NATIONAL RESEARCH FLAGSHIPS

Water for a Healthy Country

The economic value of groundwater used to irrigate lawns and gardens in the Perth metropolitan area

Dominique Lieb, Donna Brennan and Don McFarlane

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CSIRO

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The Flagship was established in 2003 as part of the CSIRO National Research Flagship Initiative.

Citation: Lieb, D., Brennan, D., and McFarlane, D.J. 2007. The economic value of groundwater used to irrigate lawns and gardens in the Perth metropolitan area. CSIRO: Water for a Healthy Country National Research Flagship Canberra.

For further information contact:
Ph: 02 6246 4565
Fax: 02 6246 4564
www.csiro.au

Acknowledgements

This project was funded by the CSIRO Water for a Healthy Country Flagship. The Department of Water provided a significant in-kind contribution in the form of data from detailed queries of their licensing databases. The project would not have been possible without the enthusiastic assistance of a number of park supervisors from local government councils, and input from bore contractors.

Special thanks are also extended to the following people who assisted with advice and data analysis:

- Daniel Pollock (CSIRO)
- Gordon Ingram (CSIRO)
- Alex Kern (Department of Water)
- Phil Commander (Department of Water)
- Michael Loh (Water Corporation)
- Ken Johnston (Sports Turf Technologies)

Thanks also for referee comments from Sorada Tapsuwan and Matt Inman.

Executive Summary

According to the Department of Water's Water Resource Licensing (WRL) database, the total annual volume of groundwater licenses allocated[1] from the Superficial Aquifer for the purposes of irrigating public greenspace in the Perth metropolitan area is 73 GL, of which about half is allocated to local government councils who use the water to maintain more than 2,000 hectares of active parks and 5,300 hectares of passive parks across the metropolitan area. The other half is used to irrigate areas used by schools, private sporting clubs and golf courses, rural hobby blocks, commercial premises and state government agencies (especially the Department of Housing and Works).

In addition to this licensed use, our estimated quantity of water used by unlicensed backyard bores for irrigating private open space is around 72 GL.

The annual financial saving associated with using groundwater for the purpose of irrigating private and public lawns and gardens, instead of using scheme water, is estimated to be $118 m. The value to households, councils and other suppliers of public greenpsace associated with adopting bores is considerably lower than this (at $63m) because prices paid for scheme water use do not reflect the cost of supply augmentation.

The total capital invested in bores for the purpose of irrigating private and public lawns and gardens is about $520 m. In addition, the capital value of irrigation infrastructure (eg pipes, sprinklers and solenoids) for watering public greenspace is estimated to be $228m. The capital value of private infrastructure is assumed to be the same whether bore- or scheme-water was the resource.

There are economies of scale associated with bore and reticulation development, which implies that the economic benefit of using shallow groundwater, in terms of cost savings compared to scheme water use, is considerably higher in the irrigation of larger areas of public greenspace, compared to smaller private gardens.

Whilst the continued development of the Superficial Aquifer for the purpose of garden irrigation could provide additional benefits to society through reduced scheme water prices by delaying more expensive drinking water sources, this needs to be weighed against considerations of the impact on the environment and on existing users. If the resource becomes limiting, then decisions regarding the relative allocation between the environment, and public and private uses, and mechanisms for transferring allocations between users, will become imperative. Variations in the spatial distribution of existing uses, in the relative importance of public and private uses, and in the potential risks to groundwater quality from over-abstraction, add to the complexity of the management problem.

[1] Licensed allocations do not necessarily equate to water use.

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1. Introduction

The Superficial Aquifer under the Perth metropolitan area provides an important water source that supplements the Integrated Water Supply System in meeting demand for urban water. The Department of Water has the responsibility for managing the aquifer and currently requires large council and institutional users to seek a license for groundwater extraction. The license stipulates the area to be irrigated and the volumes allowed but use is not measured. All stock and domestic water supplies throughout the state, including private household bores in Perth, do not require a license, and bores have been encouraged in suitable areas by the Water and Rivers Commission since 1998 and by the Water Corporation as part of their scheme demand management program. Since February 2003 financial incentives in the form of a $300 subsidy has been provided to encourage bore installations. The aquifer is seen as providing an opportunity to take pressure of the Integrated Water Supply Scheme, as 50% of Perth residential demand for scheme water is used on gardens (Loh and Coghlan 2000).

The Superficial Aquifer under the urbanised area is replenished by direct recharge of water percolating through the soil profile, and especially by stormwater run off, from roads and roofs where it has been added to compensation and absorption basins. It therefore acts as a cheap stormwater treatment, distribution and recycling facility (Smith *et al*., 2005). Groundwater levels up-gradient of the metropolitan areas have experienced falling levels in the past decades as a result of land use, abstraction and reduced rainfall. The situation for the metropolitan area is less clear although recent reports have indicated falling levels due to climate change and other factors under Perth as well (Lindsay 2004; Smith *et al*. 2005)

Given the importance of the aquifer as an alternative source to meet urban water demand, a number of questions arise as to how it should best be utilised and managed. In particular, questions regarding the potential impact of bore expansion on future bore yields, groundwater levels and environmental values arise. In 2004-2005, the CSIRO conducted a study of the potential for increasing the use of groundwater to relieve pressure on the scheme (Smith *et al*., 2005). They found that if the dry climatic conditions continue, increased use of bores could further reduce overall aquifer storage, which could increase the risk of saline intrusion in coastal and estuarine areas and threaten wetlands and down-gradients groundwater users (eg through the release of arsenic). If the management response to these adverse impacts is a withdrawal of bore access rights, then the consequences would include stranded bore assets and a surge in scheme water demand (as happened at the Belmont Racecourse in 2004/05 following salt water intrusion from the Swan Estuary).

1.1 Objectives

The motivation for this study was to quantify the uses and values of groundwater extracted from the Superficial Aquifer for the purpose of irrigating lawns and gardens in the Perth metropolitan area. The specific objectives were to:

1. Examine the spatial patterns of licensed and unlicensed bore water use

2. Examine the economic value of bore access to providers of public open space, with an emphasis on local governments

3. Assess the economics of backyard bores

4. Quantify the total value of the capital investment in bores into the Superficial Aquifer used for the purpose of lawn and garden irrigation in the Perth metropolitan area

5. Quantity the annual economic value of the aquifer for the purpose of lawns and garden irrigation

1.2 Study area

The project study area includes all the local government areas in the Perth statistical division, extending from Rockingham in the south, to Joondalup and Wanneroo in the north, and Swan and Kalumunda in the east. The boundaries of the metropolitan regions referred to in this report are shown in Appendix 1.

2. Urban Groundwater Use

2.1 Licensed Bore Use

2.1.1 Major categories of use

Estimates of licensed groundwater use by local government area, and by stated purpose of water use, were obtained from the Department of Water's licensing database. These were then categorized into three major types of uses, being for irrigation of greenspace, agriculture, and water use in industry and services. A separate query of the data base also revealed the total volume of licenses held by local governments, which was used to separate irrigated greenspace by councils from other organisations. These other organisations include for example, private golf courses, schools and other institutions that maintain extensive lawns and gardens. Some of the water uses in the Industry and Services category may also be for garden irrigation, but where possible from the licensing description, water used specifically for irrigated greenspace was separated out from industrial and service uses. Estimates of licensed groundwater use by local government area, and by stated purpose of water use, were obtained from the Department of Water's licensing database. These were then categorized into three major types of uses, being for irrigation of greenspace, agriculture, and water use in industry and services. A separate query of the data base also revealed the total volume of licenses held by local governments, which was used to separated irrigated greenspace by councils and by other organisations. These other organisations include for example, private golf courses, schools and other institutions that maintain extensive lawns and gardens. Some of the water uses in the Industry and Services category may also be for garden irrigation, but where possible from the licensing description, water used specifically for irrigated greenspace was separated out from industrial and service uses.

The breakdown of use between the superficial and confined is shown in Figure 1. Generally, apart from public water supply, most of the licensed allocations are for access to the superficial aquifer. Local government areas with clayey soils, such as Perth and Gosnells, require access to the confined aquifer. The remainder of this report focuses on uses of the superficial aquifer, excluding public water supply use. The total licensed water use for the Superficial aquifer is estimated to be 270GL, comprising 85GL allocated to the Water Corporation for public water supply and 185GL to other uses. Since the region encompasses the peri-urban areas of Wanneroo, Serpentine-Jarrahdale, Swan and Mundaring, there is a large quantity of water used in irrigated agriculture. The breakdown of water uses into the main categories shown in Figure 1 are 40 percent to agriculture, and 20 percent to each of the other uses, council greenspace, other greenspace, and industry and services. The total quantity allocated to greenspace is as large as agricultural uses.

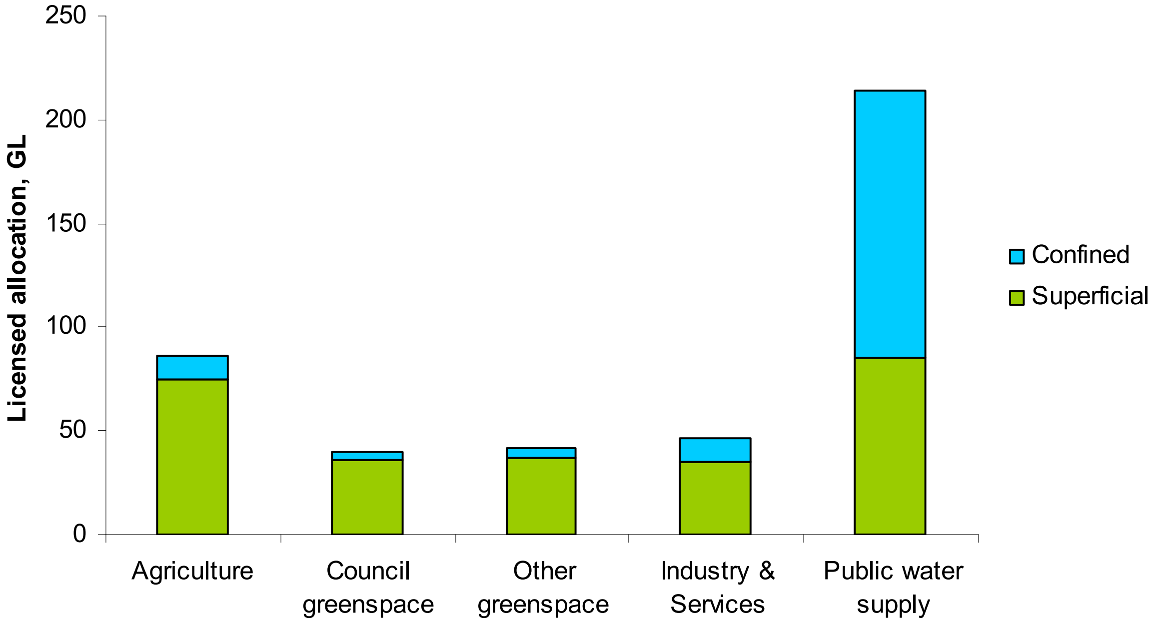

Figure 1: Licensed groundwater uses in the Perth metropolitan area, All uses, confined and superficial aquifers

2.1.2 Distribution of uses, other than public water supply, across the metropolitan area

A spatial breakdown of licensed bore volumes is shown in Figure 2, using the same regional classifications adopted by the Department of Planning and Infrastructure. These regions represent those parts of the metropolitan area that are relatively more developed (inner, middle) and those in the outer areas which contain more agricultural, industrial and crown land. The irrigation of greenspace is the predominant licensed water use in the more highly urbanised sectors. The outer sectors all have a large agricultural use, and in addition the South West, which includes Kwinana, has a large volume of licensed bores for industrial uses. The remainder of this report focuses on the use of bore water for the irrigation of lawns and gardens.

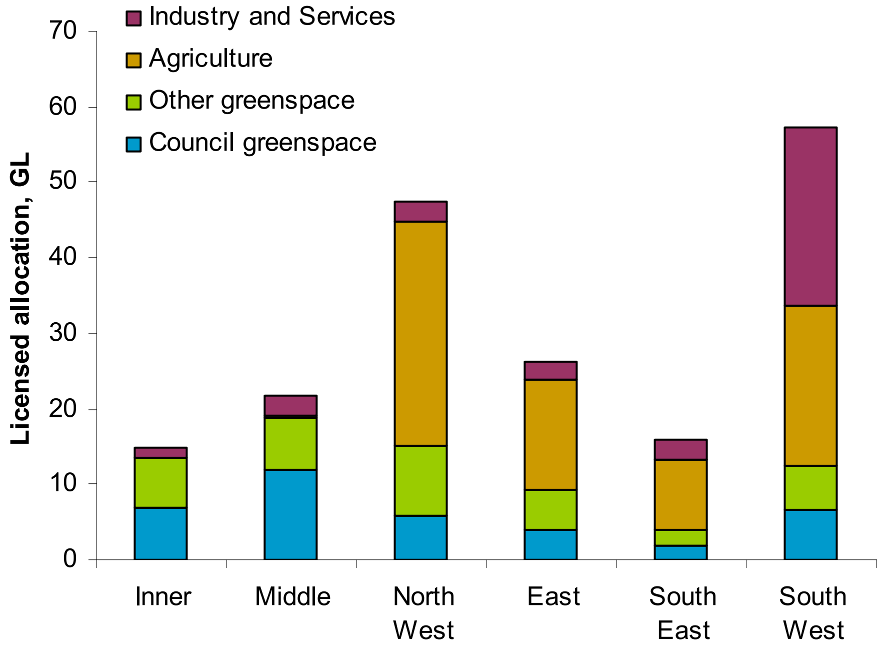

Figure 2: Spatial distribution of licensed use of groundwater from the Superficial Aquifer across the metropolitan area (excluding public water supply)

Because of variations in the degree of urbanization and the total area of land in each region, the importance of irrigated greenspace is shown relative to the size of the residential population in Figure 3. Allocations to councils are around 30-35 kL per resident, except in the North West and South East where water licenses are around 15-20 kML per resident. The relative importance of non-council greenspace varies significantly between regions. In the middle and south east regions it is relatively smaller; in the inner, North West, East and South West regions it is of similar magnitude to council greenspace.

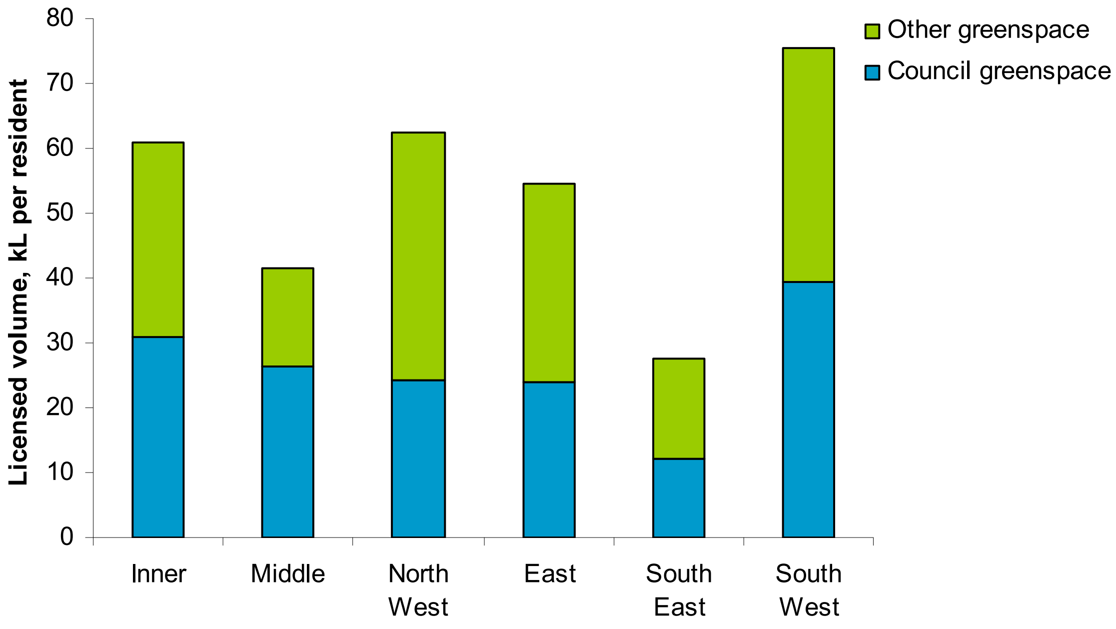

Figure 3: Water allocations for greenspace according to population, kL per resident

2.2 Unlicensed Bore Use

2.2.1 Estimation of unlicensed use

Estimating unlicensed bore use is difficult because official records on the total number of bores are not kept. A survey conducted by the Australian Bureau of Statistics in 2003 indicated that 19.4% of Perth households owned backyard bores, and an additional 4.7% had access to shared bores (ABS, 2004). Based on population statistics at that time, these figures imply that the total number of backyard bores was 116,461, and after accounting for shared bores the total number of households using bores was equal to 129,045. This estimate is similar to a survey conducted by Aquaterra which estimated around 130,000 bores in 2001. In the past 5 years it is likely that there has been an increase in the uptake of bores as a result of 2 day per week sprinkler restrictions. Since February 2003 the Water Corporation has offered a bore subsidy, and over the period up until February 2006 has processed 15,438 subsidy applications. This is likely to be a lower estimate of the actual number of bores taken up during this time period, because there is anecdotal evidence to suggest that not all people chose to apply for a subsidy because of fears of licensing fees being introduced. We used the values reported by ABS to represent the number of households with access to bores, to which we added the estimated increase since that time, to arrive at an estimate used in this study of 144,483.

There is considerable uncertainty regarding the amount of water used by households with backyard bores. In their official accounting of unlicensed bore use in Perth, the Department of Water assume that average use by bores is 800 kL per annum, which is based on several studies undertaken in the 1990s, adjusted downward to account for a reduction in average block size (Alex Kern, personal communication). In contrast, in their evaluation of the economics of household bores the Economic Regulatory Authority assume an average use of only 200 kL per bore. This lower estimate is based on advice from recent investigations by the Water Corporation on the influence of bore adoption on scheme water use, which may be biased by the inclusion of data from years when restrictions have been in place. In addition, people putting in a bore might use more water on their gardens than they would have used from the scheme even in the absence of restrictions, simply because once installed the marginal price paid for bore water is close to zero.

The Perth Domestic Water Use study measured garden use by those using scheme water and estimated that, in the period prior to restrictions, households with automatic reticulation systems used on average 384 kL per household on their gardens. An investigation of the characteristics of households surveyed by the CSIRO indicates that the average block size of those with bores was 91 m^2 higher than those without bores (and statistically significant). Based on Water Corporation's water efficiency calculator, garden water use is 0.73 kL per m^2 and lawn water use is 1.46 kL per m^2. Thus the additional water that might be used by bore owners may range from 132 kL if all additional area is allocated to lawns; to 61 kL if it is all allocated to gardens, to 0 if it is all allocated to paved area. The account for the potentially higher use associated with larger blocks, and with low marginal price, we use an estimate of 500 kL per annum in this study.

Using these assumptions regarding total bore ownership and use per household, the total estimated water used by backyard bores is 72 GL per annum. This is considerably lower than estimates that have been reported previously, for example McFarlane (2005) reports a total use of 112 GL from a study by Davidson and Yu (2004), the main reason for the difference being the higher bore use rates and a higher bore ownership assumed by the Department of Water.

2.2.2 Distribution of use across metropolitan area

In order to provide an indication of the spatial distribution of bore use across the metropolitan area, we estimated percentage use according to historical records on bore density kept by the Water Corporation, and reported in Smith *et al*. (2005). Whilst these percentages do not account for changes in the pattern of distribution that may have arisen in more recent years, they are the best information we have available. The estimated pattern of water use from backyard bores is shown in Figures 4 and 5. The middle sector has the highest use of water from backyard bores, with almost 35 GL, around half the total estimated use for the Perth metropolitan region. To account for differences in the population in each of these regions, bore use per capital is shown in figure 5. These values range from 30 to 80 kL per capita, with relatively low values in the East region, and the highest values in the Middle region. These per capita water use values indicate the importance of the Superficial aquifer in providing an alternative water source for households in the metropolitan area. For example, total scheme water supplied in the metro area is 155kL per capita, of which around 108kL per capita are supplied directly to the residential sector. Results indicate that in some areas, the aquifer supplies nearly as much water to households as does the scheme.

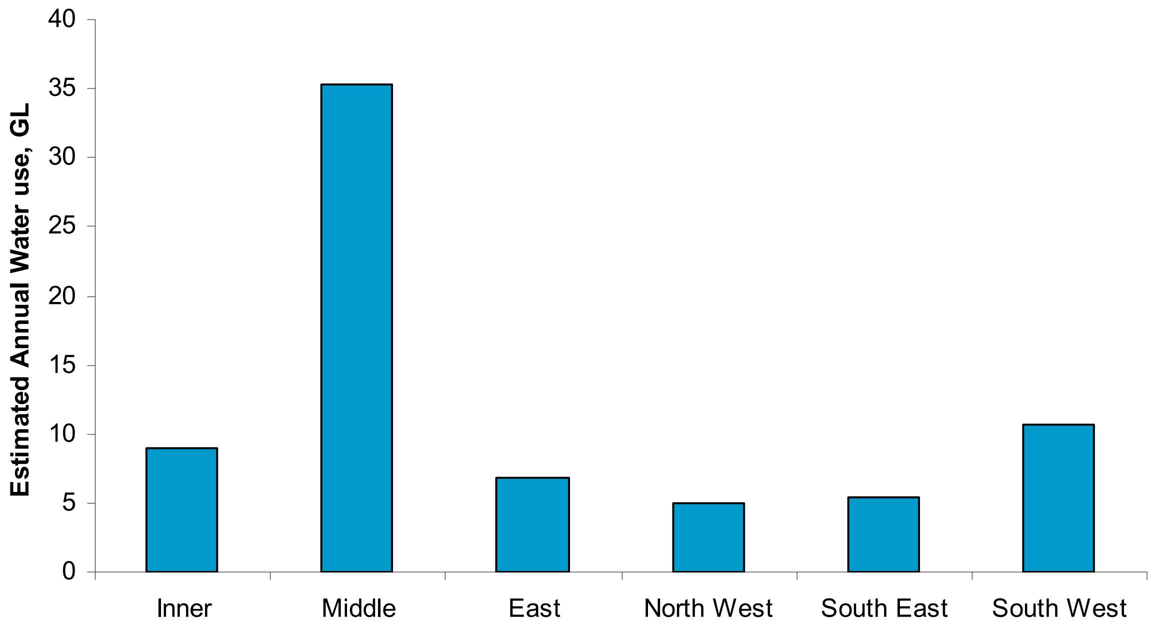

Figure 4: Estimated water use by backyard bores

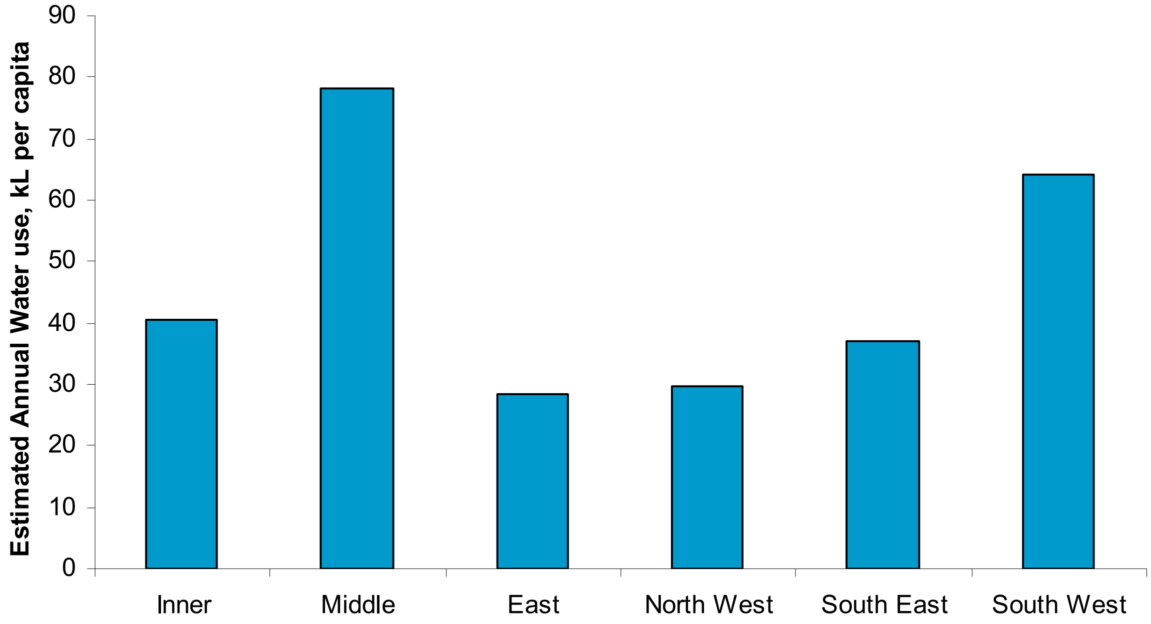

Figure 5: Estimated annual residential water use by backyard bores, kL per capita

2.3 Total bore use in the irrigation of turf and gardens

The total estimated use of bores for watering public and private lawns and gardens is shown in Figure 6. In all but the middle region, provision of public and private greenspace through councils or other institutions dominates the total water use, but the high density of backyard bores in the middle region mean that private use of bores dominates in that region.

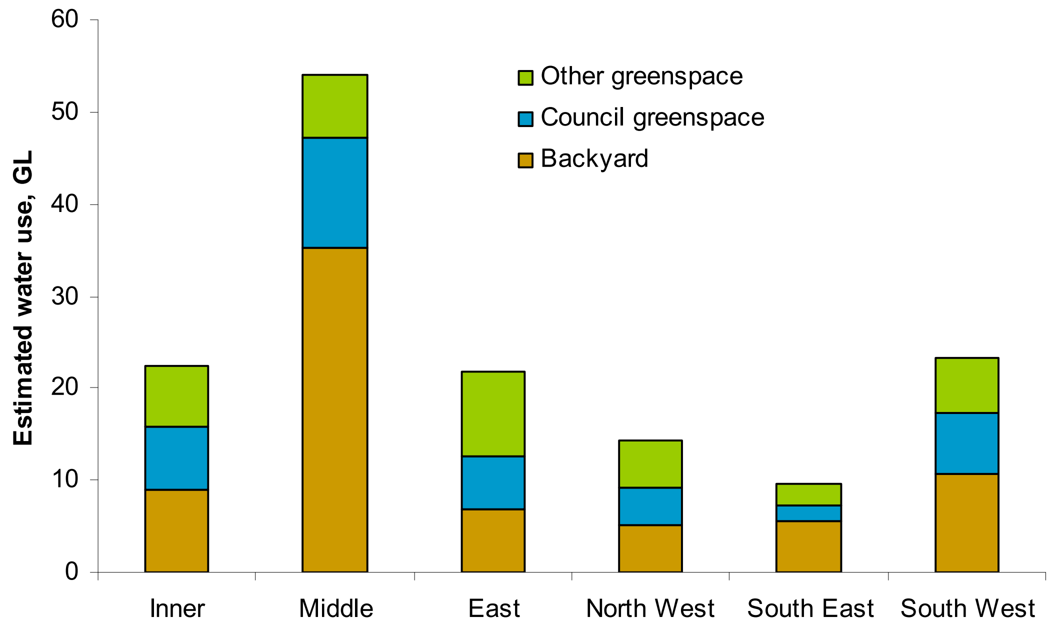

Figure 6: Estimated annual unlicensed and licensed water used on greenspace

3. The value of bores for irrigating public open space

Local governments are the major provider of irrigated lawns and gardens in public areas. In January 2006 a survey of town councils was undertaken to determine the value of investment in bores by town councils, and to elicit attitudes regarding the value of bores and the councils' potential response to reduced bore access. Of the 30 town councils surveyed, 28 responded partially and 22 responded fully to the questions asked. Information on irrigated area was obtained for the non-respondents from the council website. Further information was sought from bore contractors, regarding the cost of installing and maintaining the larger scale bores used for water public open space. Results of these investigations are presented in this section.

3.1 Characteristics of public open space provided by Local Governments

The total area of parks, excluding nature reserves, that are maintained by Local Governments, are shown in Table 1 by region. Direct comparison between the regional areas is difficult because of variations in size of and degree of urbanisation of regions. These data are also presented in Figure 7, and for purposes of comparison were scaled according to the area of residential land in each region.

Active parks are sporting grounds that must be maintained at a higher level of quality for the purpose of safety, these tend to be around 5 to 10 hectares per hundred hectares of residential land. Passive parks, which may include picnic grounds, grassed reserves, and a combination of lawns and native vegetation, tend to occupy more space. In the eastern region, which has a large area of native reserves and parks, the amount of area maintained by councils is relatively small, whereas for other regions the area of parks is 20 to 30 ha per 100 ha of residential land.

Table 1: Area of active and passive parks (excluding native reserves) managed by Local Governments

Region	*Active, ha*	*Passive, ha*	*Total, ha*	*Percent of Local Government Area*	*Ratio of parks to developed residential area*
Inner	372	970	1342	9.2%	0.29
Middle	537	1520	2057	6.7%	0.16
North West	570	920	1490	1.9%	0.25
East	186	405	591	0.3%	0.09
South East	210	821	1031	5.6%	0.16
South West	258	926	1184	2.2%	0.26

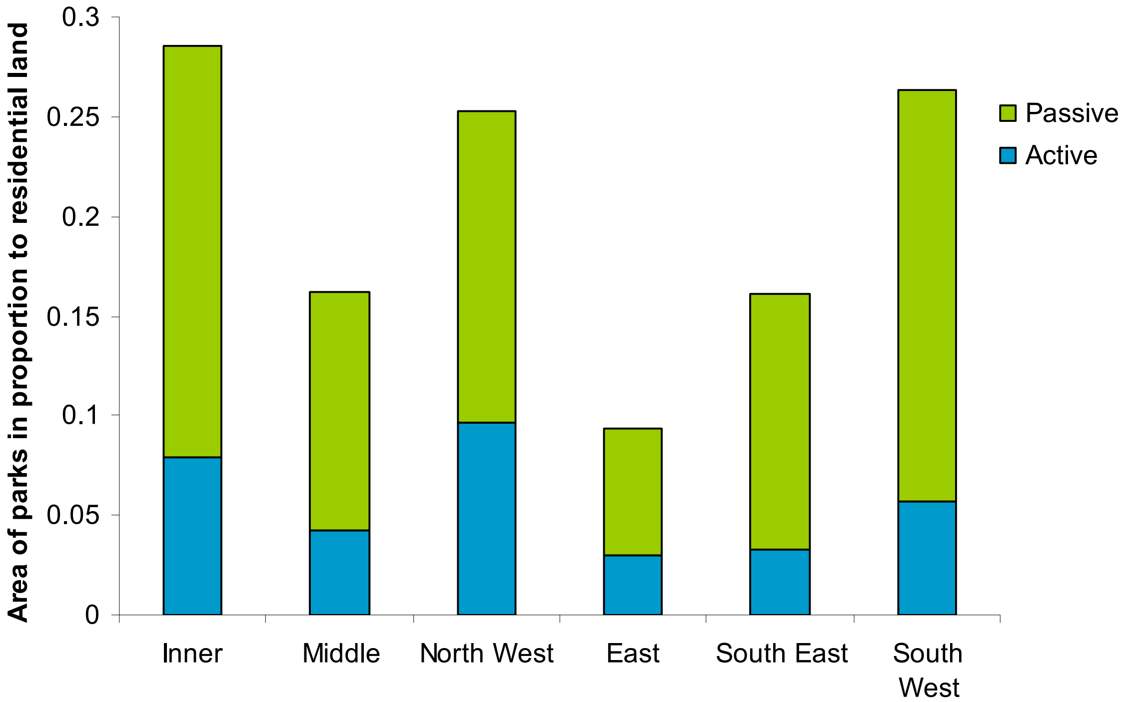

Figure 7: Area of parks relative to total residential area, by region

3.2 Importance of bores in irrigating open space

Bores are the dominant source of water used by councils in the irrigation of open space. Table 2 shows a breakdown of areas of active and passive parks by region, and the area irrigated according to method. Also shown is unirrigated area. In addition to active and passive parks, Councils also maintain other small greenspaces, such as major road verges and roundabouts, and some supply alternative non-irrigated greenspace in the form of nature reserves. Since not all councils answered questions regarding these other activities, only active and passive parks are shown in Table 2.

Table 2: Area irrigated by councils, by method of irrigation

	Active parks			*Passive parks*			
Method of irrigation	*Bore, ha*	*Scheme, ha*	*Unirrigated, ha*	*Bore, ha*	*Scheme, ha*	*Unirrigated, ha*	*Area irrigated with bores*
Inner	351	8	13	941	19	9	96%
Middle	533	4	0	1475	45	0	98%
North West	570	0	0	920	0	0	100%
East	179	7	0	371	34	0	93%
South East	178	7	9	697	25	36	92%
South West	257	0	1	922	0	4	100%

Additional data is shown in Table 3, which is based on responses by those councils who provided details on the irrigation of other areas besides active and passive parks. These ‘other’ types of greenspace are important in terms of total area, for example they are equivalent to around 70% of the size of active parks. However, there is a significantly lower reliance on bores for these spaces, with some councils electing to water them from the scheme, but most leaving them unirrigated. Discussions with some respondents revealed that these other areas are normally too small to justify putting in a bore, which is why some rely on scheme water for irrigating these areas.

Table 3: Significance of other managed greenspace (such as roadsides)*

Greenspace category	*Area of category %*	*Irrigation type % total area in category*		
		Bore	*Scheme*	*Unirrigated*
Other	17%	15%	4%	82%
Active	24%	98%	1%	1%
Passive	60%	97%	2%	1%

*Based on a subset of data from 22 out of 30 respondents.

3.2.1 Expenditure on park maintenance

Respondents provided information from their accounting records on the total annual budget for the maintenance of parks and gardens. Results were aggregated to the regional level and are shown in Table 4. Across the Perth metropolitan area, councils spend a total of $103 m per year on parks and gardens. Councils advised that lawn maintenance was the main source of expenditure against this budget. Also shown in the table is the estimated annualised capital cost, for bores and sprinkler equipment. This capital estimate was based on responses by councils on the capital cost of irrigation equipment, and estimates from bore contractors on the capital cost of bores installed for the irrigation of parks. The total *annual* cost of parks and gardens maintained by council in the Perth metropolitan area, including capital allowances, is therefore about $120 m.

Table 4: Estimated annual park costs, $m

	Annual operating and maintenance budget	*Annualised capital cost*		*Total cost per annum*
		Bores	*Irrigation equipment*	
Inner	27.11	1.03	1.87	30.01
Middle	30.70	1.61	2.90	35.21
North West	13.83	1.19	2.15	17.17
East	11.20	0.44	0.79	12.43
South East	8.80	0.70	1.26	10.76
South West	11.75	0.94	1.70	14.40
Total	**103.39**	**5.91**	**10.68**	**119.99**

Source: Annual O&M from councils, annualised capital costs based on assumed cost per irrigated hectare developed from discussions with bore contractors and parks supervisors, aggregated using irrigated hectares

Table 5 shows the total value of capital invested in bores and other irrigation equipment in public parks, by region. The total value is estimated to be $184m, but this includes the value of irrigation equipment would also be used if water were supplied from other sources. The value of sunk investment in bores is estimated to be around $74m.

Table 5: Value of capital invested in parks for the purpose of irrigation

	Bores	*Irrigation equipment*	*Total equipment cost*
Inner	12.92	19.38	32.30
Middle	20.08	30.11	50.19
North West	14.90	22.35	37.25
East	5.50	8.25	13.75
South East	8.74	13.12	21.86
South West	11.79	17.68	29.47
Total	**73.93**	**110.90**	**184.83**

Source: Capital costs based on discussion with bore contractors and park supervisors, aggregated using irrigated hectares and assumed bores per hectare.

3.2.2 The cost savings provided by bores

One estimate of the economic value of bores is the cost saving associated with avoiding the use of higher cost scheme water. This will provide an upper limit on the value of bores, as one possible response to bore failure would be to reduce the level of service provided by the councils by cutting back on irrigated area. These issues are discussed in a later section. In this section, the cost of providing irrigation water for bores and from the scheme is compared.

Data were collected on the variation in the cost of bores as affected by the size of park, and the depth to groundwater. As shown in Table 6, the capital cost of sinking bores varies significantly according to depth, the cost of deep bores being almost double the cost of the minimum depth bore.

Table 6: Capital costs ($) of large bores are affected by park area and depth of bore

	Park size		
Depth of bore (m)	*0.5 ha*	*2 ha*	*3.5 ha*
20	4,000	20,000	27,000
30	5,000	25,000	30,000
50	5,500	32,000	36,000
75	7,500	35,000	40,000

Other costs incurred by councils in using bores are the energy costs of pumping and the cost of maintaining bores. Regular maintenance is required to ensure that the bores continue to function efficiently; these costs can be around $5000-$6000 per bore every 3 years for the larger sized bores. Energy costs used in this analysis are based on cost estimates provided by a cross section of councils.

The per kL cost of irrigating parks using bores, as affected by park size and depth of the bore, are shown in Table 7. These values compare favourably to the price paid by commercial users of 79c per kL, even when depth to groundwater is large. Moreover, since it is likely that higher application rates are used on active parks (there is anecdotal evidence to suggest that active sporting grounds are irrigated at about 11 ML per ha), the economic benefit of using bores on these areas would be even larger than shown in Table 7, because average costs per kL would be even lower than those shown in the table.

Table 7: Estimated cost ($ per KL) of irrigating using a bore is affected by park size and bore depth

	Park size		
Depth of bore	*0.5 ha*	*2 ha*	*3.5 ha*
20	0.22	0.32	0.24
30	0.26	0.34	0.25
50	0.27	0.38	0.27
75	0.33	0.39	0.28

Source: Calculated from annualized capital costs and estimated electricity costs, based on an application rate of 8.3 ML per hectare

It is necessary to draw a distinction between the financial saving to the councils and the total cost saving to society. The price paid by councils is only 79 cents per kL, whereas the cost of augmenting supply through desalination is estimated to be $1.20 per kL. Thus the cost saving to society associated with using bores for the irrigation of parks is larger than the financial savings to the councils. These estimates are compared in Table 8. The total cost saving attributable to council's access to bores is $ 19 m from the point of view of the councils, and $36 m from society's perspective.

Table 8: Comparison of the cost of irrigating using bores and scheme, $m

	Using bores	*Using scheme*	
		Cost to councils	*Cost to society*
Cost of irrigation	12	31	48
Cost saving from bores		19	36

3.2.3 Innovations in Water use

Since licensed bore use has historically not been monitored, the main incentive for councils to adopt efficient water use practices has been the cost of operating the bores. A number have adopted Waterwise practices and a few have meters and remote sensors to improve their watering efficiencies.

All water users now have to comply with the 9 am to 6 pm sprinkler ban which was first introduced for scheme users in 1991, extended to unlicensed bore users in 1998 and to councils in 2003. The water conservation ethic associated with the current scheme water shortage may have helped the adoption of water efficiency innovations by local government. To explore this issue, a number of questions concerning irrigation practices were included in the local government survey, based on best management practice recommendations by the International Council for Local Environmental Initiatives (ICLEI) Water Campaign. The ICLEI campaign is a voluntary capacity building scheme that aims to improve water use efficiency by local governments (ALGA 2005). Of those councils that were questioned about water efficiency practices, only about half of the respondents had heard of the ICLEI campaign. The ICLEI report that 10 metropolitan councils in Perth have signed up to the campaign (1 in 3 councils) (ICLEI, 2005).

Of those surveyed, all councils had adopted drought tolerant species for use in some areas, and all had adopted automatic reticulation to allow for night watering. Most councils were investigating, or planning to investigate, potential innovations to water use efficiency including assessment of plant water requirements, impact of soil type and sprinkler technology on watering efficiency. Only 50 percent of councils surveyed had adopted weather stations or moisture sensors, not all of these were automated, and some respondents were skeptical about the efficacy of these technologies. However, a further 27 percent of councils stated that the use of moisture sensors and weather stations were planned for the future.

Table 9: Adoption of water efficiency innovations by councils that responded to the survey

Efficiency Innovation	*% Adopted already*	*% Planned to adopt*
Horticultural assessment to estimate water requirements.	83	8
Assessment of soil types, properties and root-zone depths.	75	8
Weather stations/ moisture sensors.	50	27
Automatic reticulation (for night irrigation)	100	0
Assessment of sprinkler technology.	82	0
Drought tolerant plant species for roundabouts and other areas.	100	0

4. The economics of backyard bores

A combination of phone interviews and written surveys of bore contractors were used to determine the cost of backyard bores for different conditions found in the Perth Metropolitan Region. The most important determinant of cost of a bore is the depth to groundwater, but other factors include the risk of bore failure through contamination by bacteria or sand, and the cost of avoiding staining caused by bores. Most respondents noted that they had the capacity to service both limestone and sandy areas and did not charge a premium for drilling through limestone. A premium is charged for drilling through rock substrate but this was not a common feature in most of the metropolitan area.

Whether or not a backyard bore is financially superior to using scheme water will depend not only on the cost of sinking and running the bore compared with the costs of buying scheme water, but the expected outdoor water use. Those with larger outdoor use have a greater incentive to adopt a bore for two reasons. First, because the total cost of the bore is independent of the volume of water used at the backyard scale, there are decreasing average costs per unit area associated with bore water use. Second, the inclining block tariff structure of urban water prices means that large users pay higher prices for scheme water use, increasing the incentive to adopt a bore.

The impact of outdoor use volume on the average cost of scheme water use is illustrated in Figure 8. The green line shows the average per unit price of scheme water use for all consumption (or equivalently, what would be charged for outdoor use if there were no indoor consumption). Also indicated by the blue lines is the cost of outdoor use, after an allowance for indoor use for different household sizes has been accounted for. It is higher than the baseline green because the discounted early consumption (eg. 42 cents per kL for the first 150 kL) is attributed to indoor consumption. As outdoor water use increases, the average price paid for outdoor water use also increases, creating a stronger incentive to switch to an alternative supply source.

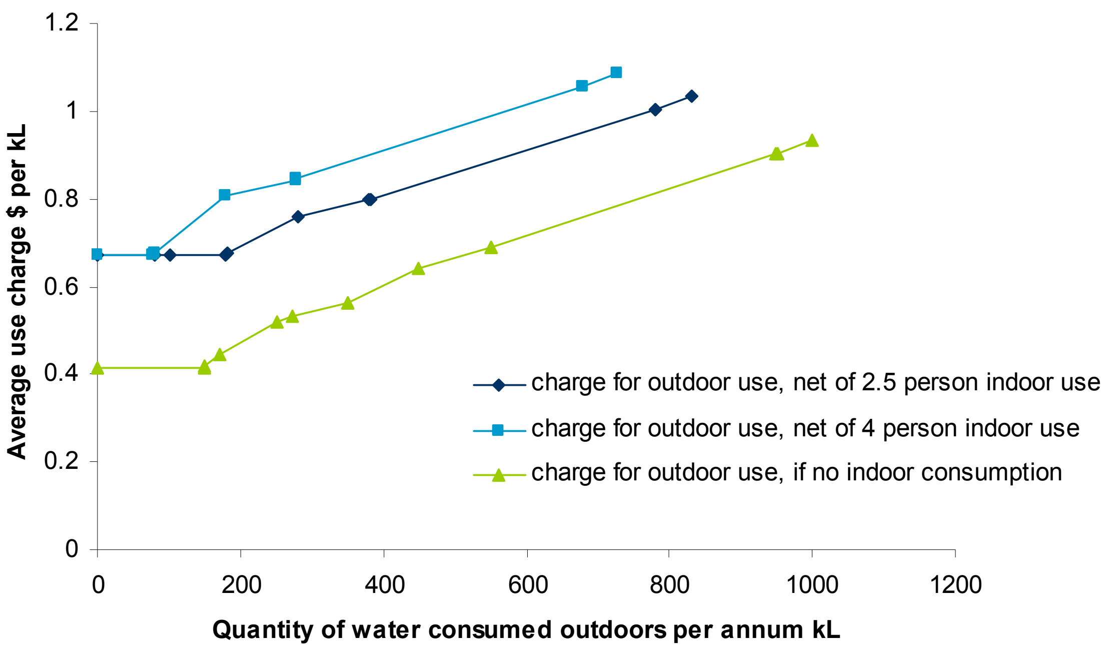

Figure 8: Demonstration of the effect of the current inclining block tariff schedule on the average cost of scheme water use

The adoption decision is illustrated in Box 1 for a number of different cost scenarios, to demonstrate how various factors influence the quantity of outdoor water use that would make adoption of a bore a purely financial decision. The impact of the $300 rebate currently given to new bore installations, and an alternative tariff structure ?, are also analysed.

Box 1. Level of garden use required to make a bore financially better than scheme use

Situation 1. Typical bore.

Around 50% of the metropolitan area has a shallow depth to groundwater that would be suitable for the minimum sized (18 m) bore, which most contractors quoted at $2,500. This would require a 1 kwh pump to run, which would cost around $20 per year to operate. Assuming no maintenance costs are incurred and the bore lasts 20 years as quoted by most contractors, the total annualised cost of the bore is $259, using the mortgage rate of interest of 6.5%. A $300 rebate on the capital cost reduces the annualised cost to $232 per annum.

In order to work out the level of use that would make a bore worthwhile to the householder, compared to using the scheme, it is necessary to make an assumption about indoor use, because prices vary with total use according to the inclining block tariff structure. In this example, it is assumed that 170kL is consumed indoors (based on a typical household size and average per capita indoor consumption). **The level of outdoor garden use at which a bore becomes economic is 343 kL per annum**, which is reduced to 321 kL where a rebate is paid.

A rule of thumb for calculating the level of use that would be required in order to make the bore economically superior from society's point of view can be obtained by comparing the total annualized cost of a bore by the long run cost of scheme supply. For example, if a bore costs $232 per year, and is used to provide *X* kL of water, then the cost of the bore is $232/*X*. In order for the bore to be cheaper than the estimated long run cost of scheme supply of $1.20 per kL (ERA 2006), a bore would have to be used to supply at least 216 kL for it to be an efficient alternative to the scheme from society's point of view.

Situation 2. Typical bore with stain control

Using the same approach, the amount of use that would make a bore financially cheaper to the householder if they had a strong preference for avoiding staining, that is associated with bores in some locations, can be calculated. The annualised cost of installing and running an 18m bore with a stain controller is $474 and with a rebate the cost is $447. The level of use required to make the bore economic is 522kL, or 500kL under a rebate scheme.

In contrast, using the cost of desalination as the benefit of avoiding scheme use, then the level of use that is required to make a stain controlled bore economic is 395 kL per annum. A rebate would reduce this value to 373 kL.

Situation 3. More expensive bore

Around 30 percent of the metropolitan area has a depth to groundwater of above 40 metres. The cost of installing a 50 metre bore was quoted at $4,800, and if stain control costs were also included, the annualised cost is calculated to be $693, or $656 with a rebate. The level of use required to make the bore economic is 696 kL, or 673kL under a rebate scheme.

In contrast, only 569 kL would be required to make the bore an economic proposition if long run marginal cost pricing signals were given to the consumer.

Without stain control, the results for a 50m bore are similar to the results for a shallow bore with stain control. That is, a bore becomes economic at around 500kL.

According to a detailed domestic water use study conducted by the Water Corporation (Loh and Coghlan 2003) prior to water restrictions being impose, average outdoor use by people using scheme water with automatic reticulation systems was 386 kL. The analysis in Box 1 suggests that the adoption of bores would make good financial sense for households currently using scheme water at typical (unrestricted) levels, if they are in shallow groundwater regions and are not affected by, or are indifferent to the impacts of, staining. The imposition of scheme water restrictions is likely to have further increased the motivation for adoption in order to avoid the impact of restrictions.

A bore rebate has only a small impact on the level of garden water use that makes a bore financially superior to scheme water. For example, owners of shallow groundwater bores are financially better at a bore water use of 343 kL per annum, whereas the rebate only shifts the level of use at which a bore becomes ‘financial’ to 321 kL per annum. In contrast, the inclining block tariff schedule currently applied in Perth creates a strong financial disincentive for adoption of a bore, compared to what would arise if the price paid by scheme water consumers was at the long run marginal cost of $1.20 / kL. Under the current pricing structure, the bore becomes economic at 343 kL per annum, whereas under a long run marginal cost pricing structure, the bore would be economic at 216 kL per annum. Thus, there would be a greater adoption of bores in the smaller subdivisions that are becoming common in the Perth metropolitan area.

Most of the analyses conducted in this report are based on a typical bore consumption of 500kL per household. At this level of consumption, it is actually worthwhile to adopt a shallow bore even after the cost of installing a stain controller is accounted for. At larger depths to groundwater, the decision to adopt a bore can be justified on a purely financial basis at 500kL of outdoor garden use, but only in the absence of the cost of avoiding stain control.

The finding that bores are quite economic at typical levels of outdoor garden use differs from the Economic Regulatory Authority’s calculations (2005). They used a capital cost of $2500 which is the typical cost of a shallow bore, but their calculations were based on water use that was significantly lower than assumed here. Their figures were based on evidence from the Water Corporation on changes in scheme water use by those households applying for bore rebates; however, this does not take into account that customers were on 2 day a week sprinkler restrictions before adopting bores.

Further illustration of the factors affecting the cost of bores is provided in Figure 9. This figure shows the total annual cost associated with an outdoor garden use of 500 kL, as affected by depth of the bore and other factors. The cost of installing sandscreens, and of drilling through rock, makes little difference to the overall decision, whereas the cost of iron bacteria contamination makes the bore uneconomic at any depth. A decision maker in an area where the risk of contamination exists would need to weigh up this risk before installing a bore.

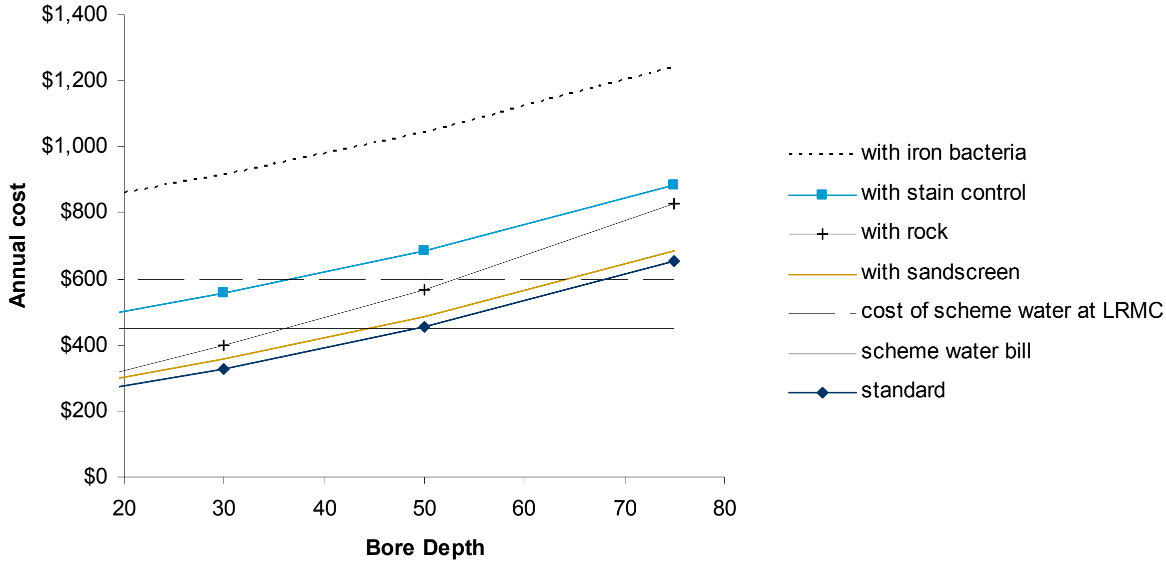

Figure 9: Annual total cost of backyard bores at 500kL outdoor garden use, as affected by resource characteristics

5. Economic value of the Superficial Aquifer under Perth

5.1 Value of current level of use

The current value of the Superficial Aquifer under the urbanised areas of Perth is the sum of values associated with irrigation of greenspace, and the benefits derived from household bores. These figures are shown in Table 10. If we take the current level of greenspace development as a given, the total value of greenspace is the avoided cost of using scheme water to provide the same level of service. In section 3.2.2, this was estimated to be $36 m, for 40 GL of water used by councils. A further 42 GL is allocated to other institutional providers of greenspace, and assuming the same cost structure, this is worth around $38 m per year. The value of groundwater used by households is the difference between the cost of supplying scheme water, and the cost of installing and running a bore. As was discussed in the previous section, the value of backyard bores depends on the depth to groundwater and estimated water use. By weighting the value based on the proportion of the Perth region at different groundwater depths, and assuming an outdoor use figure of 500 kL per annum, the total value of backyard bores is estimated to be $23 m in direct benefits to households using bores, but $44 m in total benefit to society if we assume this water would be need to be met with scheme water. The reason that there is a difference between the households and society is that most households do not the fully cost of scheme water supply in variable charges. Benefits are not in proportion to use because the benefits of household use are lower, because the costs of backyard bores are higher per kL due to diseconomies of scale. For example, typical costs are $0.56 per kL for households compared to $0.35 per kL for larger scale park irrigation.

Table 10: Annual benefit of bore water use, measured as saving in costs of avoiding scheme water use

	Use GL	*Value to decision maker, $m*	*Value to society $m*
Councils	40	20	36
Other institutions	42	21	38
Households	70	23	44
Total	**152**	**63**	**118**

Another measure of value is the total capital investment in bores used to supply water to parks and gardens. If access to bore water were no longer available, the value of capital invested in bores would be lost. Whilst backyard bore owners would be likely to substitute for scheme water use if bores were no longer functional, the watering of public greenspace may be curtailed significantly. To provide an upper bound on the value of sunk capital the total value of investment in bores and associated irrigation equipment for watering public greenspace is also shown in Table 11.

Table 11: Estimated value of sunk capital investment associated with access to Superficial aquifer

	Bore capital, $m	*Bores + associated irrigation $m*
Councils	74	185
Other institutions	78	195
Households	368	368
Total	**520**	748

5.2 Cost of reduced access to bores

The values provided in Table 10 indicate the total value of the bores as measured by the cost of substituting to the scheme. However, these represent an upper bound because in a situation where access to bores were restricted, current users would almost certainly respond by reducing their level of water use rather than switch to the scheme at the same level of use. In the case of households, this might involve reduced watering frequency in the short run, and a modification of garden layout in the long run. In the case of councils, revisions to watering schedules and irrigated area would almost certainly occur, with a resulting loss in service to communities.

A number of Local Councils were asked how they might prioritise water use if they were to undergo partial restrictions on licensed water abstraction. In general, they indicated that they would continue to water active sporting grounds and popular passive parks, and abandon irrigation on the less important passive parks. Most respondents indicated that they would not use scheme water, even if they had no access to bore water, because of the high cost involved. Some also indicated that the pressure provided by the scheme would not be sufficient for irrigating their larger parks. Respondents were the managers of parks and recreation, and it is possible that if a situation of reduced bore access did arise then the elected council members would make a political decision regarding expenditure on scheme water for irrigation. If they did choose to switch to scheme water use then the total cost they would incur from switching to the scheme would be around $20 m, which would represent a 20 percent increase in the total annual parks and gardens maintenance budget.

Other cities in Australia do not have access to bores for the irrigation of public open space. Several councils in Sydney were interviewed regarding their water use, and they indicated that they relied on scheme water use for active sporting grounds, as well as employing other water sourcing methods including recycling water, water harvesting from roads and roof tops, having small, local dams for irrigation. Those using scheme water were currently subject to restrictions but had received exemptions in some cases that allowed them to maintain playing surfaces. This experience suggests that in the absence of access to bores in Perth there might be a greater adoption of alternative water sources, such as recycling, but that use of scheme water is likely to be significant source at least for active sporting grounds.

Another indicator of the value of bores is the level of service that would not be provided to the community if the councils did opt to reduce irrigated area. Public parkland in urban areas has significant market and non-market values. For example, Harmon (2003) provides a list of the sources of these benefits, including personal, social and economic benefits. The personal benefits of recreational activities include stress management, self-confidence, spiritual growth, cardiovascular benefits and increased bone mass and strength in children. The social and cultural benefits include community, regional and national pride, family bonding and community integration; and the economic benefits include reduced health costs, increased productivity and fewer on-the-job accidents (Harmon 2003). Environmental benefits include improved relationships with nature and preservation of species diversity (Harmon 2003).

The social and environmental values of home gardens are mostly the same as for parks, although typically cardiovascular exercise cannot be as highly achieved and the enjoyment that does occur is in more private circumstances.

6. Conclusions and implications for management

The Superficial Aquifer under urban Perth provides at least 145 GL of water per year for the purpose of lawn and garden irrigation. The three major types of users are councils and other institutions who provide services to the public, and households who use bores for private gardens. The share of these three uses, summarized from Figure 6, is shown in Figure 10. Unlicensed backyard bores make up almost half the total use.

Economic analyses indicate that the per kL value of the aquifer for the irrigation of lawns and gardens is larger for public greenspace, compared to backyard bores, and this is because of the economies of scale associated with irrigating larger areas. The estimation of value was based on a comparison of the relative costs of scheme and bore water use. However, in a situation where the water in the aquifer was scarce and access to scheme water for irrigation of greenspace was restricted, measures of comparative value would need to consider the opportunity cost of allocating water to public or private use.

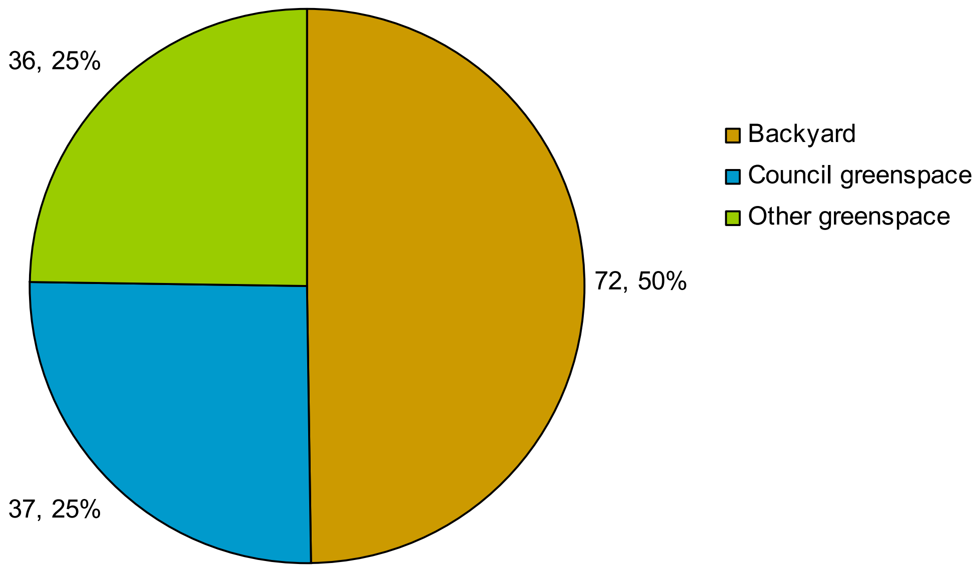

Figure 10: Summary of bore water use for irrigation of lawns and gardens in the Perth metropolitan area, values are GL and percent share of total

The total annual benefit associated with access to bores for the purpose of irrigating lawns and gardens in the Perth metropolitan area is estimated to be around $118 m. The total value of capital invested in bores is around $520 m.

Whilst the continued development of the aquifer for the purpose of garden irrigation could provide additional benefit to society through reduced scheme water use, this needs to be weighed against considerations of sustainable yield and the value of existing uses. If the resource becomes limiting, then decisions regarding the relative allocation between public and private uses, and mechanisms for transferring allocations between users will become imperative. Variations in the spatial distribution of existing uses, in the relative importance of public and private uses, and in the potential risks to groundwater quality from over-abstraction, add to the complexity of the management problem.

A major determinant on the ultimate level of use of the Superficial Aquifer under Perth is the water levels in urban wetlands which are very important cultural and environmental assets. Their loss would precede the loss of bores due to levels falling below bore intake screens, and also sea water intrusion in most urban areas.

There is still capacity for diverting stormwater into aquifers, especially in riverine and coastal suburbs. Water use efficiencies in backyard and council bores are also likely to be low. Therefore there is much scope for improved management to protect the values that have been identified in this short study.

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Appendices

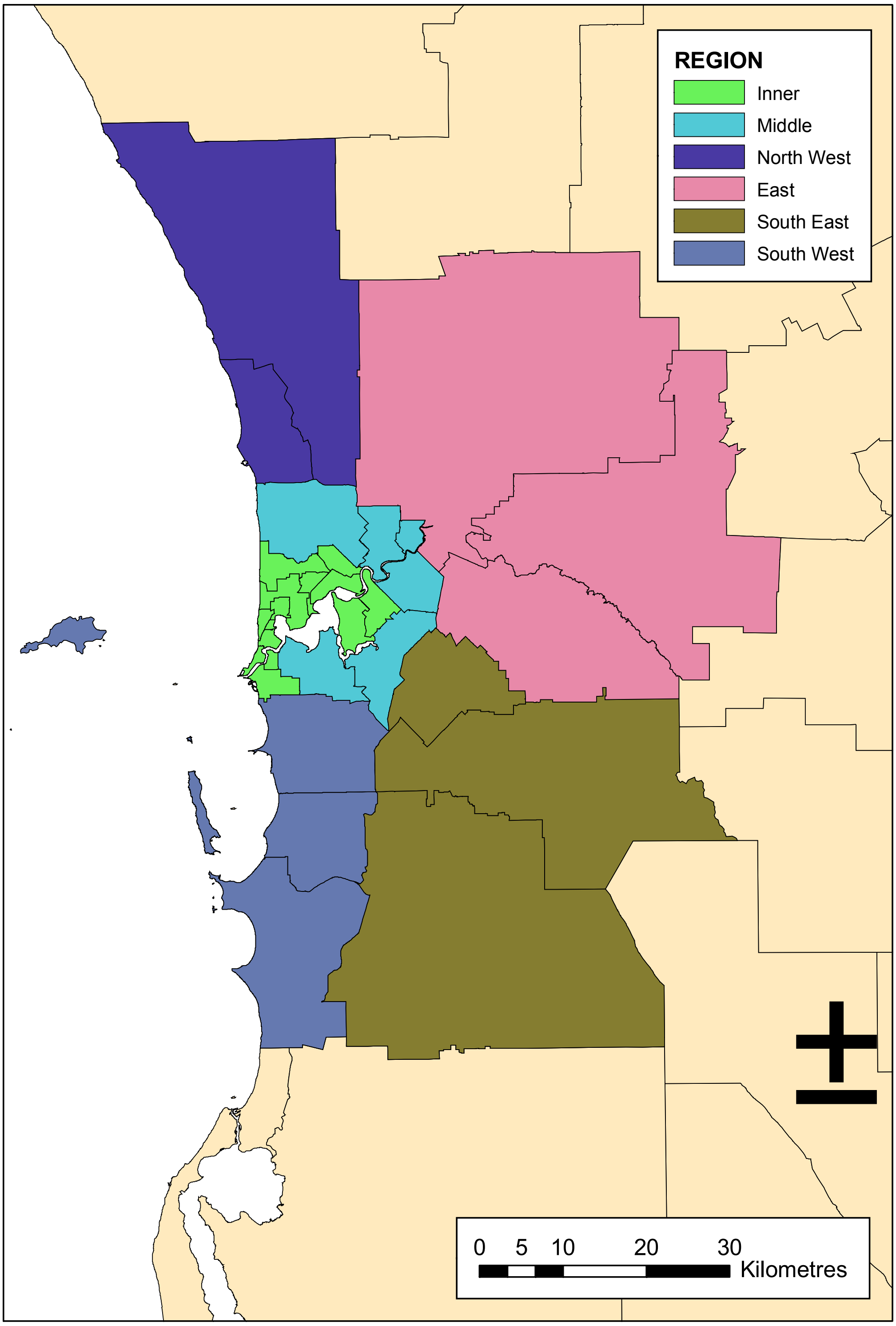

Figure A.1: Classification of regions

APPENDIX B: DETAILS OF QUESTIONNAIRES USED IN SURVEY

Survey of Councils on the Value of Bores

1. Council attributes

1.1 How much area do you have in the following categories?

Category	Area (ha)
Active parks (sporting grounds)	
Passive parks (no organised sport but not native reserves)	
Passive parks (native reserves)	
Other (verges, roundabouts, etc)	

1.2 Do the above figures include golf courses? If yes, what is the irrigated area?

1.3 What proportion is irrigated?

Category	% irrigated by bores	% irrigated by scheme	% un-irrigated
Active parks			
Passive parks (not native)			
Other			

1.4 Do you have areas where bores cannot be sunk, if so why?

1.5 Do you currently use all of your water licence allocation?

1.6 Does the council use bore water for fire fighting? If yes how much?

1.7 Does the council use bore water for lake supplementation? If yes how much?

2. Irrigation and pump specifics

2.1 What is the expected life of a pump?

2.2 What is the expected life of a bore installation?

2.3 What is the expected life of reticulation equipment?

2.4 What type of sprinklers do you use for irrigating lawns?

3. General costs and revenue associated with parks and gardens

3.1 What is the estimated cost per ha of installing sprinkler irrigation?

3.2 Approximately how much is spent per year on maintaining parks and gardens, including electricity?

3.3 How much of this is attributable to lawns (as opposed to garden beds)?

3.4 How much of this is spent on electricity for pumping water?

3.5 What is the total revenue from fees paid for access to parks and gardens, including sporting grounds?

3.6 Why do you use bore water rather than scheme? Please rank the importance of each of these reasons in order from 1 to 5, for small and large parks:

Reason	Small irrigated area < 1ha	Large irrigated area > 1ha
Bores less expensive		
Bores not subject to time of day & daily frequency restrictions		
Bores not subject to 2 day per week restrictions		
Not using scarce scheme water (good citizenship, Water Wise Council)		
Historical policy		
Other (please state)		

4. Irrigation Efficiency

4.1 Has the council undertaken any water efficiency review since 2001? If yes, when?

4.2 Does the council plan to participate in the Australian Local Government Association's International Council for Local Environmental Initiatives (ICLEI) Water Campaign? {This campaign provides capacity building in how to plan and implement water quality and conservation targets: http://www6.iclei.org/anz/water/water.htm}

4.3 Adoption of irrigation efficient practices, current and planned (please tick as appropriate):

	Practice currently used.	Plan for practice to be used in future.
Horticultural assessment - estimated water requirements.		
Change in watering frequency due to assessment.		
Assessment of soil types, properties and root zone depths.		
Weather stations/ moisture sensors.		
Automatic reticulation (for night irrigation).		
Assessment of sprinkler irrigation technology.		
Drought tolerant plant species for feature roundabouts and other areas.		
Other (please state)		

5. Potential response to restrictions on bore use

In order to estimate the value of bores, we need to ask some hypothetical questions on how the council might respond to a situation where water licences were decreased. These restrictions might arise, for example, in response to a declining aquifer level as a result of climate change, or from concerns over seawater intrusion. We are interested in the likely responses in both the short term (within 12 months) and longer term. When responding, assume that there are no spatial limitations on the pattern of restriction.

Please fill out the following tables, for the scenarios presented. Express the responses in proportion to the existing area of land irrigated. We have provided examples for each scenario which indicate *the amount of land that could be irrigated if there is no change in watering practice other than leaving some parks brown. We assume that you are using your full licensed allocation.*

5.1 Scenario A: Licences cut by 20%.

Example: 80% of original area is still irrigated by bores and the other 20% is not watered at all. This has been expressed as a proportion of existing irrigated area, but you may respond in hectare values if you prefer. The total area should add to the existing irrigated area.

Response	***Area in % or ha***
Area irrigated by bores	*80%*
Area not irrigated (brown parks)	*20%*
Total	***100%***

5.1.1 *Short term* response that would be adopted by your council: (Must add to 100% of existing irrigated area)

Response	**Area in % or ha**
Area irrigated by bores after adopting short term efficiency measures	
Area irrigated by scheme water	
Area not irrigated (brown parks)	
Other (please specify)	
Total	**100% or total irrigated area**

5.1.2 *Longer term* response that would be adopted by your council: (Must add to 100% of existing irrigated area)

Response	**Area in % or ha**
Area irrigated by bores after adopting long term efficiency measures	
Area irrigated by scheme water	
Area relandscaped to water wise gardens	
Area not irrigated (brown parks)	
Other (please specify)	
Total	**100% or total irrigated area**

5.2 Scenario 2: Licences cut by 50%

Example: the remaining 50% that can be is still irrigated by bores and the other 50% are not watered at all.

Response	***Area in % or ha***
Area irrigated by bores	*50%*
Area not irrigated (brown parks)	*50%*
Total	***100%***

5.2.1 Short term response that would be adopted by your council: (Must add to 100% of existing irrigated area)

Response	Area in % or ha
Area irrigated by bores after adopting short term efficiency measures	
Area irrigated by scheme water	
Area not irrigated (brown parks)	
Other (please specify)	
Total	**100% or total irrigated area**

5.2.2 Longer term response that would be adopted by your council: (Must add to 100% of existing irrigated area)

Response	Area in % or ha
Area irrigated by bores after adopting long term efficiency measures	
Area irrigated by scheme water	
Area relandscaped to water wise gardens	
Area not irrigated (brown parks)	
Other (please specify)	
Total	**100% or total irrigated area**

5.3 Scenario 3: Licences cut by 100%

Example: no land is irrigated by bores and 100% are not watered at all.

Response	***Area in % or ha***
Area irrigated by bores	*0%*
Area not irrigated (brown parks)	*100%*
Total	***100%***

5.3.1 Short term response that would be adopted by *your* council: (Must add to 100% of existing irrigated area)

Response	Area in % or ha
Area irrigated by bores after adopting short term efficiency measures	**0**
Area irrigated by scheme water	
Area not irrigated (brown parks)	
Other (please specify)	
Total	**100% or total irrigated area**

5.3.2 Longer term response that would be adopted by your council: (Must add to 100% of existing irrigated area)

Response	Area in % or ha
Area irrigated by bores after adopting long term efficiency measures	**0**
Area irrigated by scheme water	
Area relandscaped to water wise gardens	
Area not irrigated (brown parks)	
Other (please specify)	
Total	**100% or total irrigated area**

5.4 Detailed information regarding bore characteristics and costs

Ideally, we would like to receive an electronic copy of your detailed bore database, including information for each bore/park such as irrigated area, number of bores, bore depth, depth to ground water, bore diameter, bore output, capital cost of bore, pumping costs of bore, capital cost of pump, capital cost of irrigation, year installed and estimated annual water use. If this is not available, we would appreciate a general overview which can be provided by filling out the table below.

Park type	Number of bores	Range in depth to ground water	Range in bore diameter	Range of bore output	Range in capital cost of bores	Estimated annual water use
Active parks						
Passive parks (not native reserve)						
Others						

END OF QUESTIONNAIRE. THANK YOU FOR YOU TIME AND EFFORT.

QUESTIONNAIRE FOR BORE CONTRACTORS

Business Attributes and Market Outlook

1. How many bore contractors does your company have?

2. Have your sales of bores increased since water restrictions were introduced?

If yes, by how much (%)?

3. What growth do you expect in the market (slower, steady or higher) over the next 3 years if:

   a. Restrictions are continued

   b. Restrictions are lifted

4. Do you think that the market is already saturated in the following areas with high bore ownership? Write yes, no, or don't know for the following:

Suburb	Saturated?	Any Comment?
Dianella (61%)		
Carlisle (77%)		
Morley (78%)		
Manning (62%)		

5. Please write a number 1 to 5 as to the future impact on bore demand given the following statements (1 is strong increase in demand, 3 is no effect on demand and 5 is strong decrease in demand).

   a. There is a decrease in the size of gardens due to smaller blocks in new developments, and subdivision in older developments.

   b. There is a perceived risk by customers of bores failing due to declining groundwater levels.

   c. There is a perceived risk by customers that restrictions will be placed on bore use (e.g. watering frequency).

Household bores

Please answer the following questions for a *typical household installation*.

6. What type of pump would you recommend for the following (in kW/h)?

Depth to ground water (m)	Type of Pump (kW/h)	Cost ($)
≤ 4		
4 ≤ 10		
10 ≤ 20		
20 ≤ 40		
≥40		

7. Do you think the cost of installing a bore is different for different substrates?

Please circle: Yes / No

a. If no, continue to next question.

b. If yes, what percentage more does it cost to install a bore in limestone compared to sand and clay compared to sand (%)?

8. Do you think the cost of maintaining a bore is different for different substrates?

Please circle: Yes / No

a. If no, continue to next question.

b. If yes, what percentage more does it cost to maintain a bore in limestone compared to sand and clay compared to sand (%)?

9. Do you think the life of the pump is different for different substrates?

Please circle: Yes / No

a. If no, continue to next question.

b. If yes, what is the difference in lifetime for a pump in limestone compared to sand and clay compared to sand (years)?

10. Do you think the life of bore equipment is different for different substrates?

Please circle: Yes / No

a. If no, continue to next question.

b. If yes, what is the difference in lifetime for a bore in limestone compared to sand and clay compared to sand (years)?

11. Do you think the pumping cost of a bore is different for different substrates?

Please circle: Yes / No

a. If no, continue to next question.

b. If yes, what proportion more does it cost to maintain a bore in limestone compared to sand and clay compared to sand (%)?

12. What would be the cost of installing a bore in sand (drilling and pump) given the below circumstances ($)?

Depth to ground water (m)	Cost ($)
≤ 4	
4 ≤ 10	
10 ≤ 20	
20 ≤ 40	
≥40	

13. Do you think depth to groundwater affects maintenance costs?

Please circle: Yes / No

Please tick units or specify your own *$ per year ( )* *% of capital cost ( )*

a. If no, please state average maintenance costs and continue to next question.

b. If yes, please fill out the table below on what would it cost to maintain the bore/pump?

Depth to ground water (m)	Cost
≤ 4	
4 ≤ 10	
10 ≤ 20	
20 ≤ 40	
≥40	

14. Do you think depth to groundwater affects the life of the pump?

Please circle Yes / No

a. If no, continue to next question.

b. If yes, please fill out the table below on how long the pump would last?

Depth to ground water (m)	Life of pump (years)
≤ 4	
4 ≤ 10	
10 ≤ 20	
20 ≤ 40	
≥40	

15. Do you think that depth to groundwater affects the life of the bore equipment? Please circle: Yes / No

a. If no, continue to next question.

b. If yes, please fill out the table below on how long the bore would last?

Depth to ground water (m)	Life of bore (years)
≤ 4	
4 ≤ 10	
10 ≤ 20	
20 ≤ 40	
≥40	

16. If possible, please specify approximate pump running costs for the groundwater depths in the table below.

Please tick units or specify your own *$ per hour* ( ) *$ per kL* ( )

Depth to ground water (m)	Cost ($)
≤ 4	
4 ≤ 10	
10 ≤ 20	
20 ≤ 40	
≥40	

Shared household bores

17. What percentage of household bores that you install is shared?

18. Is it typically 2 households that are sharing, or have you installed for more than 2?

19. Are there additional costs incurred in setting up a shared bore arrangement?

20. What do you think is the community attitude to shared bores?

21. When urban customers purchase bores do you know how many attempt to get a government rebate?

Larger clients

22. Do you serve larger clients, such as councils?

a. If yes, what proportion of your business is this?

b. If no, this is the end of the questionnaire for you, thank you.

23. Do you think the costs of installing a large bore are the same regardless the substrate?

Please circle: Yes / No

a. If no, just fill in the five *sand* tables below.

b. If yes, fill in the sand tables and any other tables where costs would differ to sand.

What would be the cost of installing a bore given the different areas of lawn in the following tables are to be irrigated?

c. In sand where depth to water **≤ 4m**

Area to be irrigated (ha)	Bore and pump cost	Operating costs	Maintenance costs	Irrigation equipment cost	Lifetime of bore/pump
0.5					
2					
5					

d. In clay where depth to water **≤ 4m**

Area to be irrigated (ha)	Bore and pump cost	Operating costs	Maintenance costs	Irrigation equipment cost	Lifetime of bore/pump
0.5					
2					
5					

e. In limestone where depth to water **≤ 4m**

Area to be irrigated (ha)	Bore and pump cost	Operating costs	Maintenance costs	Irrigation equipment cost	Lifetime of bore/pump
0.5					
2					
5					

f. In sand where depth to water **4 ≤ 10m**

Area to be irrigated (ha)	Bore and pump cost	Operating costs	Maintenance costs	Irrigation equipment cost	Lifetime of bore/pump
0.5					
2					
5					

g. In clay where depth to water **4 ≤ 10m**

Area to be irrigated (ha)	Bore and pump cost	Operating costs	Maintenance costs	Irrigation equipment cost	Lifetime of bore/pump
0.5					
2					
5					

h. In limestone where depth to water **4 ≤ 10m**

Area to be irrigated (ha)	Bore and pump cost	Operating costs	Maintenance costs	Irrigation equipment cost	Lifetime of bore/pump
0.5					
2					
5					

i. In sand where depth to water **10 ≤ 20m**

Area to be irrigated (ha)	Bore and pump cost	Operating costs	Maintenance costs	Irrigation equipment cost	Lifetime of bore/pump
0.5					
2					
5					

j. In clay where depth to water **10 ≤ 20m**

Area to be irrigated (ha)	Bore and pump cost	Operating costs	Maintenance costs	Irrigation equipment cost	Lifetime of bore/pump
0.5					
2					
5					

k. In limestone where depth to water **10 ≤ 20m**

Area to be irrigated (ha)	Bore and pump cost	Operating costs	Maintenance costs	Irrigation equipment cost	Lifetime of bore/pump
0.5					
2					
5					

l. In sand where depth to water **20 ≤ 40m**

Area to be irrigated (ha)	Bore and pump cost	Operating costs	Maintenance costs	Irrigation equipment cost	Lifetime of bore/pump
0.5					
2					
5					

m. In clay where depth to water **20 ≤ 40m**

Area to be irrigated (ha)	Bore and pump cost	Operating costs	Maintenance costs	Irrigation equipment cost	Lifetime of bore/pump
0.5					
2					
5					

n. In limestone where depth to water **20 ≤ 40m**

Area to be irrigated (ha)	Bore and pump cost	Operating costs	Maintenance costs	Irrigation equipment cost	Lifetime of bore/pump
0.5					
2					
5					

o. In sand where depth to water **≥ 40m**

Area to be irrigated (ha)	Bore and pump cost	Operating costs	Maintenance costs	Irrigation equipment cost	Lifetime of bore/pump
0.5					
2					
5					

p. In clay where depth to water **≥ 40m**

Area to be irrigated (ha)	Bore and pump cost	Operating costs	Maintenance costs	Irrigation equipment cost	Lifetime of bore/pump
0.5					
2					
5					

q. In limestone where depth to water ≥ **40m**

Area to be irrigated (ha)	Bore and pump cost	Operating costs	Maintenance costs	Irrigation equipment cost	Lifetime of bore/pump
0.5					
2					
5					

END OF QUESTIONNAIRE. THANK YOU FOR YOU TIME AND EFFORT.