18% would rise to less than 25% by the middle of next century assuming a 'low' regional scenario. Utilisation would rise to about 32% under the 'moderate' scenario, while the 'extreme' regional scenario would result in a high, 76% utilisation level (Figure 11).

5.2.8 Geraldton Mid-West region

The Geraldton Mid-West region with 152 x 10^6 m^3/yr of available potable water possesses moderate water resources. About 76% of this is groundwater. The water quality is the worst of all the regions, with most being marginal.

The current low level of utilisation of about 11% would rise to about 24% by the middle of next century under the 'moderate' regional scenario. Utilisation under the 'extreme' regional scenario would still be less than 40%, and less than 20% under a 'low' scenario (Figure 12).

5.2.9 Pilbara region

The Pilbara region is fairly well endorsed with water resources, having a total of 426 x 10^6 m^3/yr of potable water. Nearly 60% of this is groundwater of which more than half is from the Canning Basin in the Great Sandy Desert. The water quality is reasonable, with more than 50% being fresh, mostly from the surface water sources.

The current level of utilisation is relatively low, with 10% of the available resources developed. Climate change is not expected to alter average conditions in this region. Under a 'medium' demand scenario the level of utilisation would rise to less than 17% since climate change is not expected to affect the yields in this region. Even with the particularly large population growth assumed for the Pilbara's 'high' demand scenario (Section 3.2), the level of utilisation would still be only 35%. Utilisation would rise only marginally to 12% under the 'low' demand scenario (Figure 13).

However, the nature of the climate and topography of the region are such that unit costs to develop water are relatively high compared with the south-west.

5.2.10 Kimberley region

The Kimberley region has abundant water resources, most of which are surface water (93%). With 7450 x 10^6 m^3/yr of available potable water resources, the region contains about 60% of the State's total potable resources. Water quality is very good, with about 95% being fresh. Climate change is not expected to affect this region.

The utilisation levels, even with very large development growth, are very small. The current level of 1% would rise to about 9% with the 'low', 12% with the 'medium', and about 26% with the 'high' demand scenario (Figure 14).

As with some of the other regions, however, demand growth centres such as Broome are often considerable distances from the large surface water resources and will probably continue to rely heavily on local ground water.

5.3 Regional overview

Figure 15 illustrates the relative volumes of available potable resources and the future utilisation levels for each region under the 'moderate' scenario. Inter-regional water transfers (from Perth-Mandurah region to Central E & W and Goldfields regions and from South-West region to Central

South region) play an important role and have been debited against the supplying region's resources. The South-West and Kimberley regions have large excess water resources which are possible sources for other regions with anticipated deficits.

The Perth-Mandurah region has the most critical long-term supply problems. The available conventional water resources will be unable to meet the long-term demand levels, even under the 'low' regional scenario. Under the 'moderate' regional scenario, nearly 300 x 10^6 m^3/yr of additional water supplies will be required by the middle of next century. A review of potential supply options to meet this deficit is presented in Section 6.

No serious water supply problems are anticipated for other regions under the 'moderate' regional scenario.

Only the Goldfields-Esperance and Central West & East regions would have supply problems under the 'extreme' scenario of 'high' demand and 'severe' climate change. A review of supply options available to the Goldfields-Esperance Region is presented in Section 7.

The potential supply problems of the Central West & East region under the 'extreme' scenario fall into two areas: the wheatbelt and the coastal plain. High demand growth in the wheatbelt would require costly upgrading of the G&AWS Scheme and exacerbate the water supply problems of the Perth-Mandurah region, from which the water is drawn. However, a demand growth of this magnitude in the wheatbelt area is unlikely. Groundwater is the principal water source available to the coastal plain area. The 'extreme' regional scenario could lead to unsustainable demand on the groundwater and subsequent "mining" of this resource unless private demand was cut back in line with groundwater yield reductions due to climate change.

The combined available water resources of the south-west corner of the State (i.e. Perth-Mandurah, Goldfields, Central West & East, South-west, Central South and Great Southern regions) are more than sufficient to meet its long-term water needs under most scenarios (Figure 16). Total demand is likely to double from the current level of about 700 x 10^6 m^3/yr to between 1200 and 1900 x 10^6 m^3/yr by the middle of next century. These demands on the combined water resources of between 1700 to 2500 x 10^6 m^3/yr would leave surplus resources under all but the extreme scenario of severe climate change coupled with high demand. Under the medium demand and moderate climate change scenarios, this corner of the State would have about 670 x 10^6 m^3/yr of surplus water resources with a combined population of nearly 2.9 million (92% of State total).

6. PERTH WATER SUPPLY OPTIONS

6.1 Introduction

6.1.1 Water resources of the Perth-Mandurah region

The surface water resources of the region were taken to be those identified by the Perth-Bunbury Study (WAWRC, 1988a) as available for consumptive purposes after an allocation for instream uses. Some 300 x 10^6 m^3/yr was considered available for consumptive use of the 382 x 10^6 m^3/yr of divertible potable resources.

A recent draft review by the Geological Survey (WAWRC, 1988b) of groundwater of the Perth Sedimentary Basin was used to estimate groundwater resources. The revised estimates were lower than previously for the Perth-Mandurah region, but higher than before in the Central and South-West regions. The effect of urbanisation to increase the yield of unconfined groundwater was incorporated by adding an assumed yield of 600 m^3/yr/ha of urbanised area.

6.1.2 Excess Perth demand

The Metropolitan Water Supply (MWS) system consists of three demand components: the base demand by metropolitan consumers, a G&AWS demand, and transfer of private (mainly groundwater) demand to the MWS system when resources for private consumption become fully committed.

The base metropolitan demand was determined by calculating demand for the population scenario levels using a relationship between Perth population size and MWS demand from the draft of a current review of the Perth sources development plan (Mauger, 1987).

The G&AWS demand was estimated as the sum of the Central West & East and Goldfields-Esperance regions' public demands under the appropriate demand scenarios.

Predicting the amount of transfer of private consumer demand to the MWS system was the most difficult. Nearly 90% of private consumption is from groundwater sources and the quantity available for private use is limited. Currently the total private consumption of groundwater for residential, institutional, industrial and irrigation use is about 180 x 10^6 m^3/yr. The total amount available for private use is estimated at only 240 x 10^6 m^3/yr. Thus competition for the available groundwater is intensifying. Horticultural use is almost at its limit and recent horticultural developments are northwards of the Perth-Mandurah region in the Moore River basin area. The private irrigation demand figures for the Perth-Mandurah region assume no increase after 1991. In reality private irrigation water use will probably decline slowly in the long term due to increased urbanisation.

Under the 'moderate' regional scenario, the available private groundwater limit will be reached about the turn of the century. Excess private demand will be transferred to the MWS system after this date, except that only half the residential demand is expected to be transferred (due to reduced per capita use), and none of the horticultural (due to horticultural activity moving elsewhere).

Demand on the MWS supply will then increase rapidly and exceed the available public supply by around 2010. Private supply sources will be fully committed and subsequent private demand increases will all be borne by the MWS system. Under the 'moderate' regional scenario, demand in excess of available resources would continue to increase at a rate of about 7 x 10^6 m^3/yr to reach a total of nearly

300×10^6 m^3/yr by the middle of next century. Excess demand under the 'low' and 'extreme' regional scenarios would be 95 $\times 10^6$ m^3/yr and 530 $\times 10^6$ m^3/yr respectively.

6.1.3 Source options assessed

Water supply sources which have the potential to meet all or part of the predicted excess demand in the Perth-Mandurah region fall into 3 groups:

- additional water resources within the region;
- inter-regional transfers to Perth from regions with excess resources;
- other source options.

The sections below summarise the results of preliminary studies (see appended documents) which consider each potential source option and estimate the quantity and approximate unit cost to supply the water to Perth. All costs are in December 1987 dollars at a discount rate of 6%.

6.2 Additional Perth region sources

6.2.1 Brackish water (Working Paper 7)

Has the potential to supply 37 $\times 10^6$ m^3/yr under a 'moderate' scenario, at approximately \$1.10/m^3.

The total amount of brackish surface water (salinity between 1000 and 5000 mg/L TSS) able to be diverted in the Perth-Mandurah region is estimated to be about 260 $\times 10^6$ m^3/yr (WAWRC, 1986). The principal sources are the Murray River and tributaries of the Swan/Avon River. The Avon River itself is saline, and although a notional 100 $\times 10^6$ m^3/yr could be drawn from it, the cost would be high and development would probably be precluded by environmental and social considerations.

The Murray River could be developed by construction of a dam upstream of the Lane-Poole Reserve to control flow to a pipehead dam and desalination plant downstream of the reserve. This would yield about 150 x 10^6 m^3/yr (Mauger, 1987). Its effect on the Reserve may be considered acceptable but its potential impact on Peel Inlet probably would not and this option is considered to be constrained.

Of the 77 x 10^6 m^3/yr potential yield of the Swan/Avon tributaries, approximately 30 x 10^6 m^3/yr is considered to be constrained by farming development and environmental considerations. Thus only 47 x 10^6 m^3/yr of brackish water in the region is considered to be available for additional supply to Perth. 42 x 10^6 m^3/yr of this brackish supply is associated with development of the Wooroloo Brook and Brockman River tributaries. Under the 'moderate' climate change scenario (C1),this would reduce to 37 x 10^6 m^3/yr by the middle of next century.

The Wooroloo Brook development consists of a major dam and storage reservoir to feed water to a treatment plant and desalination unit. The Brockman River development involves pumping from a pipehead dam on the river to the proposed Wooroloo reservoir. The cost of desalination of the brackish water from these schemes has been estimated in a desalination study (Binnie, 1988c) to be 95 cents/m^3. The total cost of the water (including dams and supply mains) would be approximately \$1.08/m^3.

There is also a small quantity (less than 25 x 10^6 m^3/yr) of brackish groundwater available in the region. However, the water is too widely dispersed to bring together into several sizeable desalination plants and cost of treating the water at a large number of small plants would be relatively high.

6.2.2 Forest thinning (Water Authority, 1987)

Has the potential to increase existing supplies by approximately 29 x 10^6 m^3/yr under a 'moderate' scenario, at 5 cents/m^3.

Stream flow from existing forested catchments in the Darling Range is, on average, only 9% of the rainfall, although up to 20% in the higher rainfall areas. The remainder passes directly back to the atmosphere by evaporation or transpiration by plants. A small reduction in forest density through thinning to reduce water transpiration by 1% is predicted to cause an increase in stream flow of about 10%, thereby increasing the yield of existing water supply sources. Preliminary studies indicate a potential stream flow increase of approximately 127 x 10^6 m^3/yr through thinning of suitable forest in high and intermediate rainfall zones. However, there is an unacceptable risk in intermediate zones that forest thinning and increased stream flow will increase salinity.

The increased yield of existing water supply sources through forest thinning in the high rainfall zones is estimated to be approximately 37 x 10^6 m^3/yr. Cost would be approximately 5 cents/m^3 for forest management. Under the 'moderate' climate change scenario, the increased yields would be reduced to 29 x 10^6 m^3/yr by the middle of next century.

The potential environmental impacts of the option include risk of spreading jarrah dieback and disturbance of the ecology and aesthetics of the forest. These risks are significant and would require careful evaluation before the project could be approved.

6.2.3 Reuse of wastewater (Working Paper 8)

Has the potential to supply about 58 x 10^6 m^3/yr for industry, park irrigation and groundwater recharge at 20c to $3.00/$m^3$.

The volume of wastewater potentially available for supply is significant. The current volume of 60 x 10^6 m^3/yr of treated wastewater discharged to sea is estimated to triple to nearly 180 x 10^6 m^3/yr by the middle of next century under the 'moderate' population scenario for Perth.

A number of reuse applications are potentially available:

(a) industrial water supply;
(b) irrigation of parks and recreation grounds;
(c) aquifer recharge and wetland replenishment;
(d) irrigation for agriculture;
(e) irrigation for domestic gardens;
(f) potable water supply.

Irrigation for agriculture (principally horticulture) is unlikely since the horticultural industry relies on private extraction of low cost groundwater. Agriculturalists have tended to move to areas of plentiful groundwater rather than pay the higher cost of reticulated water. Household treatment of domestic wastewater for reuse on the garden is possible with small on-site treatment systems, but the initial capital cost (about $5000) and the unit cost of the treated water (approximately $4/$m^3$) are not considered economic. Reuse of the "grey" water from washing machines on the garden has health risks and is banned by the Health Department. Reuse of wastewater for supplementing the potable water supply is possible but considered unlikely due to the high cost of the tertiary treatment required, possible health risks and uncertainty of community acceptance.

The most promising applications appear to be industrial use, irrigation of parks and recreation grounds and aquifer recharge.

The relatively large groundwater resources on the coastal plain under Perth has made the reuse of wastewater for industrial or institutional (e.g. parks and recreation grounds) purposes unwarranted. However, as groundwater resources in the Perth-Mandurah region become fully committed, reuse of wastewater may become a viable option for meeting some of the excess growth in private demand. This would reduce the pressure on providing new supply sources for the MWS system.

The best potential supplier of treated wastewater for reuse by industry is the Wastewater Treatment Plant (WWTP) at Woodman Point, since its outfall pipe runs through the Kwinana Special Industrial Area. However, additional secondary and probably some tertiary treatment of the wastewater would be required. Tertiary treatment greatly increases the cost of reclaimed water but the unit cost is difficult to estimate until the required quantity and quality of the water has been defined. Approximately 100 x 10^6 m^3/yr of reclaimed water could be supplied by the middle of next century at a cost of \$1.50/m^3 (secondary plus some tertiary treatment).

This potential supply volume will probably be greater than the potential demand at Kwinana since, under the 'medium' demand scenario, the estimated total private industrial demand for the region is only 50 x 10^6 m^3/yr and the excess private industrial demand over available resources only 25 x 10^6 m^3/yr. The relatively high cost of the water would prevent private industrial users switching from groundwater to reclaimed water. It is also unlikely that industrial users of the public supply system, who would be consuming about 35×10^6 m^3/yr by the middle of next century, would switch to reclaimed water. Hence it is assumed that the industrial demand for reclaimed water would be no more than 25×10^6 m^3/yr.

Industrial demand for cooling water favours low salinity water. Using the more saline wastewater effluent would require approximately twice the quantity to achieve the same cooling. Thus the 'equivalent' unit cost of wastewater to meet the industrial demand for low salinity water would be about \$3.00/m^3 (2 x \$1.50/m).

Wastewater is currently reused to irrigate parks and recreation grounds in some country towns, and is a viable future option for Perth after the available groundwater is fully committed. However, it is unlikely to displace the use of cheap groundwater at existing parks and recreation grounds, and the water demand of suitably located future ones is unlikely to be more than 15×10^6 m^3/yr by the middle of next century. The secondary treated effluent would require disinfection, and assuming a transportation distance of about 2 km, the cost would be approximately 20 cents/m^3.

The Beenyup and proposed Alkimos WWTPs also have the potential to recharge the groundwater aquifer. However, the effluent would require some tertiary treatment to reduce the high nutrient levels before being recharged. An estimated total of about 18×10^6 m^3/yr of reclaimed wastewater could be used for aquifer recharge in the long term at a cost of about \$1.50/m^3. The cost of re-extracting the water for supply to the MWS system would add about 20 cents/m^3, bringing the total cost of this supply source to about \$1.70/m^3.

6.2.4 Excess drainage (Working Paper 9)

Around 40 x 10^6 m^3/yr could be harnessed under a 'moderate' scenario, for direct supply to the MWS and through groundwater recharge, at 30 to 55 cents/m^3.

The current excess runoff in the region to the ocean and river estuaries has been estimated to be about 100 x 10^6 m^3/yr from urban and 150 x 10^6 m^3/yr from rural areas. By the middle of next century the excess runoff from the urban area under the 'moderate' population scenario is estimated to rise to about 190 x 10^6 m^3/yr.

Most excess rural runoff flows into the Peel Inlet. In view of the current problems with the inlet it is likely that extraction of a significant portion of this flow would not be acceptable. Also the water quality is poor, with relatively high nitrate and phosphorous levels and bacteriological counts. Treatment of the water would be expensive (>$1.00/m) and costs would be further increased by the variable nature of the streamflow, the river diversion works and water conveyance costs. Hence this is not considered to be a viable supply option at the present time.

There are a number of significant problems associated with development of the excess urban drainage as a water supply source. The drainage system is dispersed and not suited to collection into a small number of facilities; the resource is seasonal, with most excess runoff in winter when demand is low; development of large urban storage facilities to harness the full yield potential would be very difficult; there are potential health risks in using excess drainage water from urban areas in the potable water supply system.

The principal methods for harnessing this potential resource are -

- direct supply after treatment;
- recharge of groundwater for later extraction.

The direct supply method would involve diversion from main drains and pumping to a nearby treatment plant, before being delivered into the MWS system. This would be similar to the system used to treat groundwater. The cost of direct supply of excess drainage water has been estimated at about 30 cents/m^3.

Recharge of groundwater by excess drainage water would involve either diversion to local recharge basins or if this was not possible, diversion and transfer to more remote recharge basins. The estimated supply costs are approximately 30c/m^3 to recharge the local groundwater and 20c/m^3 for later extraction, giving a total cost of about 50 cents/m^3. The estimated total supply cost if the water was diverted to remote recharge basins is about 55 cents/m^3.

Probably no more than 25% of the excess urban drainage could in reality be harnessed for water supply purposes. Thus the potential long-term supply volume would be less than 50 x 10^6 m^3/yr. Under 'moderate' and 'severe' climate scenarios this would reduce to about 40 x 10^6 and 30 x 10^6 m^3/yr, respectively.

6.2.5 Rainwater tanks (Working Paper 10)

Unlikely to supply more than 12 x 10^6 m^3/yr at $2.10/$m^3$.

The installation of domestic rainwater tanks to collect roof runoff would not provide a major additional freshwater supply.

The annual supply for each household would vary depending on the size of the tank and the use made of the water. A large 20 kL tank would provide an annual supply of about 70 kL with 90% reliability. However, the capital cost of about $1100.00 and the unit cost of about $2.10/$m^3$ are relatively high. Also, conveying 70 kL per year from the tank for use in the house would require significant effort or additional cost and widespread use is unlikely. A smaller tank of 5 kL capacity would probably be more attractive as it would have a similar unit cost of water for less capital investment. This would provide about 30 kL per year.

If half of all the residential households in Perth installed a 5 kL tank the total supply would still be less than 12×10^6 m^3/yr by 2050. This gain would be diminished by a reduction in the groundwater recharge.

Potential health risks are also associated with the use of rainwater tanks.

6.2.6 Groundwater manipulation

Artificial manipulation could increase yields but is constrained by environmental considerations.

The values of sustainable yield for the unconfined shallow groundwater resources of the coastal plain are based on estimates of the annual 'throughflow' of groundwater to the ocean or river estuaries. These yields are generally less than 20% of the direct rainfall on the recharge areas due to evapo-transpiration of water from wetlands and vegetation (Mauger, 1987).

The effects of climate change on groundwater yields from the shallow groundwater on the coastal plain are uncertain. A reduction in rainfall could be offset by an increase in net recharge. If the current levels of groundwater beneath the surface were lowered by a few metres, either naturally by climate change or artificially through increased extraction, there would be a reduction in evapo-transpiration losses. This could result in an increase in net recharge to the groundwater and an increased sustainable yield at the new groundwater levels.

However, artificial lowering of the shallow groundwater would so adversely affect the natural environment, particularly wetlands, that this action is precluded as an option to increase groundwater supply in the Perth-Mandurah region.

6.2.7 Groundwater storage

Could supplement supplies but regular 'mining' is constrained by environmental considerations.

Deep confined aquifers beneath the coastal plain contain groundwater of potable quality in very large quantities but with a very small annual recharge rate relative to the storage volume (Mauger, 1987). Periodic use of this store to supplement the conventional surface and groundwater sources would significantly improve the efficiency of the MWS system and increase overall yields. However, the environmental effects are uncertain and their acceptability would have to be established before this option could be pursued.

Direct 'mining' of the aquifer groundwater storage is a possibility, but the likely environmental impacts are considered to preclude this supply option.

6.3 Inter-regional transfers to Perth

6.3.1 South-West sources

Could supply all of Perth's deficit under most scenarios at approximately 53 cents/m^3.

The review of the South-West region's present and future water requirements in section 5.2.6 indicated that the region will continue to have large surplus resources (second only to the Kimberleys). The water quality of the region's resources is also good, with about 70% of the potable water being fresh.

Under a 'moderate' climate change scenario the region's surplus resources would vary from 730 x 10^6 m^3/yr ('high' regional demand) to 920 x 10^6 m^3/yr ('low' regional demand).

These are well in excess of the Perth deficits of between 300 x 10^6 m^3/yr ('medium' demand) and 410 x 10^6 m^3/yr ('high' demand) under a 'moderate' climate change.

Under a 'high' climate change scenario the South-West region's surplus resources would reduce to between 420 x 10^6 m^3/yr ('high' regional demand) and 610 x 10^6 m^3/yr ('low' regional demand). These are similar in size to the Perth deficits of 410 x 10^6 m^3/yr ('medium' demand) to 530 x 10^6 m^3/yr ('high' demand) under 'high' climate change. Hence the only scenario in which surplus resources of the South-West region would be unable to supply the Perth demand deficit, would be if 'high' climate change and 'high' demands occurred in both regions at the same time.

The Darling Scarp dominates water resources of the South-West. Most groundwater is contained in the coastal plain to the west of the Scarp, and most potential dam sites for harnessing stream flows are adjacent to the scarp on the east. Thus both the surface and groundwater resources could be conveniently developed by a single trunk main alongside the Scarp on the coastal plain.

Water resource basins (Figure 2) were used as a basis for calculating the region's surplus water resources. The available water resources within each basin were determined after an allocation for instream uses. The total regional population was apportioned amongst the basins in line with current sub-regional population growth trends (Australian Bureau of Statistics, 1986, 1987) and the 1984 water use values (WAWRC, 1986) were pro ratered by population to determine future water demands for each basin. The surplus available to a trunk main development was then calculated for each of the regional scenarios.

Public supply irrigation demand in the South-West is high. The current allocation of approximately 160 x 10^6 m^3/yr (123 in consumption plus 37 in losses) accounts for about 90% of all publicly supplied water and some 57% of the total water consumption in the South-West region. For the purposes of this study public supply irrigation demand has been kept constant at the current level through time. However, in view of the proximity of this water to Perth, a change in use from irrigation to public water supply would need to be considered in the long term.

The basins fell into two groups. The northern basins of Harvey (613), Collie (612) and Preston (611) had virtually no surplus groundwater and only modest surplus surface water by the middle of next century under the 'moderate' regional scenario. Indeed, these basins had excess private demands on groundwater which were either transferred into the public supply system or in the case of horticultural demand, moved to the Busselton basin (610). The southern group of basins consisting of Busselton (610), Blackwood (609), Donnelly (608), Warren (607) and Shannon (606) had significant surplus water resources. Busselton and Blackwood had large groundwater surpluses and the others had large surface water surpluses.

A conceptual supply scheme was developed to progressively harness the surplus water and deliver it into the MWS system near Mandurah (Binnie, 1988b). There would be progressive development of the trunk main system alongside the Scarp picking up sources in each region up to the limit of the demand required for Perth (Figure 17). It would mainly harness surface water sources because of the lack of surplus groundwater in the three northern basins and the generally cheaper unit cost of surface sources. The total capital cost would be approximately $1260M.

Perth excess demand was assumed to commence about 2010 and increase at a rate of about 7 x 10^6 m^3/yr to a total of about 300 x 10^6 m^3/yr by 2050 ('medium' demand scenario). The overall unit cost of progressively providing up to 300 x 10^6 m^3/yr of water to Perth was estimated to be approximately 53 cents/m^3. The cost is not sensitive to supply volume, since a demand of 400 x 10^6 m^3/yr would only reduce the unit cost by a few percent to approximately 52 cents/m^3.

Direct energy costs account for about 12% of the total unit cost of the water. Under the energy scenario of a doubling of the current price of energy by 2050, the total unit cost of water would increase by about 5 cents/m^3 from 53 cents to 58 cents per cubic metre (12% increase).

The unit cost is sensitive to discount rates. The costs at discount rates of 4% and 8% are 20% lower and higher respectively than the cost of 41 cents/m^3 at a 6% discount rate.

6.3.2 Moore River basin groundwater (Working Paper 11)

Could supply up to 110 x 10^6 m^3/yr under a 'moderate' scenario at approximately 54 cents/m^3.

Significant groundwater resources exist due north of Perth on the coastal plain of the Moore River basin (Figure 18) in the Central West and East region (Section 5.2.4). These are part of the extensive groundwater resources of the Perth Sedimentary Basin that stretches from north of Geraldton to south of Busselton. The groundwater of the Moore River basin is not of high quality with about 66% being marginal.

A recent upsurge in private irrigation activity in the area is expected to continue due to restrictions on horticultural activity in the Perth region and a growing export market. Private irrigation use under the 'moderate' regional scenario would consume about 60% of the 270 x 10^6 m^3/yr available groundwater by the middle of next century, leaving about 110 x 10^6 m^3/yr surplus. Private irrigation would consume all of the available groundwater under the 'extreme' regional scenario.

A conceptual supply scheme for harnessing any surplus resources consists of six groundwater schemes and a series of transfer mains to deliver the water into the MWS system near Yanchep (Figure 18). The estimated cost of progressively supplying a total of 110 x 10^6 m^3/yr at a growth rate of about 7 x 10^6 m^3/yr is 54 cents/m^3.

6.3.3 Pilbara sources

Could supply 210 x 10^6 m^3/yr to Perth at \$4.90-\$5.10/m^3.

The Pilbara region has a reasonable amount of surplus water resources. Some 350 x 10^6 m^3/yr would be theoretically available under the 'medium' regional demand scenario and even under a 'high' scenario, some 275 x 10^6 m^3/yr would be surplus (Section 5.2.9).

However, there are significant problems in attempting to harness these surplus resources for Perth. Foremost is obviously the distance from Perth. Even the most accessible sources are over 1400 km away approximately 140 x 10^6 m^3/yr of the surplus is groundwater of the Canning Basin, widely dispersed in the Great Sandy Desert north of Port Hedland. The region's rugged terrain and climate of highly variable rainfall and high evaporation also make development relatively costly. A conceptual supply scheme to Perth could develop approximately 210 x 10^6 m^3/yr (excluding the Canning Basin groundwater) at approximately 80c-\$1.00/m^3 (Sadler, 1974) and deliver to Perth at a total unit cost of about \$4.90-\$5.10/m^3.

6.3.4 Kimberley source

Could supply the required 300 x 10^6 m^3/yr to Perth at a total unit cost of \$5.35/m^3.

The Kimberley region has abundant water resources of a high quality (Section 5.2.10). A single dam on the Fitzroy River, at Dimond Gorge for instance, would yield about 870 x 10^6 m^3/yr, i.e. enough to supply the total long-term public and private water supply needs of Perth and the G&AWS Scheme.

The major drawback of a Kimberley water supply for Perth is simply distance. The capital and operating costs of transferring water over long distances are high. This is illustrated by the fact that it is significantly cheaper to develop a new source on the Fitzroy River to supply Perth than to transport water a further 450 km from the existing Ord River Dam.

A conceptual supply scheme was evaluated (Binnie, 1988a) based on construction of a dam on the Fitzroy River at Dimond Gorge to allow partly regulated stream flows to be collected at a suitable location downstream for pumping to Perth via steel pipelines. Three pipeline routes were evaluated (Figure 19), and the costs were approximately proportional to distance. Hence the shorter, central route had the lowest cost.

The transfer system would be built in stages as demand increased. For the 'medium' demand scenario, with demand in Perth increasing by about 7 x 10^6 m^3/yr up to a total of about 300 x 10^6 m^3/yr, a single 1400 mm diameter steel pipeline system would be constructed initially, then duplicated and finally triplicated. Power would be supplied from a power station in Perth via high voltage above-ground transmission lines running alongside the pipeline. The total capital cost would be approximately $9580M.

The estimated cost of delivering the water to Perth to meet the excess demand of 300 x 10^6 m^3/yr is approximately \$5.35/m^3. The cost is sensitive to supply volume. A demand of 400 x 10^6 m^3/yr would decrease the unit cost by about 15% to approximately \$4.55/m^3.

Direct energy costs account for nearly 20% of the total unit cost of the delivered water. Under the energy scenario of a doubling of the current price of energy by 2050, the total unit cost of the water would increase by about 75 cents/m^3 from \$5.35 to \$6.10 per cubic metre (14% increase).

The unit cost of the water is very sensitive to the discount rate used. The costs at discount rates of 4% and 8% are 25% lower and 30% higher respectively than the \$5.35/m^3 at a 6% discount rate.

6.4 Other source options

6.4.1 Seawater desalination

Could progressively meet all excess demand requirements at approximately \$1.95/m^3.

The Perth-Mandurah region has only limited potable water resources but has access to the virtually unlimited saline resource of the Indian Ocean. Situated as it is on a coastal plain with urban growth expected to be largely along corridors adjacent to the ocean, the city is ideally situated to develop a series of seawater desalination plants along the coast to match demand growth.

A study was carried out to evaluate the alternative desalination technologies available to determine the most suitable for Perth and the unit cost of the water (Binnie, 1988c). The costs have been based on a conceptual desalination plant module progressively increasing its production capacity over four years to an output of 150 million litres per day (MLD) or approximately 52 x 10^6 m^3/yr. Six such desalination plants would be progressively installed along the coast to produce the 300 x 10^6 m^3/yr excess demand under the 'moderate' regional scenario for Perth. The total capital cost of the plants would be approximately \$2180M.

Binnie (1988c) concluded that the reverse osmosis (R.O.) process was significantly less expensive than the currently more widely used multi-stage flash (M.S.F.) process. Significant improvements in the technology of membranes used in the RO process has reduced the need for pre-treatment of the saline water and reduced the pressure levels required to desalt the water.

The cost of the desalinated water produced by the RO process using current technology is estimated to be approximately $\$1.95/m^3$. Continuing improvements in membrane technology expected over the next few decades should reduce this cost by 20% to approximately $\$1.60/m^3$. The unit cost is not sensitive to supply volume, since the conceptual plant modules develop their full output capacity within a relatively few years.

Direct energy costs account for about 40% of the total unit cost of the water. A doubling of the current price of energy by 2050 would increase the total unit cost of water by about 80 cents/m^3 from \$1.95 to \$2.75 per cubic metre (41% increase). However, continuing improvements in membrane technology would help offset this increase and the likely future cost would be about $\$2.25/m^3$ (15% increase).

The unit cost is not sensitive to discount rates. The costs at discount rates of 4% and 8% are 5% lower and higher respectively than the $\$1.95/m^3$ at a 6% discount rate.

6.4.2 Icebergs

A possible option but constrained by difficulties for the foreseeable future.

Interest in the potential use of icebergs for water supply purposes commenced in the early 1970s with a paper by Weeks & Cambell (1973) which proposed delivering icebergs of about 1 km^3 volume to the south-west of Australia. Interest strengthened during the 1970s with the formation of a company called Iceberg Transport International (ITT) under the chairmanship of Prince Al Faisal Al Saud of Saudi Arabia to investigate the commercial feasibility of harnessing icebergs for water supply.

The commercial viability centred on being able to deliver iceberg water to the Middle East for less than the cost of desalination of seawater. Obtaining reliable costing information is difficult, with estimates of delivery varying from 40 cents/m^3 to \$2.20/m^3. However, the earlier confidence that iceberg water could be delivered to the Middle East for less than the cost of desalination of seawater appears to be waning, and interest has declined.

A 0.1 km^3 iceberg towed to a deepwater channel near Rottnest could yield about 100×10^6 m^3 of freshwater over about 3 years. However, there would be many problems in harnessing a water supply from an iceberg even assuming it could be successfully delivered to a location near Rottnest. Extracting freshwater from the continuously melting iceberg would be difficult, as would anchoring it to prevent it drifting or becoming unstable as it reduced in size. Transporting the water to the mainland by either offshore pipeline or small tankers would add about 45-50 cents/m^3 to the cost. Storage facilities would probably be required to allow the water temperature to increase to a reasonable level and prevent a significant increase to the cost of domestic water heating.

6.4.3 Tankering

Cheaper than piping water over long distances, and could supply the required 300 x 10^6 m^3/yr from the Kimberleys at \$3.30/m^3.

Tankers have been used elsewhere for water supply purposes and are being currently investigated for large scale operations in the Middle East (Farooq & Al-Layla, 1987) and North America. The most economical operations involve large tankers (i.e. in excess of 300 000 tonnes).

Binnie (1988a) included a preliminary investigation of the use of large (300 000 tonne) sea tankers to transport water to Perth from the Kimberley region. The conceptual scheme involved the purchase of a fleet of tankers and the installation of facilities for on-loading at Black Rocks (near Derby), and for off-loading at Rottnest. The unit cost of approximately \$3.30/m^3 was surprisingly low in comparison with the pipeline options. However, a fleet of more than 38 tankers would be required to operate continuously to supply the 300 x 10^6 m^3/yr excess water demand for Perth.

A nearer source of surplus water for Perth is the South-West. On the same conceptual basis as the Kimberley proposal, the cost of tankering water from the South-West would be about \$1.30/m^3 - significantly more expensive than transporting the water by pipeline. It is apparent that pipeline transportation in Western Australia is more economic for relatively short distances of a few hundred kilometres, but over longer distances tankering has the potential to be significantly cheaper than to pipe water over the same distance.

6.5 Evaluation of water supply options for Perth

6.5.1 Range of supply options

The water supply options for Perth outlined in the previous sections are summarised in the table below:

SOURCE	YIELD[1] (10^6 m^3/yr)	COST ($/$m^3$)	COMMENTS
Additional Perth region sources			
. Brackish water	37	1.10	requires desalination
. Forest thinning	29	0.05	environmental impacts require further investigation.
. Reuse of wastewater[2]	25	3.00	industrial,
	15	0.20	public irrigation &
	18	1.70	aquifer recharge use.
. Excess drainage	40	0.30-0.55	
. Rainwater tanks	12	2.10	potential health risks.
. Groundwater manipulation	not estimated	not estimated	constrained by wetlands.
. Groundwater storage	not estimated	not estimated	environmental acceptability uncertain.
Inter-regional transfers to Perth			
. South-West sources	730-920[3]	0.53	mainly surface water sources.
. Moore River basin	0-110[3]	0.54	mostly marginal quality.
. Pilbara sources	210	4.90-5.10	
. Kimberley sources	870	5.35	
Other source options			
. Seawater desalination	>500	1.95	
. Icebergs	> 30	Unknown	feasibility not proven.
. Tankering	>300	3.30	cheaper than piping water over very long distances.

Table 2: SUMMARY OF WATER SUPPLY OPTIONS FOR PERTH

(1) Yield at 2050 assuming 'moderate' climate change (C1).

(2) Not for domestic use.

(3) Surplus resources under 'high' and 'medium' regional demand scenarios respectively.

The additional Perth-Mandurah region source options vary from small to moderate in size with a combined annual yield of approximately 170 x 10^6 m^3/yr (i.e. about half of the supply deficit under the 'moderate' regional scenario).

'Groundwater manipulation' and 'groundwater storage' are likely to be constrained by environmental considerations. The high unit cost of the 'rainwater tank' option make installation by a significant number of householders unlikely and its total contribution as a resource would be small.

Interregional transfers to Perth from the South-West, Moore River, Pilbara and Kimberley are all potentially feasible. The large size and relatively low cost of the South West option make it an attractive long-term supply option. Likewise the Moore River basin groundwater is a potentially important supply option and an allocation for public supply use should be preserved. In contrast to these two options, the high cost of the Pilbara and Kimberley options make then unattractive.

Of the remaining source options, the desalination of seawater remains a robust long-term supply option. Tankering water is a possible long-term option for transporting water over very long distances (>1000 kms). However, the feasibility of the use of icebergs for water supply purposes has not been proven and the costs are unknown.

Rearranging the proven and sizeable options approximately in order of their unit costs results in the following table:

SOURCE	YIELD ($\times 10^6$ m^3/yr)	COST ($/$m^3$)
. Forest thinning	29	0.05
. Excess drainage	40	0.30-0.55
. South-West sources	730-920	0.53
. Moore River basin	0-110	0.54
. Brackish water	37	1.10
. Reuse of wastewater[(1)]	43	1.70-3.00
. Seawater desalination	>500	1.95
. Tankering	>300	3.30
. Pilbara sources	210	4.90-5.10
. Kimberley sources	870	5.35

(1) Not for domestic use.

Table 3: RANKED WATER SUPPLY OPTIONS FOR PERTH

6.5.2 Major long-term supply options

The three major long-term supply options are: water from the South-west, water from the Kimberleys and desalination of seawater. A comparison of their associated costs are provided in Table 4.

SUPPLY OPTION	CAPITAL COST ($M)	UNIT COST[(1)] ($/$m^3$)	EFFECT ON UNIT COST OF CHANGES IN DEMAND[(2)]	ENERGY COST[(3)]	DISCOUNT RATE[(4)]
South West	1260	0.53	-0.01	+0.05	±0.08
Desalination	2180	1.95	Small	+0.79	±0.10
Kimberley	9580	5.35	-0.82	+0.73	±1.50

(1) Demand of 300 million m^3/yr, energy cost of 10c/kWh, discount rate of 6%.

(2) Demand of 400 million m^3/yr.

(3) Energy cost of 20c/kWh.

(4) Discount rates of 8% and 4%.

Table 4: COST COMPARISON OF MAJOR SUPPLY OPTIONS FOR PERTH

The South West supply option dominates because of its relatively large volumes and low cost. Variations in demand, energy cost and discount rates have little effect on its overall unit cost.

The cost of seawater desalination is an important benchmark. Since the supply is virtually unlimited, its unit cost effectively provides an upper limit on the cost of supply options for Perth (Mauger, 1987).

The Kimberley supply option has significantly greater capital and unit costs than desalination. It is also much more sensitive to variations in demand and discount rates. The effect on unit costs of a doubling of direct energy costs would be about the same for both options. Hence the Kimberley supply option is not competitive with desalination unless it can provide sufficient additional social and economic benefits to the State to offset its higher cost. Studies are continuing on the nature and magnitude of these potential additional benefits.

6.5.3 Supply options to meet excess demand

Excess demand in the Perth-Mandurah region (including G&AWS demand) under 'low', 'moderate' and 'extreme' regional scenarios would be approximately 95, 300 and 530 million cubic metres per year respectively.

The 'low' excess demand value could be met by additional resources within the region, or transfers of a portion of the surplus resources of adjacent regions (South-West or Moore River basin).

The 'moderate' excess demand of approximately 300×10^6 m^3/yr would require some transfer of water from adjacent regions, particularly the South-West. Surplus South-West resources are so large that even under an 'extreme' regional scenario, they would still be able to supply the full 'moderate' excess demand needs of Perth.

The 'extreme' excess demand of approximately 530 x 10^6 m^3/yr would require substantial transfers of water from the South-West and Moore River basin areas and may require some seawater desalination. Under a 'severe' climate change the surplus water resources in the South-West would be 420-610 million m^3/yr (depending on demand). If limited water were able to be harnessed from the additional sources in the Perth region and the Moore River basin, some use of desalinated seawater would be required.

7.0 GOLDFIELDS WATER SUPPLY OPTIONS

7.1 Introduction

The Goldfields area has a severe lack of available potable water resources (see Section 5.2.2). There are no surface water sources, and divertible potable groundwater sources are small and widely scattered, making them unsuitable for harnessing into a reticulated supply scheme for Kalgoorlie.

The area's potable water supply needs have been met since the turn of the century by water transfer from Mundaring Weir in the Perth-Mandurah region via the Goldfields and Agricultural Water Supply (G&AWS) scheme. Current demand is about 13 x 10^6/yr, of which approximately 5 x 10^6 m^3/yr is for industrial use.

Industrial demand for saline water has increased greatly in recent years, from less than 2 x 10^6 m^3/yr in 1984 to the current level of about 14 x 10^6 m^3/yr. Further growth in demand is expected over the next few years, with a doubling to about 32 x 10^6 m^3/yr by the early 1990s (BHP Eng., 1988). Previous industrial demand has been met from local hypersaline groundwater found in ancient river courses ('paleochannels') in the area.

A 'medium' demand scenario was developed based on the increase in industrial demand anticipated by the BHP Eng. report. Predicting long-term industrial demand in the Goldfields is extremely difficult. The 'medium' scenario assumes demand will remain constant at the new higher level of 32 x 10^6 m^3/yr through to the middle of next century. The increased mining activity is not expected to significantly increase the population and hence potable water demand in the

Goldfields (Dept of Resources Devel. pers. comm.). The 'medium' scenario assumes potable water demand on the G&AWS will increase from 14 to 17 x 10^6 m^3/yr by the middle of next century, in line with the population growth scenario for the region outlined in Section 3.2.

A 'high' demand scenario was developed by assuming that the region would grow at the same rate as the fastest growing region (the South West). This effectively resulted in a doubling of the 'medium' potable and saline water demand values. Although this demand scenario is considered to be artificially high it is useful in testing the water supply implications of higher than expected regional demand.

7.2 Supply options (see Binnie report 1988d)

The two existing supply sources (G&AWS and paleochannel groundwater) and eight additional potential supply options were evaluated (Figure 20).

7.2.1 Existing G&AWS scheme

The existing G&AWS scheme pumps approximately 24 x 10^6 m^3/yr of water from Mundaring Weir, of which approximately 13 x 10^6 m^3/yr is supplied to the Goldfields.

The existing Goldfields scheme has a maximum supply capacity of approximately 17 x 10^6 m^3/yr at an estimated current cost of approximately \$1.80/m^3. Hence without significant upgrading the scheme is not able to meet the industrial saline water demand, or large increases in potable water demand.

7.2.2 Additional Perth supply

Additional water could be supplied to the Goldfields from the Perth-Mandurah region, but this would require significant upgrading of the existing scheme or an additional supply main.

However, the water resources of the Perth-Mandurah region are likely to be in deficit by the middle of next century, hence pumping additional large quantities of water to the Goldfields would require importing equivalent amounts from an adjacent region such as the South West, at a cost of about $0.53/m^3$ (Binnie, 1988b).

The cost of providing additional water from Perth via a new supply main (including the cost of importing an equivalent amount from the South West) is estimated to be between $2.20 and $7.40/m^3$, depending on demand.

7.2.3 Local saline groundwater (paleochannels)

The current major water source for private industry in the Goldfields is the locally available hypersaline (40 000 to 200 000 mg/L TDS) groundwater found in the ancient river courses (paleochannels). The paleochannel resources have a negligible recharge fate, hence current extraction is 'mining' the resource and its life is limited. As the paleochannel resources close to the mining centres are exhausted, users will have to progressively go further afield to new paleochannel sources.

The total volume of paleochannel water within a radius of 100 km of Kalgoorlie is estimated to be approximately 1100×10^6 m^3 (BHP Eng., 1988). Assuming the paleochannel resources are proportional to area, extraction at a radius of 135 km of Kalgoorlie would be required by 2050 to satisfy the 'medium' demand scenario private industrial use total of approximately 2000×10^6 m^3. To meet the 'high demand scenario private industrial total of about 3300×10^6 m^3 extraction would be occurring at a radius of about 175 km of Kalgoorlie.

The current cost of extracting and piping the hypersaline groundwater varies according to distance and magnitude of demand, but is estimated to be an average of about \$0.30/m^3. The majority of mining projects in the Kalgoorlie area are within a 50 km radius of the town. The cost of obtaining paleochannel water from 135 km out is estimated to be about \$1.60/m^3 and from 175 km out, approximately \$2.40/m^3.

Small quantities of paleochannel groundwater are currently desalinated for industrial use. Desalination on a large scale could be carried out to supply some of the excess potable water requirements of the 'high' demand scenario, but there are a number of difficulties. Only the better quality hypersaline waters (i.e. less than 60 000 mg/L TDS) would be suitable and their locations and total volume are not known. The desalination costs are difficult to estimate, but would be at least that of seawater desalination (i.e. approximately \$2.00/m^3). Hence the total cost of extraction and desalination would vary from at least \$2.30/m^3 initially to more than \$4.65/m^3 in the future as water is drawn from further afield.

7.2.4 Regional potable groundwater (Wiluna)

The divertible potable groundwater resources of the Goldfields-Esperance region are small and widely scattered. The high cost of piping water over long distances makes it impractical to harness a number of small, widely dispersed sources into a scheme large enough to supply the Goldfields' water needs.

The largest known divertible potable groundwater source in the region is the Pardoo calcrete aquifer at Wiluna, some 470 km from Kalgoorlie. The storage volume of the aquifer is estimated to be 104 x 10^6 m^3 and its renewable yield only 4.5 x 10^6 m^3/yr (Geological Survey, 1972).

Piping the water to Kalgoorlie to meet the excess potable or saline demands would involve 'mining' the resource as the annual volumes required would greatly exceed the renewable yield. In some of the demand cases examined, the storage would be completedly exhausted within a few years.

Since the amount of water able to be extracted from the aquifer is limited, the unit cost of the water is quite high, varying from about $8.65 to $12.70/$m^3$ depending on demand.

The Pardoo calcrete aquifer is the current supply source for Wiluna, and in reality would not be available for supply to Kalgoorlie but would be preserved as a renewable resource for Wiluna's long-term water needs.

7.2.5 Esperance seawater supply

The possibility of a seawater pipeline from Esperance (a distance of about 350 km) is currently being investigated by the Kalgoorlie Development Corporation. The seawater would replace the local hypersaline groundwater as the primary source of saline water for industrial use.

The cost of the delivered seawater is estimated to be $1.20 to $1.70/$m^3$ depending on demand (Binnie, 1988d).

The seawater could also be desalinated to provide a potable water supply to Kalgoorlie. If the desalination was carried out at Esperance a separate supply main would be required to deliver the desalted water to Kalgoorlie. Alternatively, an enlarged single supply main would deliver seawater to

Kalgoorlie where a portion would be desalted for potable use. Although only one-third of the seawater entering the desalination plant would be recovered as potable water, the other two thirds would not be wasted, as it would be used for industrial demand.

The cost of providing a potable supply of desalinated seawater from Esperance is estimated to be between \$3.00 and \$6.35/m^3 depending on demand.

7.2.6 Moore River basin groundwater supply

The large surplus groundwater resources on the coastal plain of the Moore River basin north of Perth could be piped directly to the Goldfields. Such a scheme would have the added advantage of being able to provide additional water supplies to the northern end of the Agricultural Water Supply scheme. The distance to Kalgoorlie is approximately 600 km.

The estimated cost of delivering potable water to Kalgoorlie is between \$1.80 and \$6.90/m^3, depending on demand.

7.2.7 South West supply

The Deep River in the Shannon River basin of the South West region has a divertible yield of approximately 120×10^6 m^3/yr. This surplus yield could be diverted and piped to the Goldfields. Such a scheme would have the added benefit of being able to provide additional water supplies to the southern end of the Great Southern Towns Water Supply scheme. The distance to Kalgoorlie is approximately 650 km.

The estimated cost of the water at Kalgoorlie is between \$1.95 and \$8.00/m^3 depending on demand.

7.2.8 Kimberley supply

The Fitzroy River could be developed and piped to Kalgoorlie, over a distance of about 1400 km.

The estimated cost of water from such a scheme would be between \$4.00 and \$17.00/m^3 depending on demand.

7.3 Evaluation of Goldfields supply options

7.3.1 Comparison of supply options

Table 5 below summarises the potential supply options for the Goldfields outlined above.

The supply options fall into 5 basic groups as follows:

- Existing G&AWS supply - potable
- Local paleochannels supply - hypersaline and desalinated
- Esperance seawater supply - saline and desalinated
- Inter-regional supply (Moore River basin, Southwest, Perth) - potable
- Remote supply (Kimberley, Wiluna) - potable

The existing G&AWS supply is the least expensive potable source, but its additional capacity is limited.

The local paleochannel groundwater is the least expensive source for private industrial demand, with relatively large storage volumes, but the resource is limited and will progressively become more expensive as water is drawn from further afield. The cost of providing desalinated potable water would be moderate initially, but increase steadily with time as supplies are drawn from further out.

Potential sources	Water Quality	Distance (km)	'MEDIUM' DEMAND RETIC.[A]	'MEDIUM' DEMAND PRIVATE INDUST.[B]	'HIGH' DEMAND SEPARATE SUPPLY RETIC.[C]	'HIGH' DEMAND SEPARATE SUPPLY PRIV.INDUST.[D]	'HIGH' DEMAND COMBINED SUPPLY[E] RETIC.	'HIGH' DEMAND COMBINED SUPPLY[E] PRIV.INDUST.
			Unit Costs ($/m^3)					
1) Existing G&AWS scheme	potable	520	1.80	-	-	-	-	-
2) Additional Perth supply	potable	520	-	2.95	7.40	2.15	2.25	2.45
3) Local saline groundwater		25-175						
- raw groundwater	saline		-	0.3-1.60	-	0.3-2.40	-	0.3-2.65
- desalinated	potable		-	-	2.30-2.40		2.3-4.65	
4) Regional potable groundwater (Wiluna)	potable	470	-	11.10	8.65	10.45	12.50	12.70
5) Esperance seawater supply		350						
- raw seawater	saline		-	1.70	-	1.20	-	-
- desalination at Esperance	potable		-	3.70	6.30	3.20	3.10	3.30
- seawater with	saline							1.30
desalination at Kalgoorlie	potable		-				3.10	
6) Moore River basin groundwater supply	potable	600	-	2.65	6.90	1.85	1.80	2.00
7) South West supply	potable	650	-	2.90	8.00	1.95	2.05	2.25
8) Kimberley supply	potable	1400	-	5.95	17.00	4.00	4.20	4.40

(A) Potable demand of 14-17 x 10^6 m^3/yr can all be supplied from G&AWS.
(B) Saline or potable demand of 21-32 x 10^6 m^3/yr.
(C) Potable demand of 15-35 x 10^6 m^3 yr (0-18 x 10^6/yr excess over G&AWS capacity)
(D) Combined demand of 23-84 x 10^6 m^3/yr (0-18 potable & 23-66 saline or potable)

TABLE 5: SUMMARY OF WATER SUPPLY OPTIONS FOR THE GOLDFIELDS

Piping seawater from Esperance for private industrial use would be more expensive than using the local paleochannel supplies, but this situation may be reversed in the long term if heavy demand exhausts the paleochannel storages in the vicinity of Kalgoorlie. Likewise, although the current cost of providing desalinated seawater would be higher than desalinated local groundwater, in the long term this situation could be reversed, depending on the size of demand. The relatively high cost of a dual supply (potable and saline) system in comparison with a single large main from Esperance favours desalinating the seawater at Kalgoorlie rather than Esperance.

The costs of the inter-regional supply schemes from the Moore River basin, the Southwest, or Perth are similar, but favour the former. To be competitive, this supply source would need to provide the combined excess retic and private industrial demands. The cost of providing the excess reticulation demand alone is prohibitive.

The 'remote' supply options of the Kimberleys and Wiluna, are significantly more expensive than all the other options. Additional social and economic development benefits generated by the Kimberley option would need to be large to justify the additional expense. The Pardoo calcrete aquifer resources are too small and valuable as a supply source for Wiluna to be diverted to Kalgoorlie.

7.3.2 'Medium' demand scenario

The existing G&AWS scheme has the capacity to meet the current and long-term reticulation supply needs of the Goldfields under the 'medium' demand scenario.

The total private industrial demand of approximately 2000×10^6 m^3 by the year 2050 under the 'medium' demand scenario can be met by the existing supply source of the local hypersaline groundwater.

However, by the end of this time frame all the local groundwater within a 135 km radius of Kalgoorlie would have been exhausted, and the high cost (>$1.60/$m^3$) of continuing to go further afield for more water would make a seawater pipeline from Esperance a competitive option at $1.70/$m^3$.

7.3.3 'High' demand scenario

The three basic supply options to meet the high demand scenario are compared in Table 6 below.

		SUPPLY COSTS ($/$m^3$)			
SUPPLY OPTION	WATER	SEPARATE SUPPLY		COMBINED SUPPLY	
	QUALITY	RETIC.	PRIV IND.	RETIC.	PRIV.IND.
* Local hypersaline groundwater					
- raw groundwater	saline		0.30-2.40		0.30-2.65
- desalinated	potable	2.30-2.40		2.30-4.65	
* Esperance seawater					
- raw seawater	saline		1.20		
- seawater &	saline				1.30
desalinated	potable			3.10	
* Moore River basin	potable	6.90	1.85	1.80	2.00

TABLE 6: COMPARISON OF GOLDFIELDS 'HIGH' DEMAND SUPPLY OPTIONS

From an examination of the table it is clear that, in the short term at least, local hypersaline groundwater will continue to provide the lowest cost supply for private industrial demand. While industrial demand is being met by local groundwater the cost of $6.90/m^3 for water from the Moore River basin will remain prohibitively expensive and desalination of the local groundwater at about $2.30/m^3 will provide the cheapest source of potable water to meet excess reticulation demands.

After about 2015 groundwater within a 120 km radius of Kalgoorlie would have been exhausted and the cost of continuing to go further afield for more groundwater to meet industrial demand will become more expensive than developing a seawater supply scheme from Esperance at $1.30/m^3.

The two other supply options would then become attractive alternatives. Seawater from Esperance would provide cheaper water for industrial use ($1.30 compared with $2.00), but more expensive potable water (after desalination) for reticulation demand use ($3.10 compared with $1.80). This would present a difficult choice, with the mining companies favouring the seawater pipeline from Esperance and the urban consumers favouring the freshwater supply from the Moore River basin. However, since the private industrial demand is three times greater than the excess reticulation system demand, the combined cost to the two consumers of the seawater supply scheme from Esperance is less.

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A HILL	Advice, Regional demands.
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F WOOD	Investigation, Desalination sub-study.
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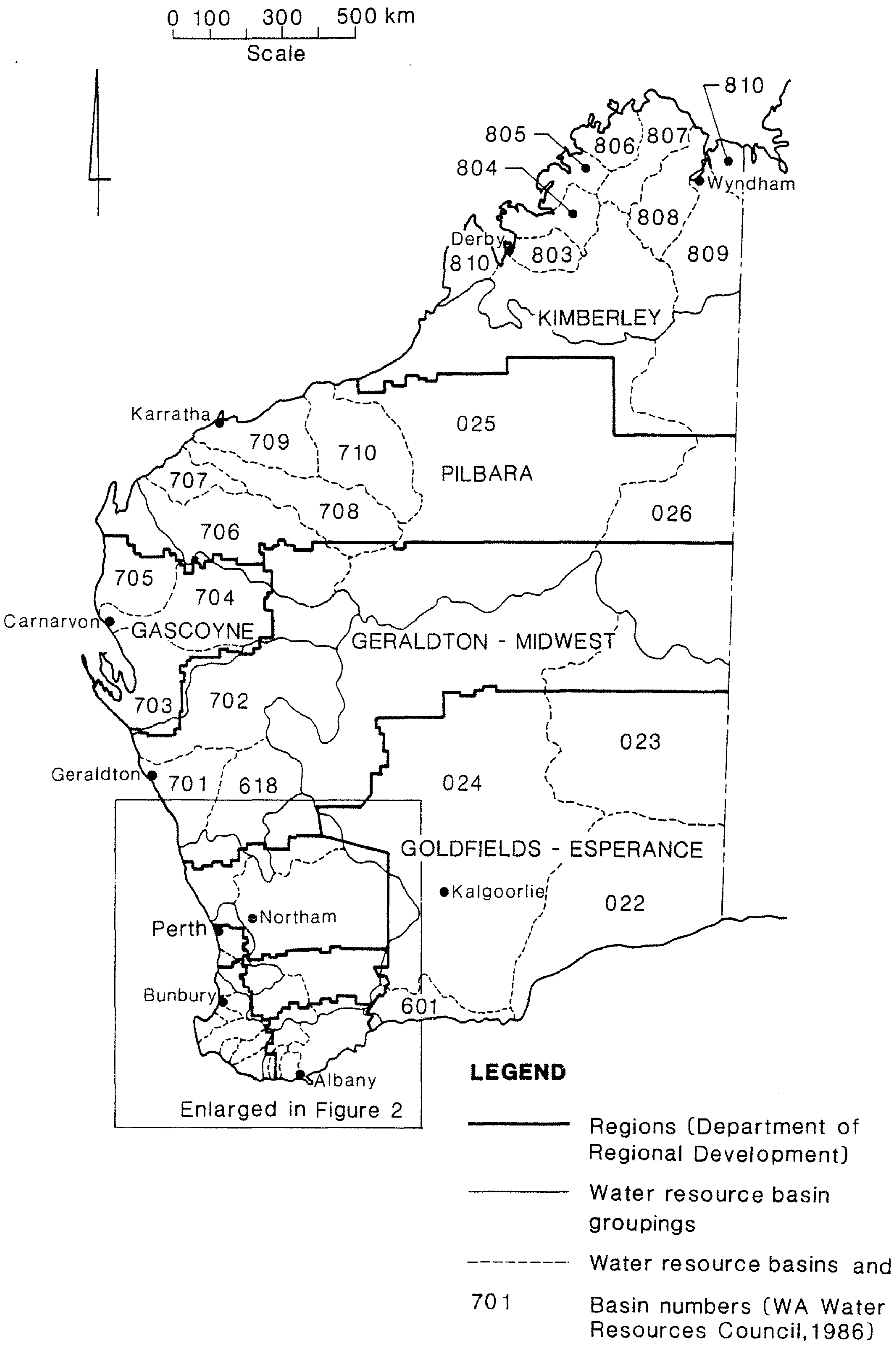

Figure 1: Regional and Water Resources Boundaries - State

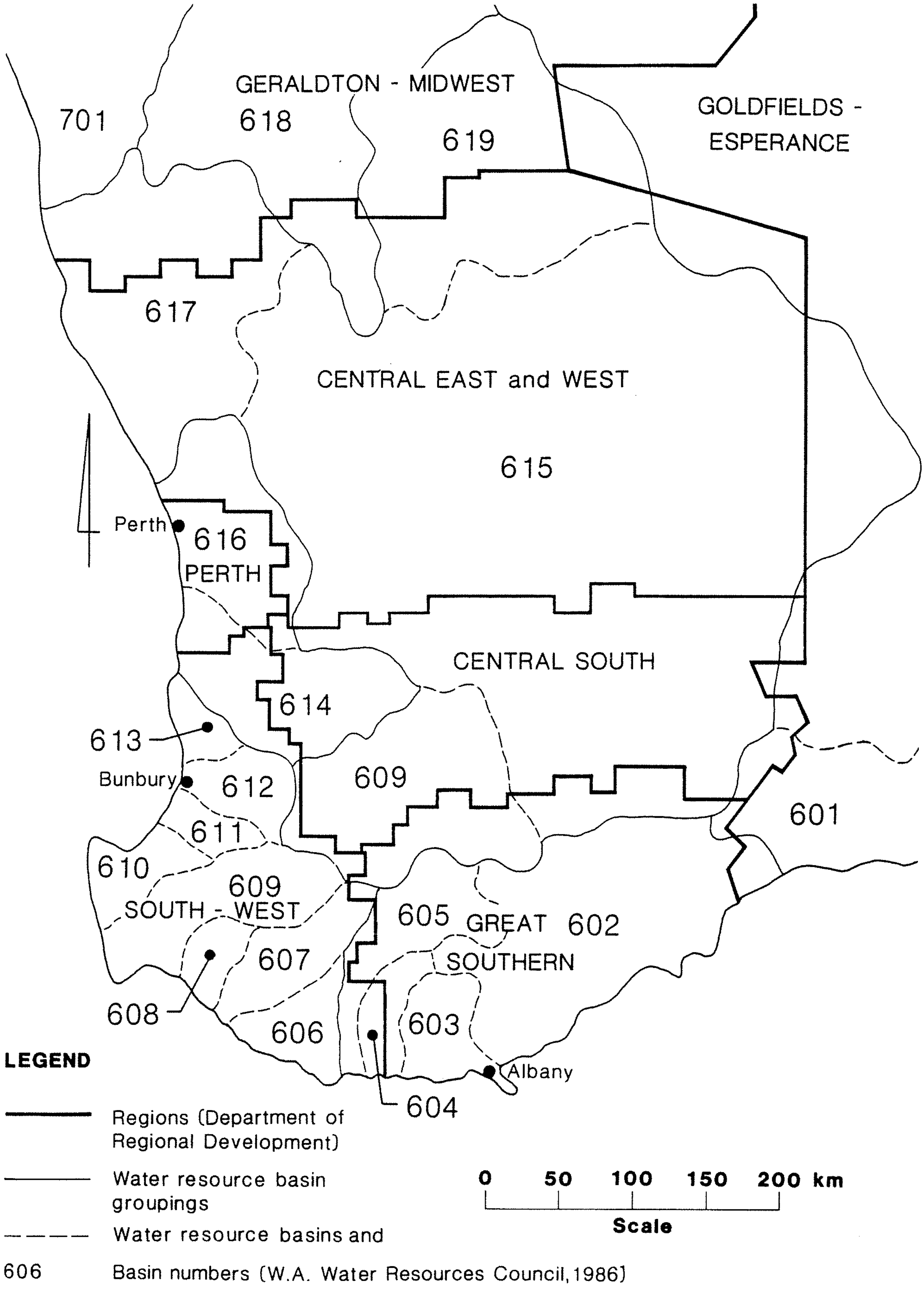

Figure 2: Regional and Water Resources Boundaries - south west

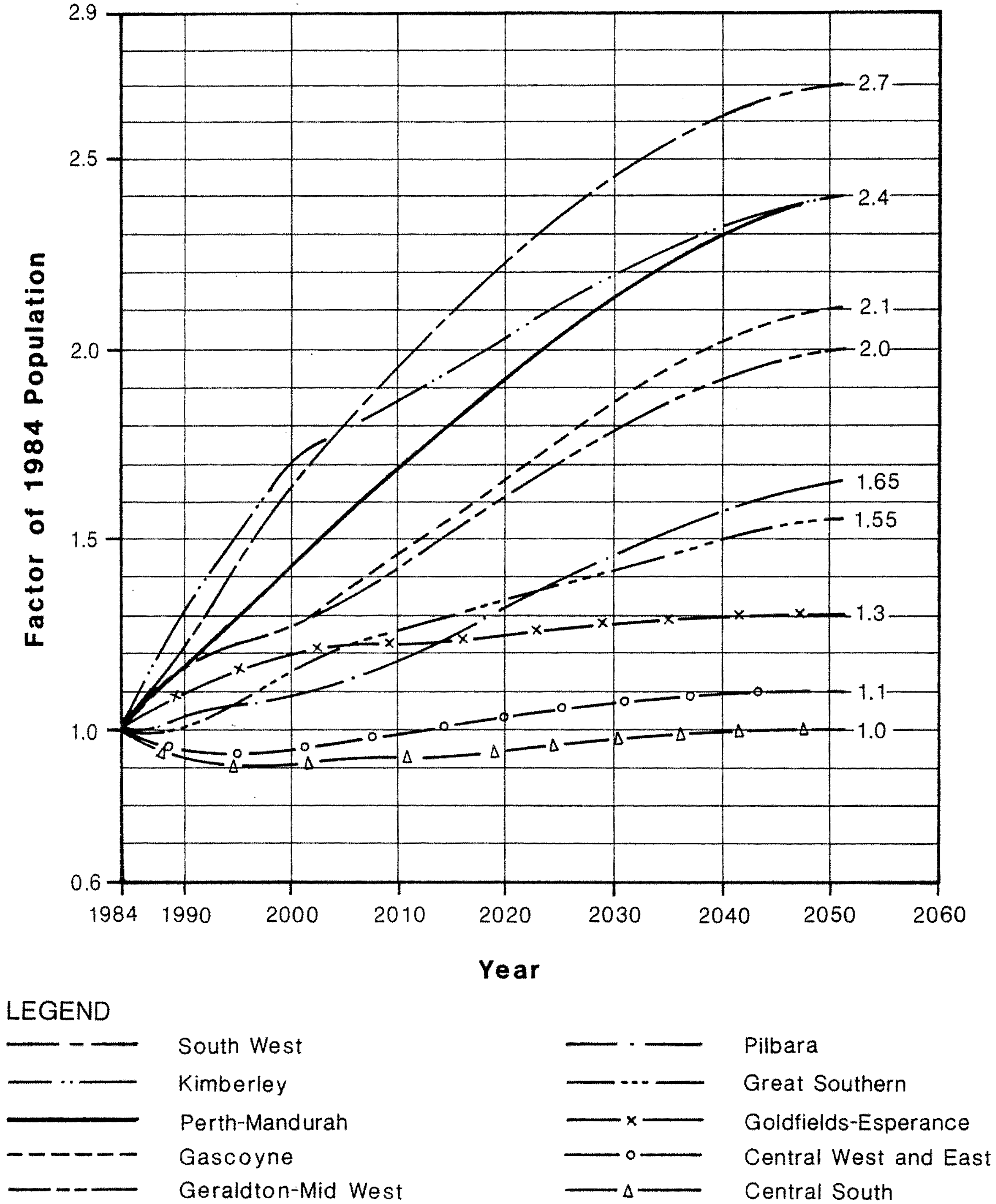

Figure 3: Regional `moderate` population scenarios

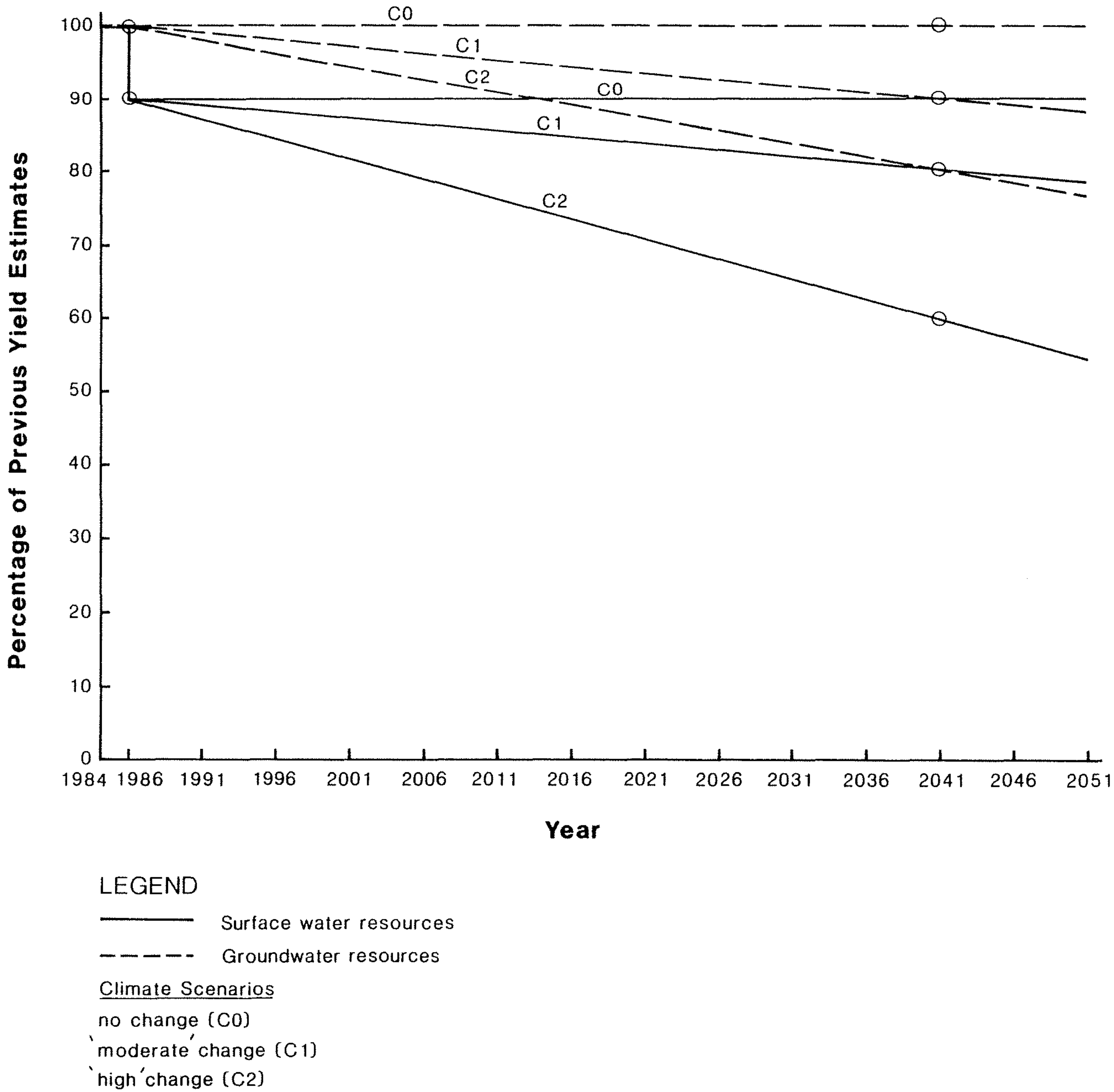

Figure 4: Climate scenarios

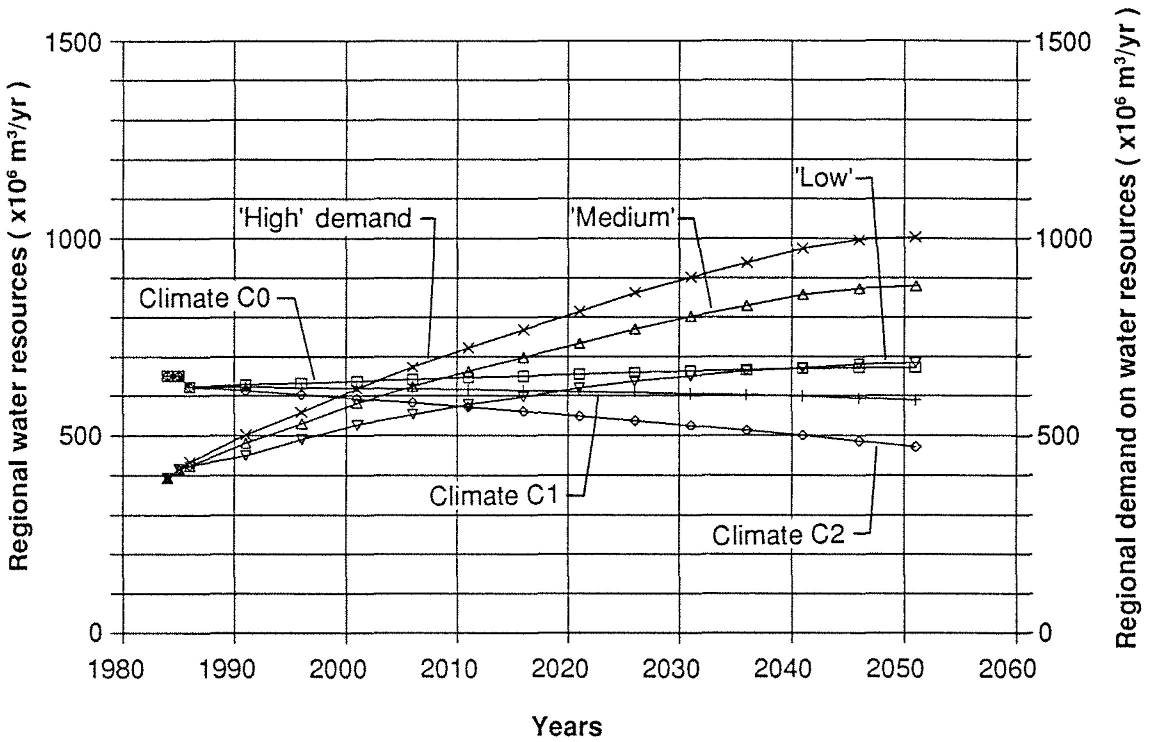

Figure 5: Regional water resource utilisation; Perth–Mandurah

Note: Values include G&AWS demand

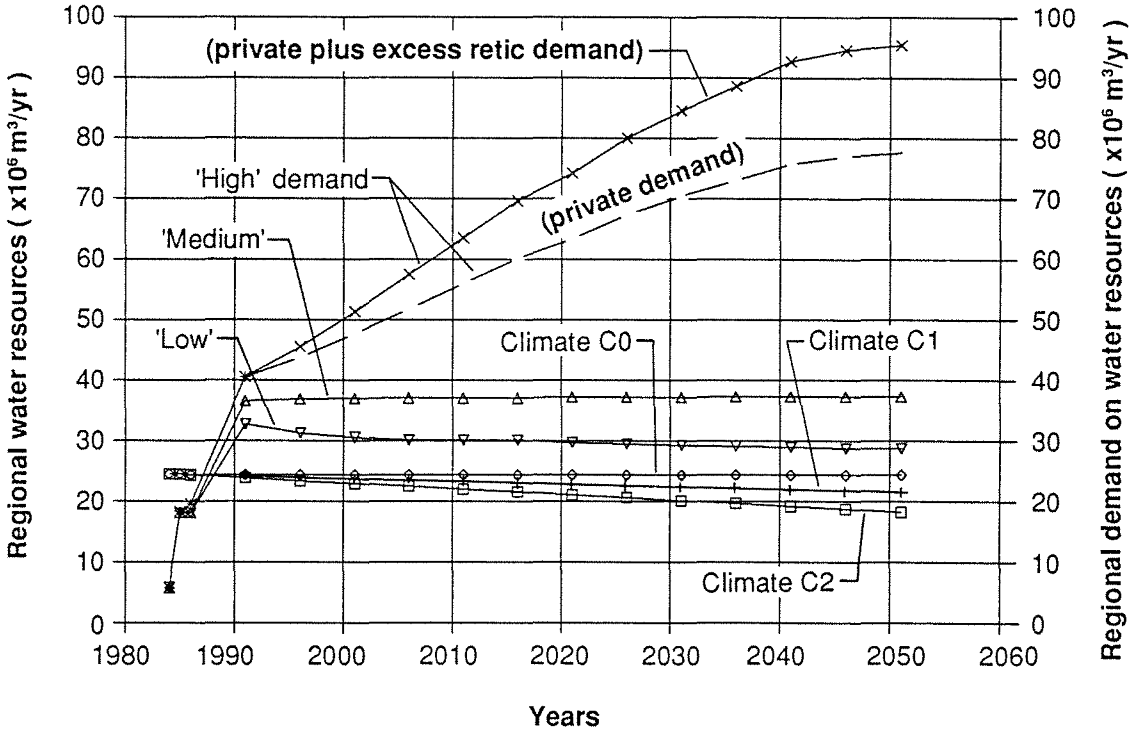

Figure 6: Regional water resource utilisation; Goldfields–Esperance

Note: Values exclude G&AWS demand

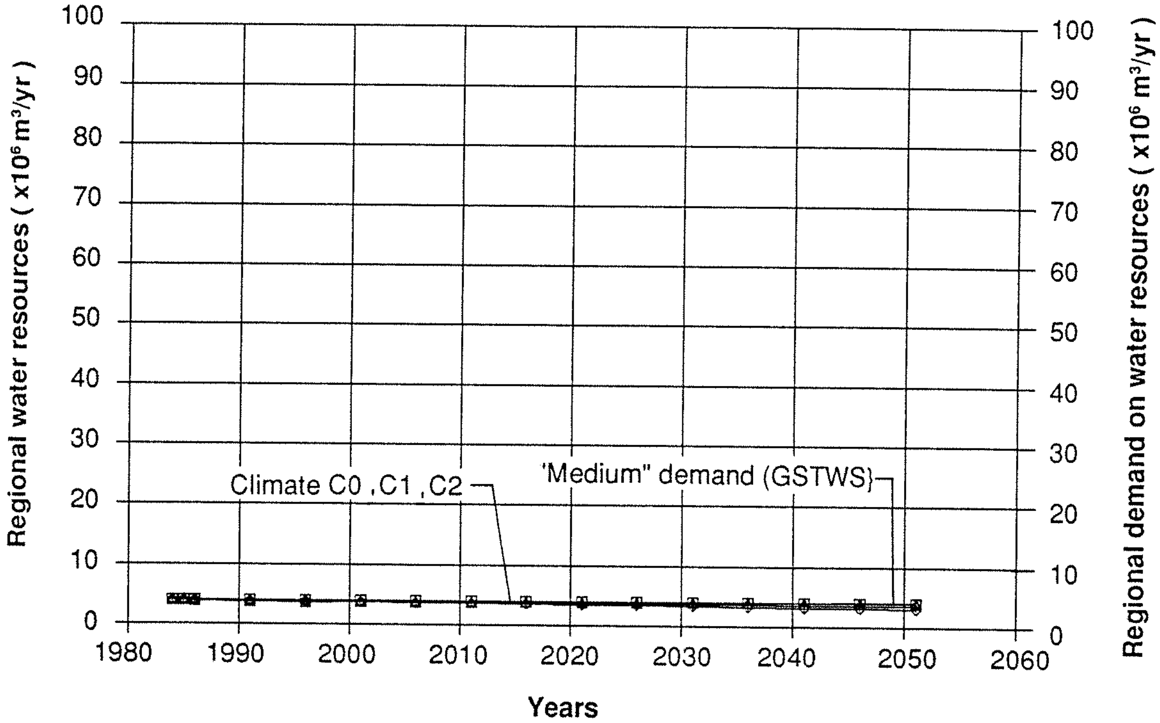

Figure 7: Regional water resource utilisation; Central South

note: GSTWS demand values included in South West demand

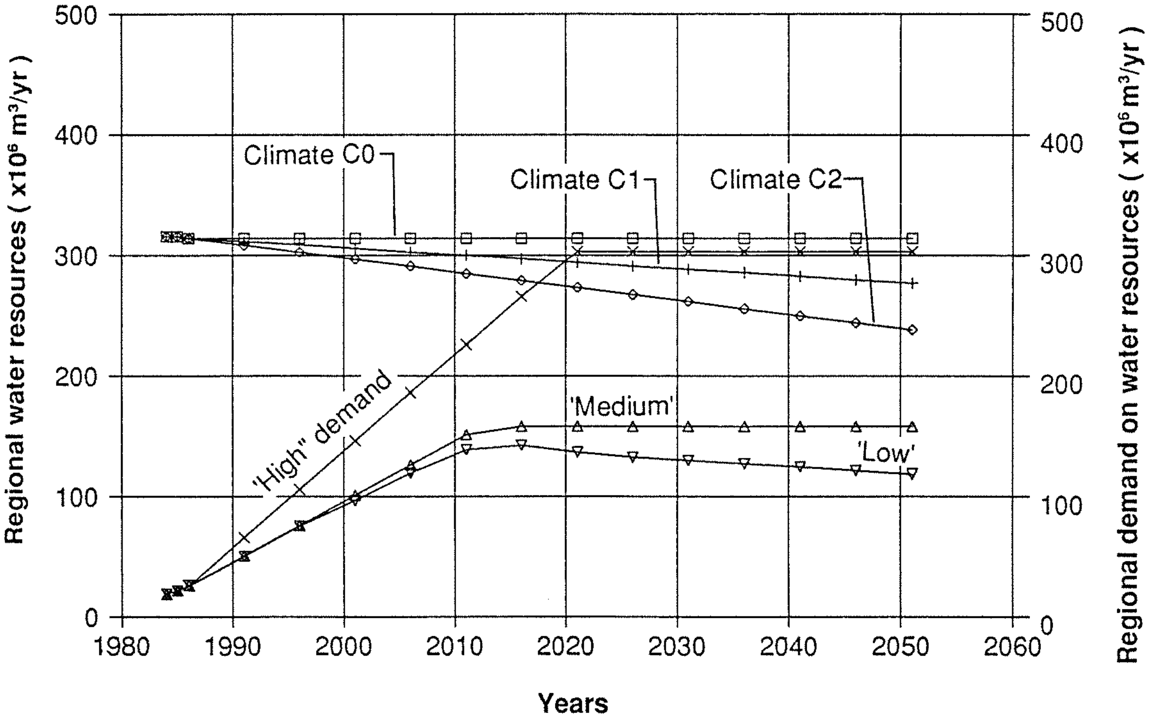

Figure 8: Regional water resource utilisation; Central West and East

Note: Values exclude G&AWS demand

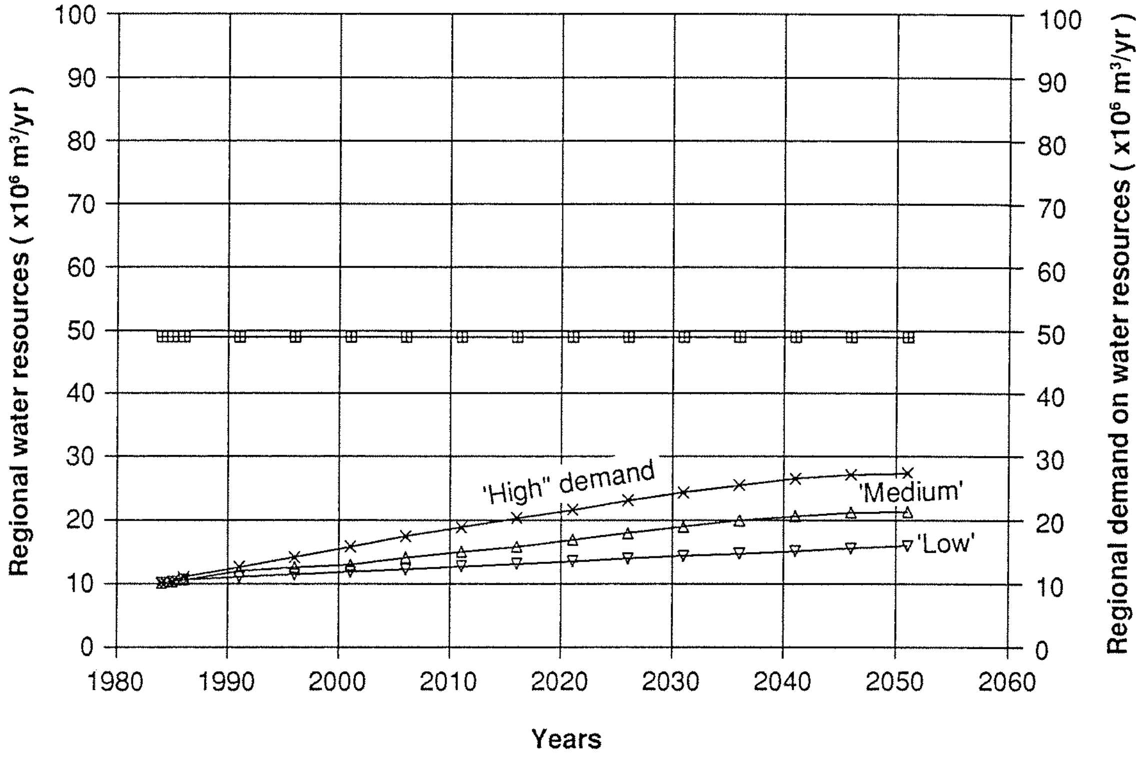

Figure 9: Regional water resource utilisation; Gascoyne

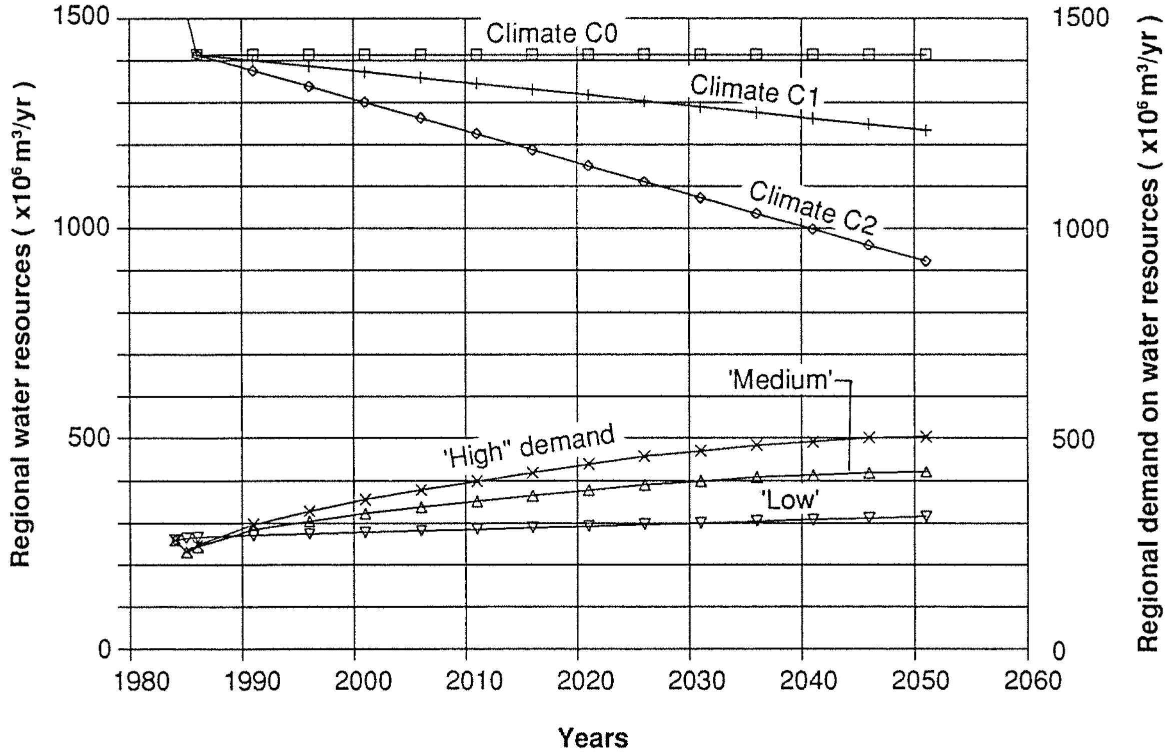

Figure 10: Regional water resource utilisation; South West

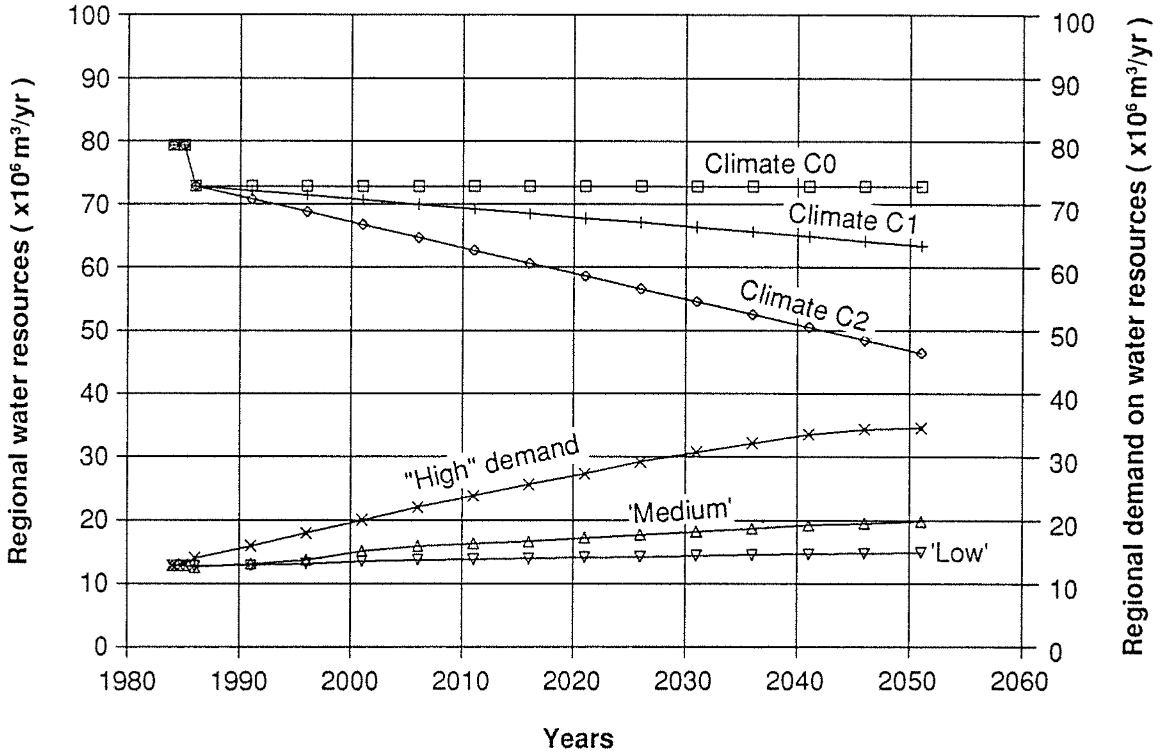

Figure 11: Regional water resource utilisation; Great Southern

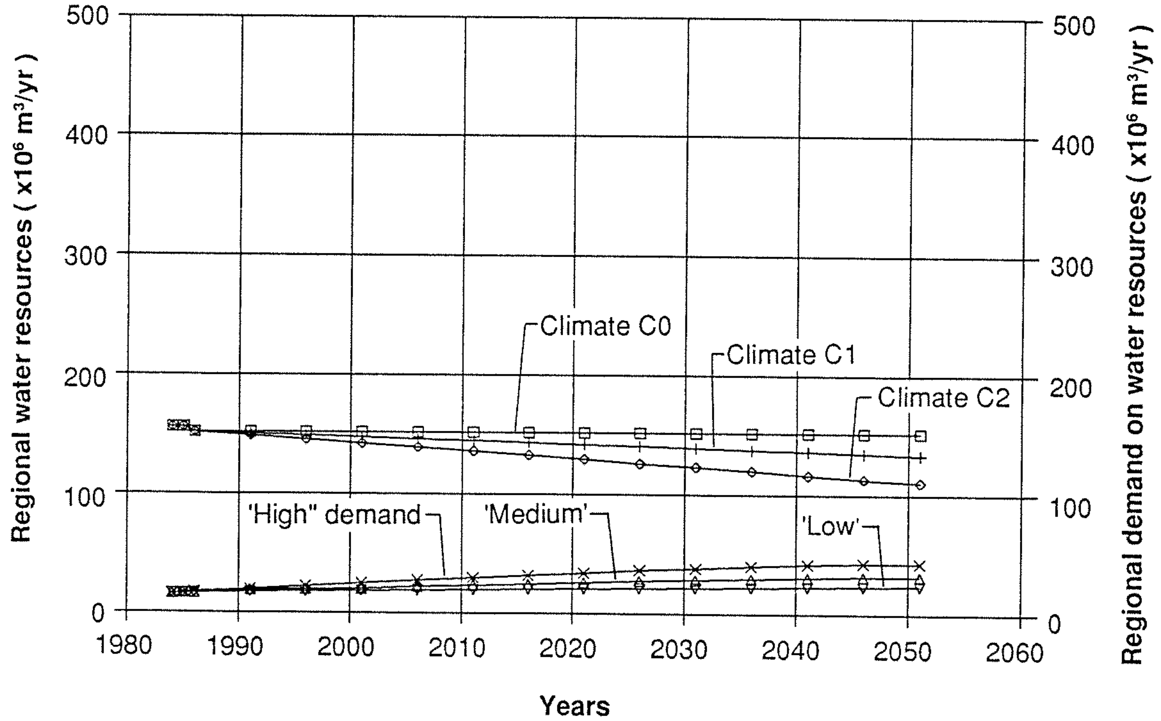

Figure 12: Regional water resource utilisation; Geraldton - Mid-West

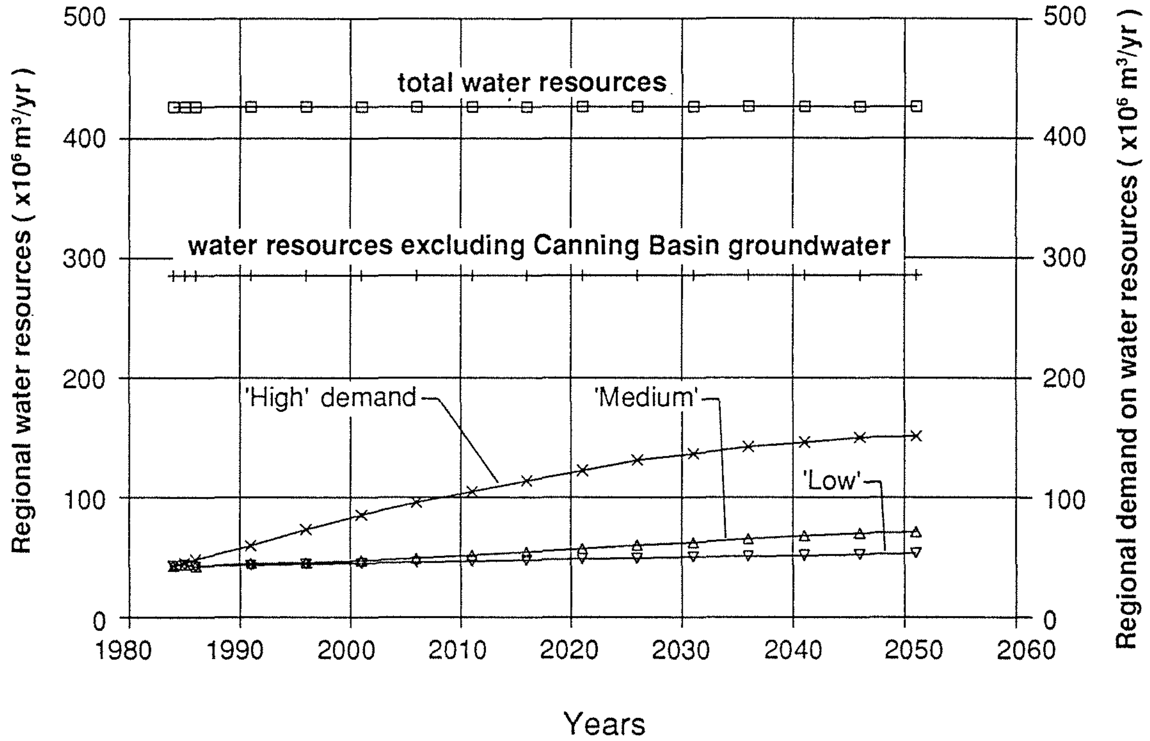

Figure 13: Regional water resource utilisation; Pilbara

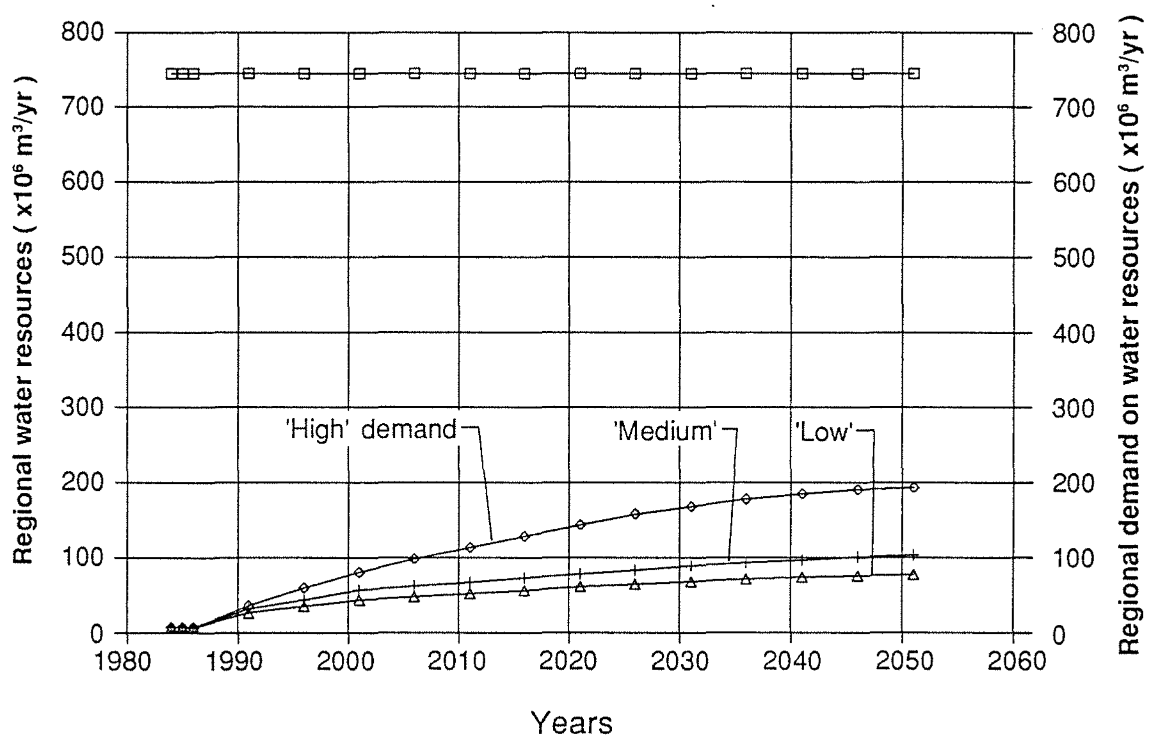

Figure 14: Regional water resource utilisation; Kimberley

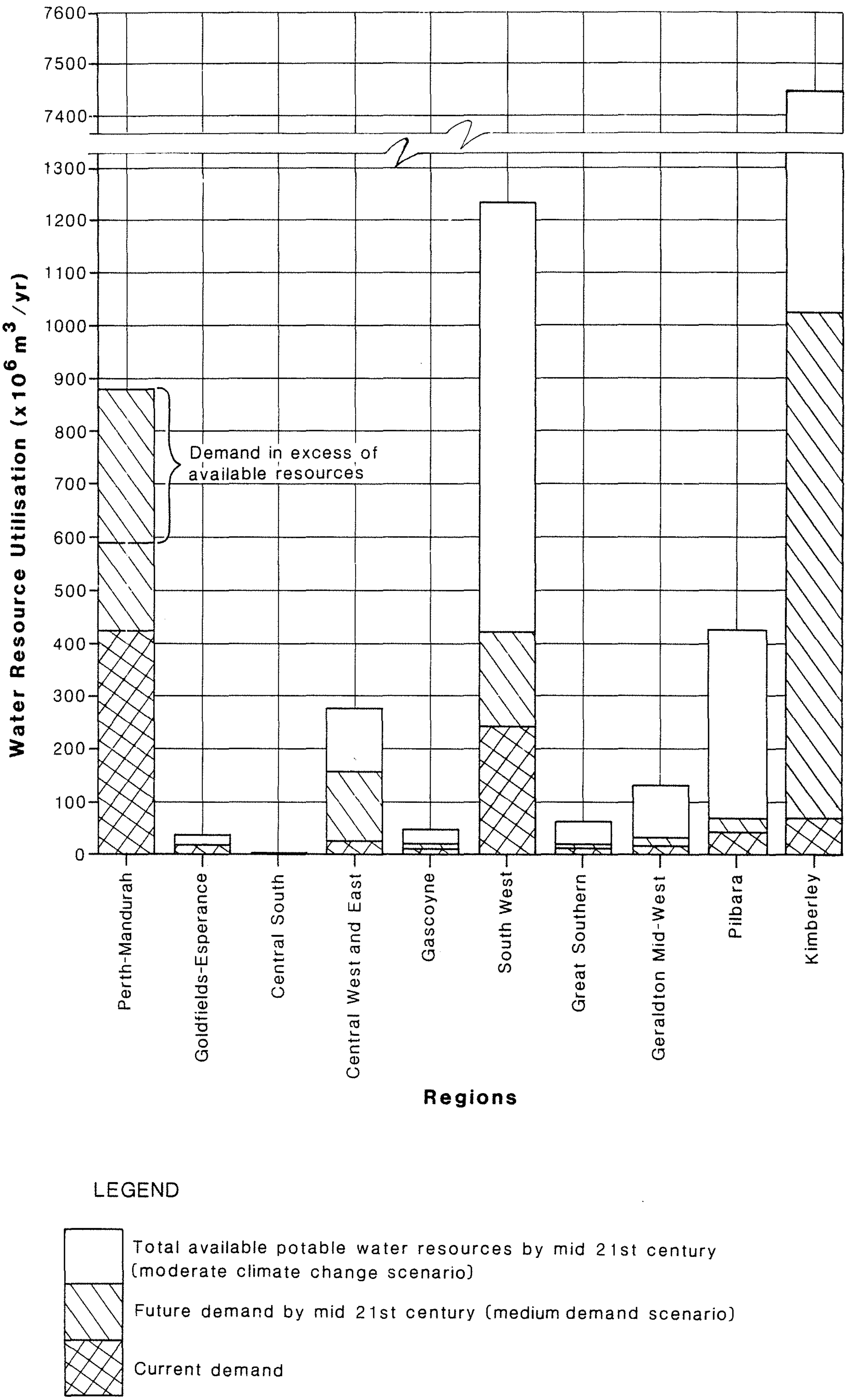

Figure 15: Comparison of regional water resource utilisation

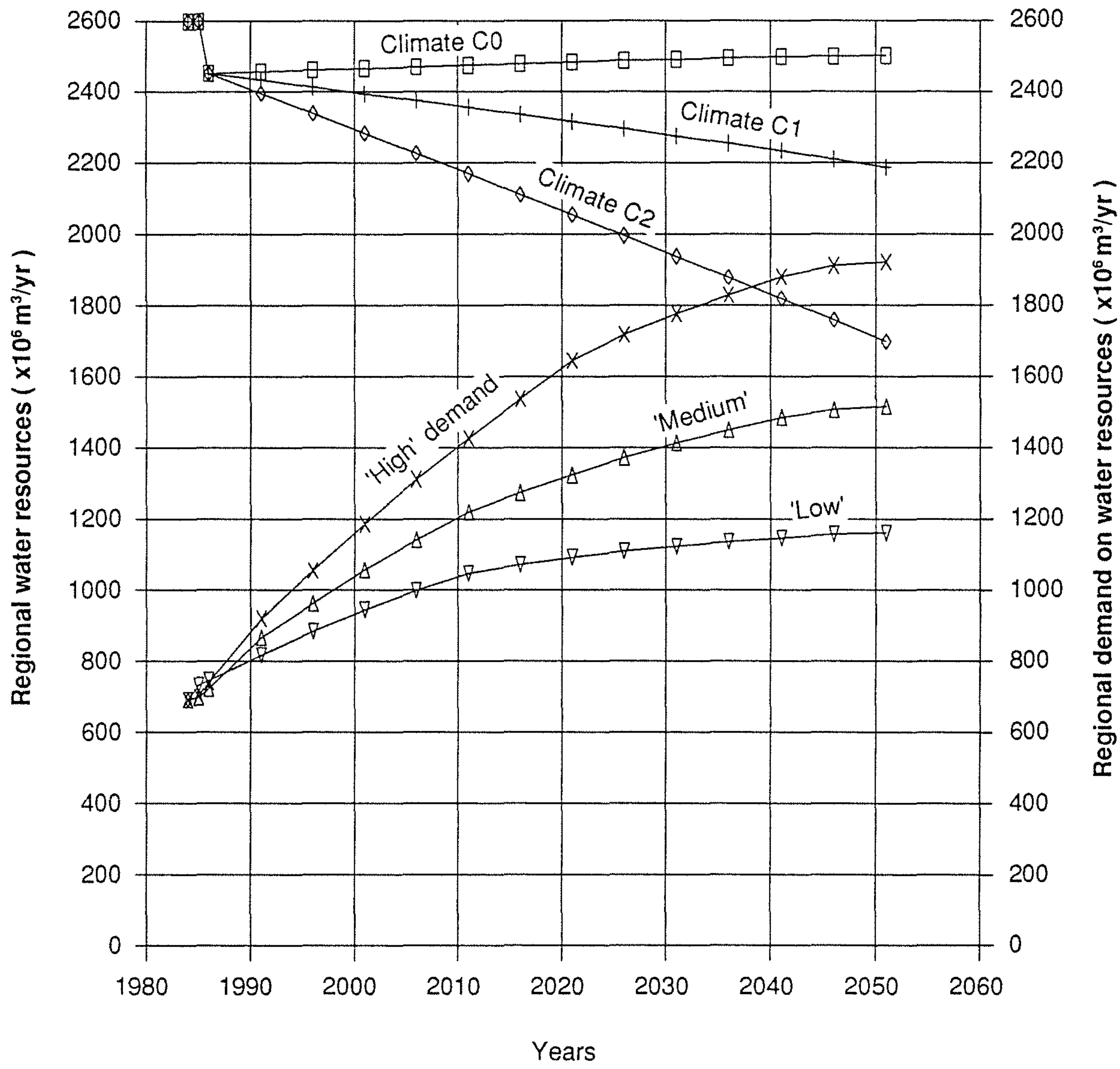

Figure 16: Water resource utilisation in the south-west corner of the State

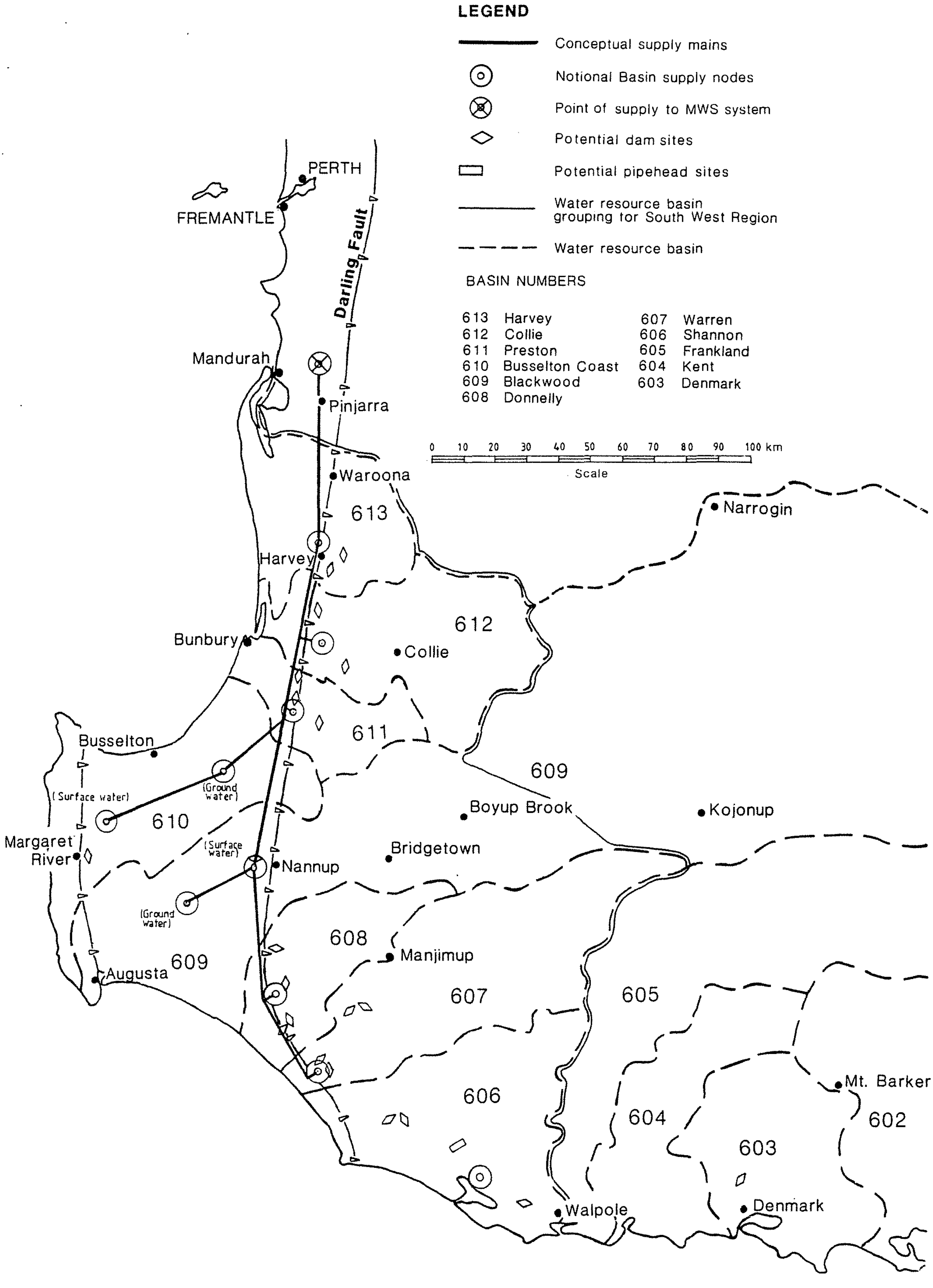

Figure 17: South West water supply options for Perth

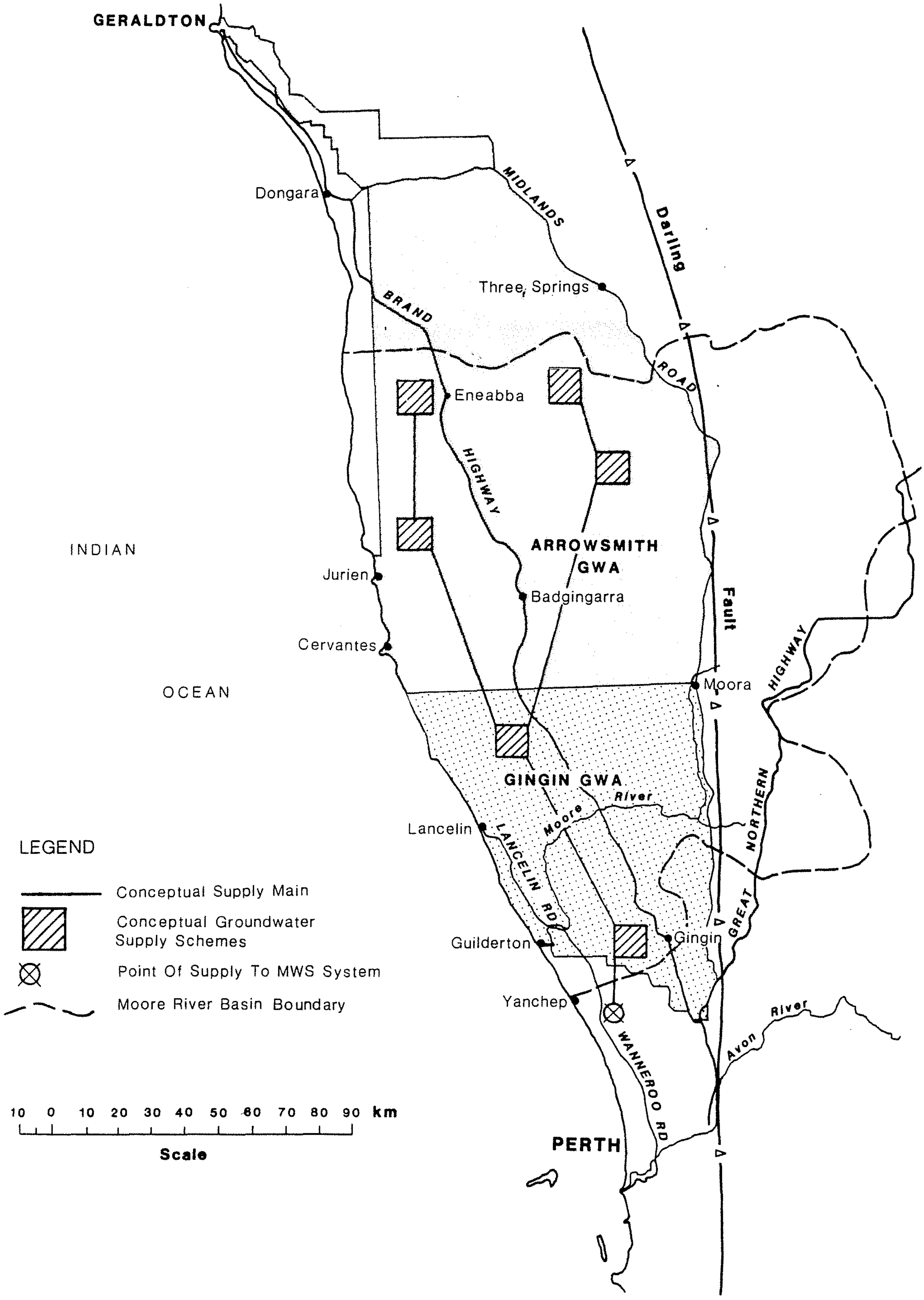

Figure 18: Moore River Basin water supply options for Perth

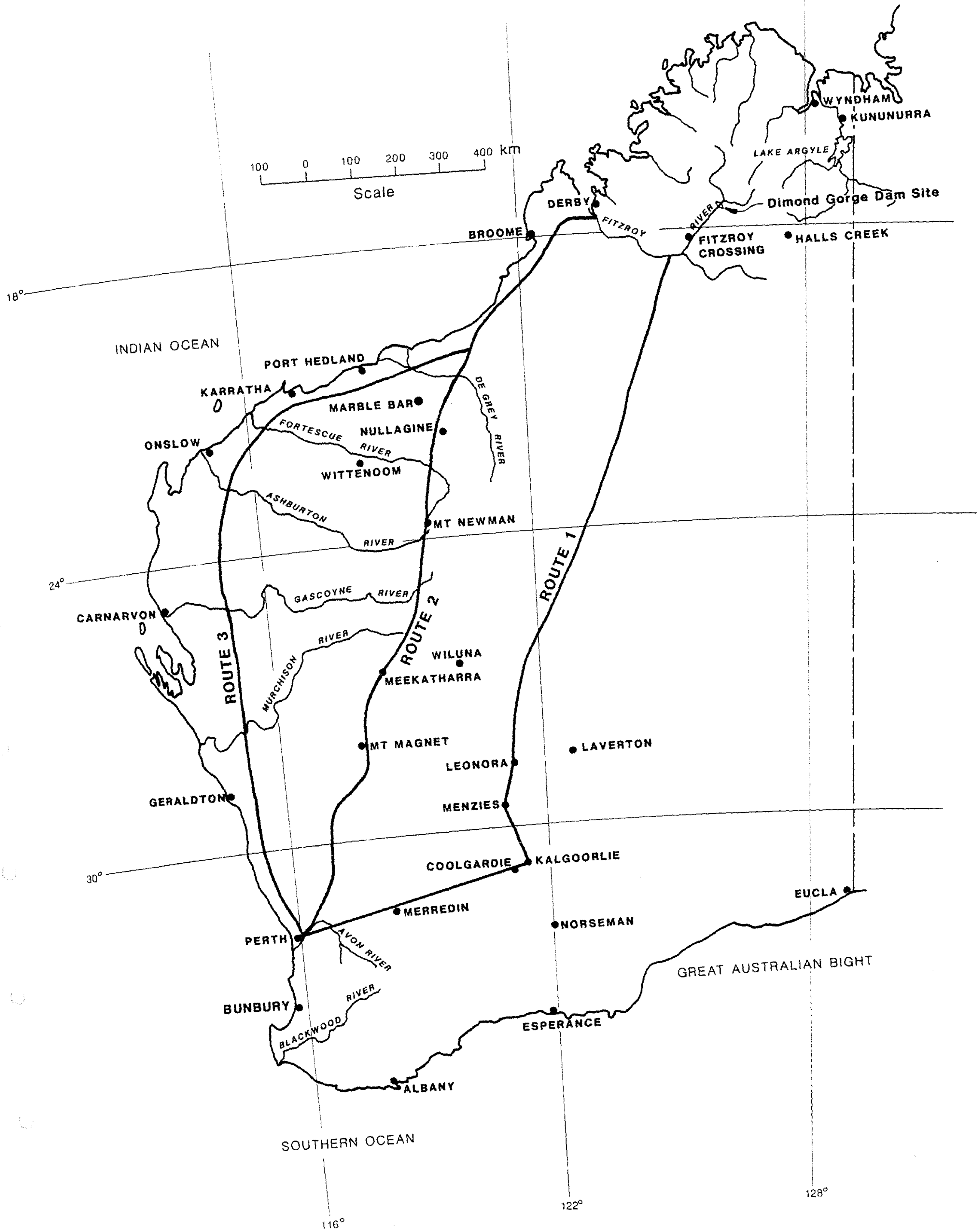

Figure 19: Kimberley water supply options for Perth

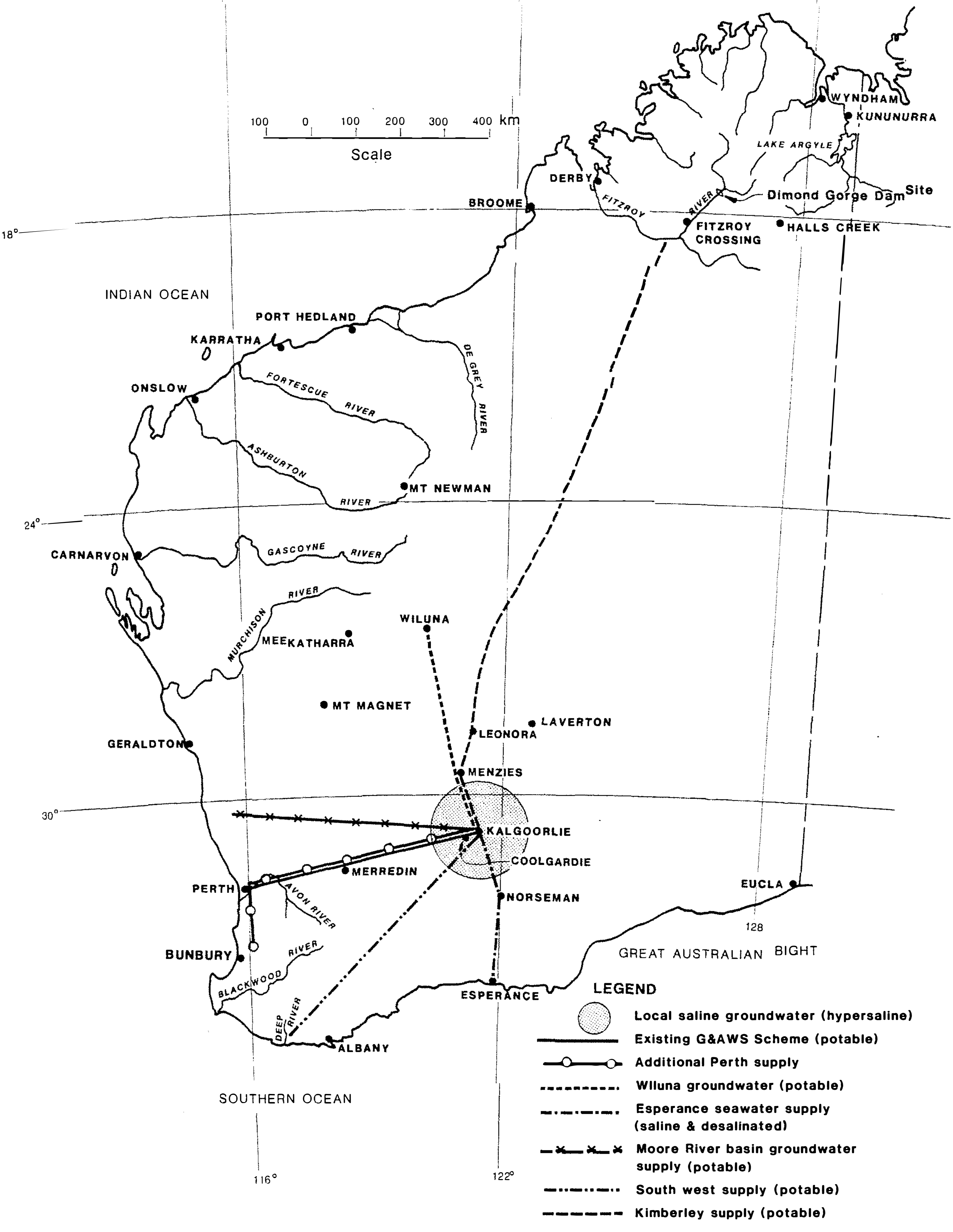

Figure 20: Goldfield water supply options for Perth