Financial costs, energy consumption and greenhouse gas emissions for major supply water sources and demand management options for metropolitan Adelaide

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Executive Summary

This report explores the cost, energy consumption and gross greenhouse gas emissions of various water supply and demand management options for the Metropolitan Adelaide Region. The following eight water sources are considered for a range of potable and non-potable purposes:

- supply from the Mount Lofty Ranges catchments
- pumping from the River Murray
- desalinated seawater
- groundwater
- harvested stormwater
- recycled wastewater
- roof or rainwater captured in rainwater tanks
- demand management, including various household appliances.

These options have different economic, environmental and social impacts. The optimal combination of these resources is explored in the project 'Optimal Water Resources Mix for Metropolitan Adelaide', where a multi-objective optimisation algorithm will be used. This report provides the input data that will be used in that modelling and optimisation study.

The attributes that have been selected to describe each option for the optimisation process are:

- volume of water produced or saved (GL/year)
- capital cost ($/ML/year), computed as the capital cost divided by the capacity of the plant/water source (in ML/year)
- operational cost ($/kL)
- embodied energy (MWh/ML/year), computed as the embodied energy divided by the capacity of the plant/water source (in ML/year)
- operational energy (MWh/ML/year)
- capital (gross) greenhouse gas (GHG) emissions (tonnesCO2-e/ ML/year), computed as the capital GHGs divided by the capacity of the plant/water source (in ML/year)
- operational (gross) GHG emissions (tonnesCO2-e/ML).

Derivation of the values for these attributes is fully described in the body of this report, and the values are summarised in Table 1.

The only capital costs that are included in this study are the costs of new infrastructure. The capital costs of existing infrastructure (as of March 2013) are not included as this has been spent already and can't be recovered. Essentially it is a 'sunk cost'.

Operational costs have been included for both existing and new facilities. For existing infrastructure the operational costs consist only of operating costs. These operating costs depend on the volume of water that is supplied from these sources in the future. Ongoing maintenance costs for existing infrastructure will be incurred regardless of the new options chosen and so they has not been including in the cost analysis.

The new facilities that are considered in the study include new stormwater harvesting schemes, upgrades of wastewater treatment facilities and distribution networks for the treated stormwater and wastewater. Operational costs for new facilities include both operating and maintenance costs. Maintenance costs have been estimated as an average cost per kL produced rather than as a fixed cost per year. Hence they will be zero in any year that a facility has zero output. In reality there will be fixed maintenance costs unrelated to the volume of water produced and hence this may potentially lead to different optimisation outcomes. As it is unlikely that any facility will have zero output in future years, this error in estimation is acceptable given the other uncertainties in the cost estimates.

The exception is the Adelaide Desalination Plant that could be operated at low levels of output (after the initial proving period) in most years and will only be run at high levels of output during drought years. The assumed operating cost of the Adelaide desalination plant is $30m per year plus $1 /kL produced. Thus there is a fixed cost of $30m per year regardless of output. This is a constant that is included in the cost estimates of all options and so, does not make any difference to the choice between options.

All values are approximate and subject to change should more accurate or specific information become available. Costs, energy and gross greenhouse gas emissions have been estimated considering each intervention independently from the others, although there may be some interactions between options, e.g. if demand management reduces water consumption, the wastewater volume is reduced and this may impact the quantity of water available to be recycled. It should be noted that the purchase of carbon offsets or green energy can be used to fully or partially offset the gross greenhouse gas emissions.

Where possible, local data (from the Adelaide Metropolitan region or from South Australia) have been used. Where local data are not available, values from the literature have been used.

The purpose of this report is to publish these data, including assumptions, approximations and any other caveats that are relevant to their interpretation and use. Note that all values reported are subject to some level of uncertainty, but the costs for Mount Lofty Ranges, Murray River and Adelaide desalination plant are considered to have a lower uncertainty as there are more data available for these sources and these data are Adelaide-based. For other sources it has not been possible to collect specific information and data from other States and

Countries have been used. Some values refer to different years and these have been inflated to March 2013. Specific assumptions, such as the water use for which the costs, energy and GHGs are computed and the capacity/yield of the option, are highlighted in the body of the report.

The superscripts *h*, *m* and *l* in Table 1 refer to a qualitative classification of the reliability of the values (high, medium and low reliability, respectively): values sourced from direct observation or estimated through the use of a calibrated model of the actual system are classified as having high reliability; values based on observations or estimates made for closely related systems or developed from multiple literature sources are classified as having medium reliability; values derived from literature values that have been developed from a single or few literature sources are classified as having low reliability.

It would be possible to reduce the uncertainty associated with the costs, energy and GHG values reported in this work. However, whether it is worthwhile reducing this uncertainty and how much effort is required depends on the degree of uncertainty required in the results, how easy it is to reduce this uncertainty and on which water sources will be used predominantly.

Note that the degree of reliability associated with the values given in this report is considered to be acceptable given that the aim of the study is to demonstrate the framework developed in the project 'Optimal Water Resources Mix for Metropolitan Adelaide' rather than come up with specific recommendations for the Adelaide Metropolitan system.

TABLE 1: VOLUME OF WATER SUPPLIED/SAVED, CAPITAL, OPERATIONAL COSTS, AND EMBODIED AND OPERATIONAL ENERGY AND GREENHOUSE GAS EMISSIONS FOR THE WATER SOURCES

Capacity	Capital cost*	Operational cost	Embodied energy	Capital GHG emissions	Operational energy	Operational GHG emissions
GL/year	**$'000/ML/year****	**$/kL**	**MWh/ ML/year****	**tonnesCO_2-e/ ML/year****	**MWh/ ML**	**tonnesCO_2-e/ ML**
Water from Mount Lofty Ranges						
121 (average year) *(h)* 30 (dry year) *(h)*	$0***	$0.24 *(h)*	0***	0***	0.3 *(h)*	0.24 *(h)*
Pumping from Murray River						
130 (current entitlement) *(h)* +190 (additional pipe capacity) *(m)* (320 in total) *(m)*	$13.96m every 20 years for pump replacement *(l)*	$0.44 for current entitlement *(h)* $0.74/kL in excess of current entitlement *(m)*	0***	0***	1.9 *(h)*	1.5 *(h)*
Desalinated water						
100 *(h)*	$1.7m every 20 years for pump replacement *(l)*	$1.00 + $30m per year *(h)*	0***	0***	5 *(h)*	4.29 (gross) *(h)* 0.34 (net accounting for green energy) *(m)*
Groundwater						
3 *(l)*	$1.0 *(l)* + $0.12m every 20 years for pump replacement *(l)*	$0.36 *(l)*	Not estimated	Not estimated	1.2 *(l)*	0.95 *(l)*
Stormwater: Wetland without ASR						
Harvesting 48.8 *(h)*	Values given in Table 15 *(h)*		5.131 *(l)*	1.502 *(l)*		
Distribution 48.8 *(h)*						
Irrigation of public open space	$18.9 *(l)*	$0.45 *(l)*	7.746 *(l)*	5.958 *(l)*	0.27 *(l)*	0.22 *(l)*
Greenfield third pipe system for non-potable use	$42.1 *(l)*	$0.88 *(l)*	0.772 *(l)*	23.655 *(l)*	0.61 *(l)*	0.49 *(l)*
Brownfield third pipe system for non-potable use	$64.1 *(l)*	$0.88 *(l)*	30.772 *(l)*	23.655 *(l)*	0.61 *(l)*	0.49 *(l)*
Blending with treated wastewater then greenfield third pipe system for non-potable use	$30.6 *(l)*	$0.81 *(l)*	29.612 *(l)*	23.151 *(l)*	0.76 *(l)*	0.60 *(l)*

Capacity	Capital cost*	Operational cost	Embodied energy	Capital GHG emissions	Operational energy	Operational GHG emissions
GL/year	$'000/ML/year**	$/kL	MWh/ ML/year**	tonnesCO_2-e/ ML/year**	MWh/ ML	tonnesCO_2-e/ ML
Blending with treated wastewater then brownfield third pipe system for non-potable use	$52.6 (l)	$0.81 (l)	29.612 (l)	23.151 (l)	0.76 (l)	0.60 (l)
Transfer to reservoir for potable use	$4.7***** (l)	$0.79 (l)	4.006***** (l)	4.070***** (l)	1.04 (l)	0.83 (l)
Stormwater: Wetland with ASR						
48.8 Harvesting (h)	Values given in Table 15(h)		5.131 (l)	1.502 (l)		
48.8 Distribution (h)						
Irrigation of public open space	$8.0 (l)	$0.42 (l)	3.257 (l)	3.702 (l)	0.63 (l)	0.50 (l)
Disinfection and irrigation of public open space	$8.2 (l)	$0.43 (l)	3.257 (l)	3.702 (l)	0.63 (l)	0.50 (l)
Blending with treated wastewater and irrigation	$6.6 (l)	$0.63 (l)	3.501 (l)	3.214 (l)	0.89 (l)	0.70 (l)
Greenfield third pipe system for non-potable use	$27.9 (l)	$0.69 (l)	25.981 (l)	21.379 (l)	0.97 (l)	0.77 (l)
Brownfield third pipe system for non-potable use	$49.9 (l)	$0.69 (l)	25.981 (l)	21.379 (l)	0.97 (l)	0.77 (l)
Blending with treated wastewater then greenfield third pipe system for non-potable use	$24.5 (l)	$0.69 (l)	25.843 (l)	20.774 (l)	0.89 (l)	0.70 (l)
Blending with treated wastewater then brownfield third pipe system for non-potable use	$46.4 (l)	$0.70 (l)	25.843 (l)	20.774 (l)	0.89 (l)	0.70 (l)
Direct injection for potable use	$9.1 **** (l)	$1.26 (l)	0.437**** (l)	1.475**** (l)	1.39 (l)	1.08 (l)
Transfer to reservoir for potable use	$5. 6 ***** (l)	$0.94 (l)	5.008***** (l)	5.158***** (l)	1.35 (l)	1.06 (l)
Treatment and transfer to reservoir for potable use	$6.3 ***** (l)	$1.16 (l)	4.008***** (l)	5.158***** (l)	1.80 (l)	1.41 (l)
Wastewater reuse						
98.55 (h)	$20.3 (l)	$2.00 (l)	Not estimated	Not estimated	0.69 (m)	0.84 (m)
2 kL Rainwater tanks (design life: 25 years)						
2.9 for indoor & outdoor use (l) (22 kL/year/tank) (l)	$139.4-$164.7 (l) ($3.0–$3. 6*10^3 /tank) (h)	$0.36 (l)	61.632 (l)	48.689 (l)	1.45 (l)	1.15kgCO_2-e/kL (l)

Capacity	Capital cost*	Operational cost	Embodied energy	Capital GHG emissions	Operational energy	Operational GHG emissions
GL/year	**$’000/ML/year****	**$/kL**	**MWh/ ML/year****	**tonnesCO_2-e/ ML/year****	**MWh/ ML**	**tonnesCO_2-e/ ML**
1.3 for outdoor use only [l] (10 kL/year/tank) [l]	$164.0–$254.4 [l] ($1.6–$2.5*10^3 /tank) [h]	$0.30 [l]	137.487 [l]	108.615 [l]	1.20 [l]	0.95kgCO_2-e/kL [l]
(based on 2kL tank connected to 100m2 roof)	10% of the construction costs to be added every 25 years [m] Pump replacement ($355/pump) every 10 years [m]	$22/year for maintenance [m]	1.333/tank [h]	1.0533 tonnesCO_2-e/tank [h]		
5 kL Rainwater tanks (design life: 25 years)						
5.8 for indoor & outdoor use [l] (44 kL/year/tank) [l]	$81.1-$93.8 [l] ($3.5–$4.1*10^3 /tank) [h]	$0.36 [l]	54.924 [l]	43.390 [l]	1.45 [l]	1.15kgCO_2-e/kL [l]
2.5 for outdoor use only [l] (19 kL/year/tank) [l]	111.7–158.8 [l] ($2.1–$3.0*10^3 /tank) [h]	$0.30 [l]	127.424 [l]	100.665 [l]	1.20 [l]	0.95kgCO_2-e/kL [l]
(based on 5kL tank connected to 100m2 roof)	10% of the construction costs to be added every 25 years [m] Pump replacement ($355/pump) every 10 years [m]	$22/year for maintenance [m]	2.417/tank [h]	1.909 tonnesCO_2-e/tank [h]		
Demand management – water restrictions						
10% of current total demand [l]	$71/year/ household [l]	-	Not estimated	Not estimated	Not estimated	Not estimated
20% of current total demand [l]	$170/year/household [l]	-	Not estimated	Not estimated	Not estimated	Not estimated
Advertisement costs	$1.15m/year for water utility [l]	-				
Washing machines						
2.4 [l] (water saving 20.2 kL/year/household) [l]	$794/appliance [m] (design life: 8 years)	-	Not estimated	Not estimated	-26.1 [l]	-20.61 [l]
Tap timers						
2.2 [l] (water saving 8.15 kL/year/household) [l]	$75/appliance [m] (design life: 10 years)	-	Not estimated	Not estimated	-0.69 [l]	-0.54 [l]
Low flow showerheads						

Capacity	Capital cost*	Operational cost	Embodied energy	Capital GHG emissions	Operational energy	Operational GHG emissions
GL/year	$'000/ML/year**	$/kL	MWh/ ML/year**	tonnesCO_2-e/ ML/year**	MWh/ ML	tonnesCO_2-e/ ML
2.3 (l) (water saving 13.8 kL/year/household) (l)	$76/appliance (m) (design life: 10 years)	-	Not estimated	Not estimated	-29.76 (l)	-14.82 (l)
Low flow taps						
0.4 (l) (water saving 3.34 kL/year/household – 2 appliances per house are installed) (l)	$752 for 2 appliances (m) (design life: 10 years)	-	Not estimated	Not estimated	-0.69 (l)	-0.54 (l)
Dual flush toilet						
0.4 (l) (water saving 8.4 kL/year/household) (l)	$753/appliance (m) (design life 10 years)	-	Not estimated	Not estimated	-0.69 (l)	-0.54 (l)

* unless other specified

** The capital costs, embodied energy and the capital GHG emissions reported are based on the capacity of the option: e.g. if the embodied energy to build a stormwater harvesting facility is 5 MWh/ML/year and the facility is able to deliver 1000 ML/year, the total embodied energy of that facility is 5000 MWh,

*** It is assumed that the existing capacity of Mount Lofty Ranges, Murray River and Desalination plant cannot be reduced and therefore the embodied energy and capital emissions of these options are assumed to be equal to zero.

**** based on pipe length of 1 km

***** based on pipe length of about 11 km

h, *m*, *l*: indicates high, medium and low reliability of the values, respectively.

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INTRODUCTION

The work reported in this document was conducted in 2012-13 as part of the research program of the Goyder Institute for Water Research's *Optimal Water Resources Mix for Metropolitan Adelaide* project (October 2012-March 2014).

The metropolitan region of Adelaide has multiple sources of water – surface water, groundwater, desalinated water, stormwater, roof or rain water, recycled water and the River Murray – that can be utilised and managed for supplying the city's water needs. The ability to determine the 'optimal mix' of these sources under likely future conditions is necessary to underpin an efficient and sustainable solution for Adelaide. To achieve this, consideration must first be given to the trade-offs between a range of important objectives, from supply security and economic costs to social preferences and environmental impacts. The Optimal Water Resources Mix project was designed to build a strong information base to inform these discussions and planning initiatives through:

- engaging with stakeholders to provide an effective communication pathway and an agreed basis for evaluating alternative water supply mixes
- providing a model that simulates the Adelaide water supply system
- developing a multi-objective optimisation methodology to assess trade-offs
- monitoring household water use to better predict demand
- performing legal and governance analysis in delivering water solutions
- conducting economic analysis of the direct and in-direct costs of supplying water from the multiple sources
- improving understanding of social values and preferences regarding water solutions.

The study reported herein was conducted within the optimisation component of the Optimal Water Resources Mix Project, and funded through the Goyder Institute for Water Research.

Over the period 2004/05 to 2010/11, SA Water supplied on average 139 GL/year of water to the Adelaide Metropolitan region (as shown in Figure 1; National Water Commission, 2010; South Australian Water Corporation, 2011). On average 60% of the water over this period came from the Mount Lofty Ranges and the rest from the Murray River (Water for Good, 2010). However, the supply from the Murray River can reach up to 90% in dry years. The same report highlights that these resources are threatened by development and human activities, both in terms of quantity and quality.

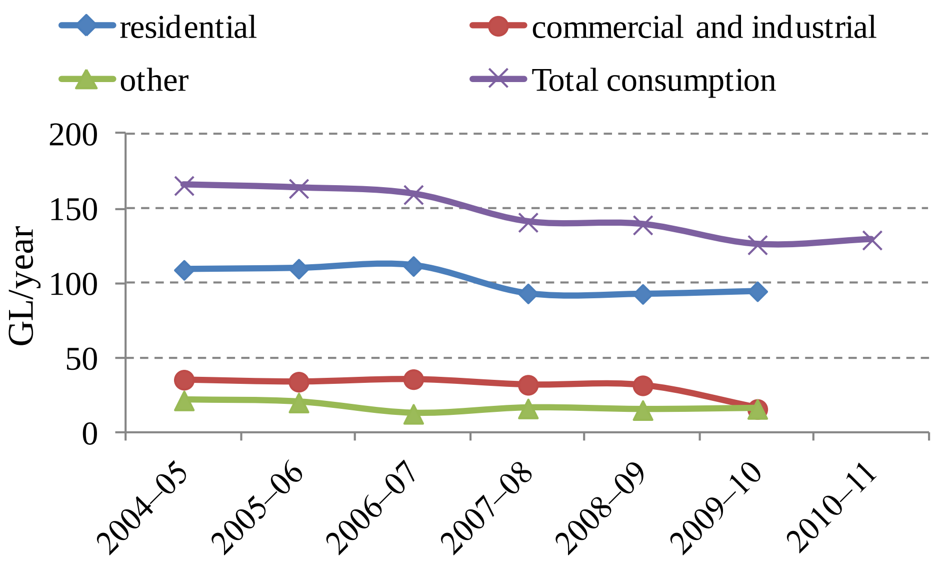


FIGURE 1: POTABLE WATER SUPPLY FOR METROPOLITAN ADELAIDE (NATIONAL WATER COMMISSION, 2010; 2010-11 DATA FROM SOUTH AUSTRALIAN WATER CORPORATION, 2011).

The Water for Good plan (2010) estimated a water deficit for Greater Adelaide by 2050 equal to 32 GL/year and 68 GL/year under moderate and extreme dry year events if no additional water security measures are taken. This estimate takes into account an increased demand due to the increased population and the reduced water yield due to climate change and already considers 100 GL/year from the desalination plant and 50 GL/year water demand savings from Water Proofing Adelaide (Government of South Australia, 2004).

The estimate made by Marsden Jacob Associates (2006a) suggests that in 2020 about 220 GL/year would be required to satisfy the demand of the Adelaide Metropolitan region (the region boundary is denoted by the red line in Figure 2). This demand is also confirmed by ATSE (2012).

PURPOSE OF THIS REPORT

This report analyses volumes, costs, energy and greenhouse gas emissions for the eight sources of water considered in the *Optimal Water Resources Mix for Metropolitan Adelaide* project (July 2012-March 2014). These are:

- supply from the Mount Lofty Ranges catchments
- pumping from the River Murray
- desalinated water
- groundwater
- harvested stormwater
- recycled wastewater
- roof or rainwater captured in rainwater tanks

- demand management, including various household appliances.

It should be noted that the purpose of the *Optimal Water Resources Mix for Metropolitan Adelaide* (OWRM) project is to present and demonstrate an approach that could be used to optimise the use of various water supply options for Adelaide. It is not intended to come up with specific recommendations for that city. The volumes, cost, energy and greenhouse gas values that are presented in this report are based on literature values and are adequate for the purposes of the OWRM project. Any specific conclusions that arise from that study would need to take into account the uncertainties in the input data and model assumptions before being implemented. This could be assessed through a thorough sensitivity analysis. The reliability of the data presented in this report is discussed in the Summary.

STRUCTURE OF THIS REPORT

The report contains a chapter for each option, describing its:

- availability
- cost
- energy and greenhouse gas emissions.

Estimates of the costs of the different water supply options for Adelaide are presented as capital costs and operational costs. The next chapter presents the methods used to compute water supply costs. In the optimisation phase of the *Optimal Water Resources Mix Project*, project costs will be compared using net present value using a time horizon of 25 year and a discount rate of 6% per annum, as these are the values currently used in South Australia. There are different ways to estimate the water supply cost and several estimates exist for the current mix of water sources in Adelaide. The method used in this report is described in the next chapter and other methods are covered in Appendix A.

Two aspects of the environmental impacts of the supply sources considered are the energy and gross greenhouse gas emissions (GHGs). Gross greenhouse gas emissions are used throughout this report. These gross greenhouse gas emission figures are presented for completeness, however, they were not used in the modelling or optimisation components of the Optimal Water Resources Mix for Metropolitan Adelaide project (July 2012-March 2014) as energy was used instead.

It is recognised that carbon offsets or green energy are currently purchased for some of the water resource options (e.g. the Adelaide desalination plant). The greenhouse gas emission factor for green energy is zero. A number of current and new facilities could also have associated carbon offsets or green energy (e.g. new stormwater harvesting facilities). The use of offsets and green energy would need to be taken into account if an analysis of greenhouse gas emissions of the total supply system is undertaken in future studies.

Energy and gross greenhouse gas emissions (GHGs) have been estimated as capital and operational energy and GHGs, respectively. Capital energy is referred to as ‘embodied energy’ and it estimates the energy used to build the intervention (e.g. how much energy is used to produce the concrete to build the housing of the pumping station). Embodied and operational energy can then be converted in embodied and operational GHGs by using an emission factor. More details about GHGs and the scope of emissions can be found in Appendix B. This report analyses the full cycle emissions. The methodology used to compute costs, energy and gross GHGs of the water supply options considered can be found in Appendix C. A zero discount factor is recommended for computing the net present value of energy and GHGs. Limited data exists for computing the embodied energy: the estimates in this report do not include energy involved in the construction of pumps and other appliances. The following sections present the estimated costs, energy and gross greenhouse gas emissions of the supply options for the Adelaide Metropolitan region.

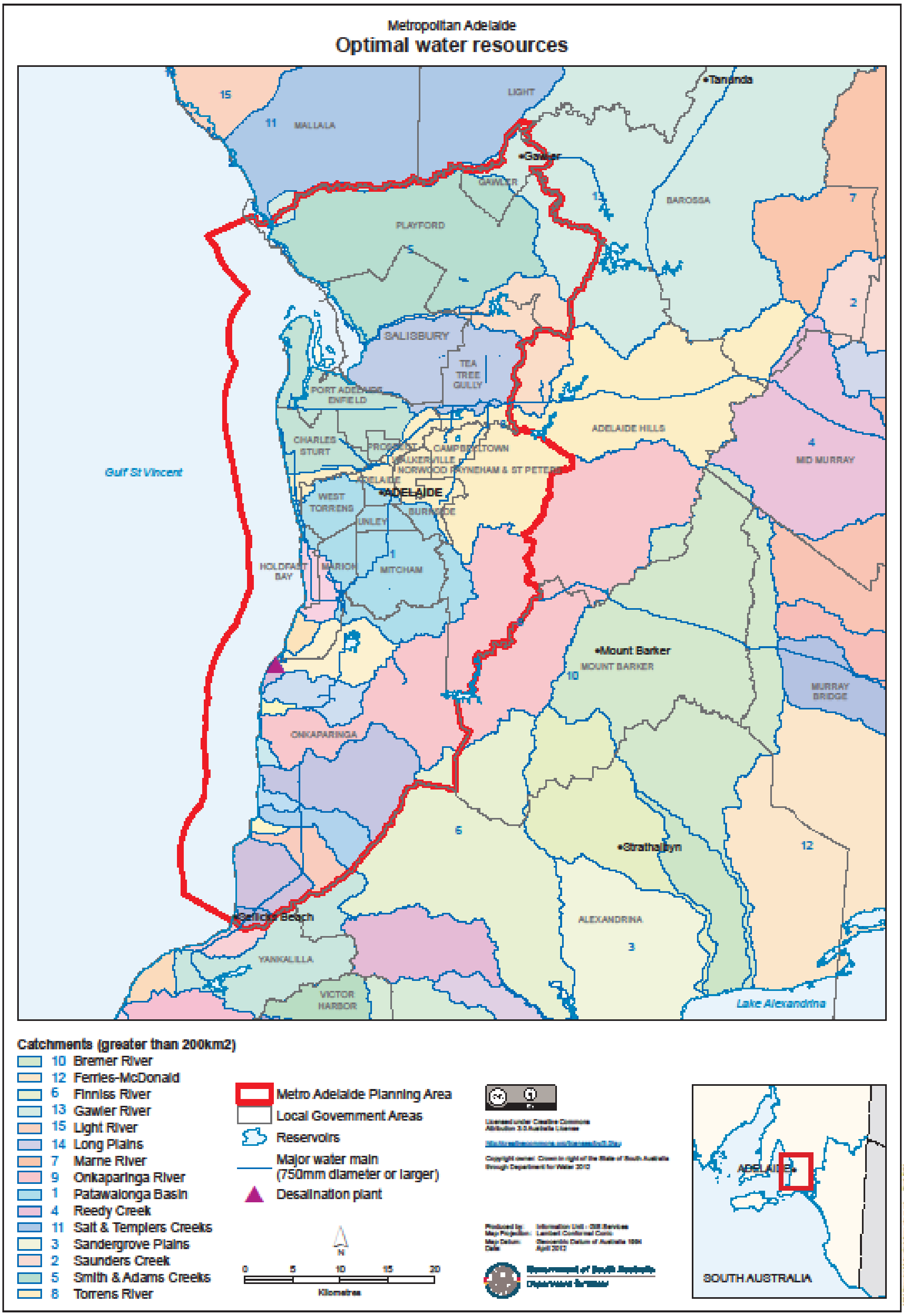


FIGURE 2: THE ADELAIDE METROPOLITAN AREA USED FOR THE CASE STUDY (THE REGION WITHIN THE RED LINE)

METHOD USED TO ESTIMATE THE COST OF WATER SUPPLY OPTIONS

Supplying water is an economic activity that incurs costs that are reflected to varying degrees in the water price. There are various ways of analysing the costs associated with water supply. Firstly, costs are usually divided into capital costs and operational costs.

Capital costs are associated with the construction of major works (e.g. the construction of desalination plants, pump or pipe systems) that occur only once at the beginning of the design life of the facility. Operational costs occur throughout the whole design life of the facility and are usually associated with the consumption of energy or materials (e.g. to operate a pump) and expenses associated with personnel. The operational costs can vary from one time period to another, e.g. a pump can be operated or switched off depending on needs.

In this report, a distinction is drawn between existing and new facilities as indicated in Table 1.

TABLE 1: CAPITAL AND OPERATIONAL COSTS INCLUDED IN THIS PROJECT

Type of Facility	Capital Costs	Operational Costs
Existing facilities	Not included	Operating costs only
New facilities	Included	Operating and maintenance costs

The only capital costs that are included in this study are the costs of new infrastructure. The capital cost of existing infrastructure (as of March 2013) are not included as this has been spent already and can't be recovered. Essentially it is a 'sunk cost'.

Operational costs have been included for both existing and new facilities. For existing infrastructure the operational costs consist only of operating costs. These operating costs depend on the volume of water that is supplied from these sources in the future. Ongoing maintenance costs for existing infrastructure will be incurred regardless of the new options chosen and so they has not been including in the cost analysis.

The new facilities that are considered in the study include new stormwater harvesting schemes, upgrades of wastewater treatment facilities and distribution networks for the treated stormwater and wastewater. Operational costs for new facilities include both operating and maintenance costs. Maintenance costs have been estimated as an average cost per kL produced rather than as a fixed cost per year. Hence they will be zero in any year that a facility has zero output. In reality there will be fixed maintenance costs unrelated to the volume of water produced and hence this may potentially lead to different optimisation outcomes. As it is unlikely that any facility will have zero output in future years, this error in estimation is acceptable given the other uncertainties in the cost estimates.

The exception is the Adelaide Desalination Plant that could be operated at low levels of output (after the initial proving period) in most years and will only be run at high levels of output during drought years. The assumed operating cost of the Adelaide desalination plant is $30m per year plus $1 /kL produced. Thus there is a fixed cost of $30m per year regardless of output. This is a constant that is included in the cost estimates of all options and so, does not make any difference to the choice between options.

The cost analysis is complicated by the fact that the information available is site-specific and often refers to different years. In addition, the electricity tariff is not publicly available and operating costs have been computed based on estimates of the electric tariff and of the energy consumption. Although it is known that the water utility (SA Water) has a multi-pattern tariff, specific data are not available and, for simplicity, a constant tariff has been adopted. Different electricity prices are used for the different sources to take into account that some options may have lower electricity rates due to large energy consumption. For example, a price of 0.15$/kWh will be assumed to compute the energy costs related to treating Mount Lofty Ranges water, pumping from the Murray River and for desalination, while $0.25/kWh will be adopted for the other supply options. This reflects the fact that SA Water pays a lower tariff for electricity due to the large quantities consumed.

As capital and operational costs occur at different times, it is not possible to compare them directly and it is necessary to consider them over a specified period of time. This is usually done by taking into account a discount rate,that weights future payments compared to present ones. An economic analysis of capital and operational costs can be undertaken in two possible ways: (a) by converting the anticipated operational costs for the design life of the facility to ‘present value’ at the beginning of the project (Figure 3); or (b) by spreading the capital costs uniformly throughout the design life of the work (Figure 4). In this report, the former option will be used.

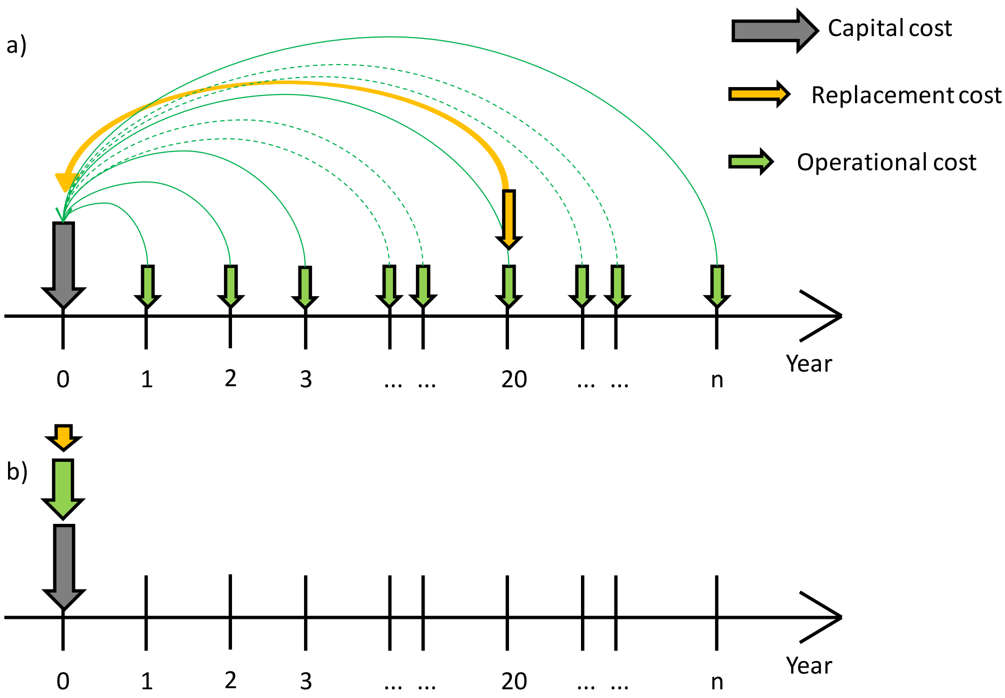


FIGURE 3: TOTAL COST OF THE FACILITY: CAPITAL, OPERATIONAL AND REPLACEMENT COSTS (A) REFERRED TO THE SAME INITIAL TIME (B).

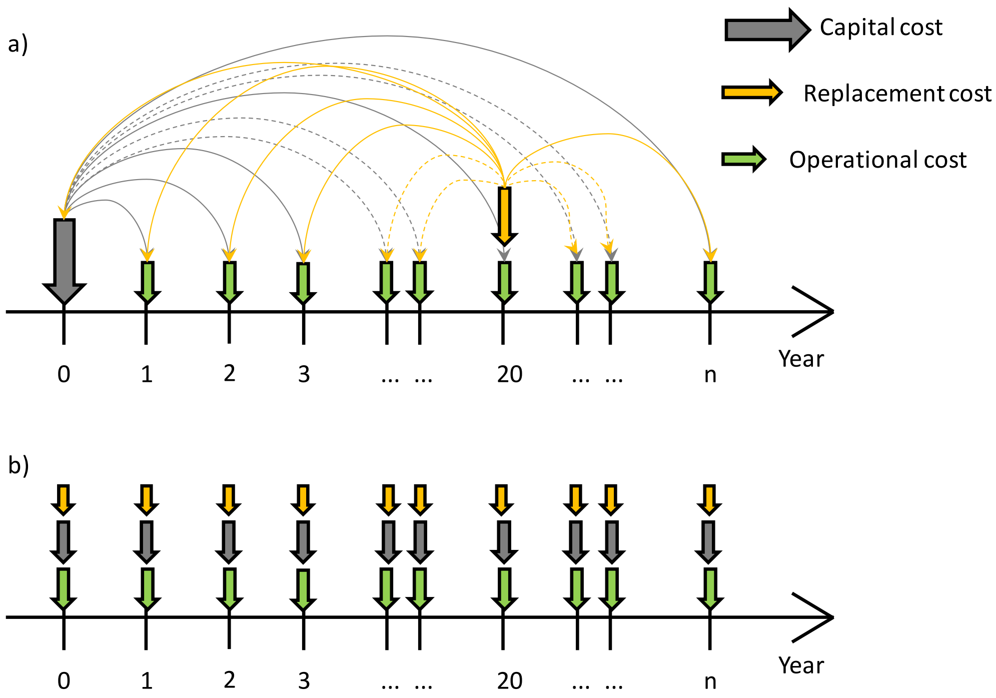


FIGURE 4: CAPITAL, OPERATIONAL AND REPLACEMENT COSTS (A) ARE UNIFORMLY SPREAD THROUGHOUT THE DESIGN LIFE OF THE PROJECT (B).

The baseline for costs in this study is March 2013. Previous data analysed to estimate the capital and operational costs of the various water supply options have been inflated to March 2013 values using the Consumer Price Index as outlined in Appendix D.

SUPPLY FROM THE MOUNT LOFTY RANGES

SOURCE AVAILABILITY

In an average year, one of the major water sources for Adelaide is the catchments and reservoirs located in the Mount Lofty Ranges. As reported by Sustainable Focus and Clark (2008), on average the Adelaide Hills, i.e. the part of the Mount Lofty Ranges closest to Adelaide, provide 121 GL/year. However, this quantity can decrease to as little as 30 GL in a dry year, necessitating most of the supply to be taken from other sources – primarily the River Murray.

The Sustainable Focus and Clark report estimates an average annual runoff of 180 GL/year in the catchments. However, on average, 15 GL/year are lost by evaporation, 10 GL/year are diverted to farm dams and 34 GL/year spills. Therefore only 121 GL/year (56% of the demand) can be used to supply Adelaide in an average year. The report also estimates that increasing the storage capacity of the reservoirs in the Hills to capture the 34 GL/year currently spilled is not a viable option because of the increased evaporation.

An additional alternative mentioned in Sustainable Focus and Clark (2008) is the possibility of storing Mount Lofty Ranges water in an aquifer so as to avoid evaporation losses. It has to be noted that the release of flow for environmental reasons is still a requirement in this case. Although this option could be viable, the identification of suitable aquifers and locations as well as additional data on the capacities of the aquifers are necessary.

COST

Supplying Adelaide using water from this source is not an energy intensive process: taking into account the costs associated with water treatment, chemicals and delivery, an operational cost equal to $0.24/kL for water sourced from the Mount Lofty Ranges has been assumed.

Energy and GHG Emissions

As the energy consumption is 0.3 kWh/kL (ATSE, 2012), the greenhouse gas (GHG) emissions associated with supplying water from the Mount Lofty Ranges are 0.24 kgCO_2-e/kL. GHG emissions due to the use of chemicals are not included.

Summary

It will be assumed that only 30-121 GL/year (depending on the rainfall), will be available from the Mount Lofty Ranges and that the operational costs amount to 0.24 $/kL. Note that capital costs are considered sunk costs (Table 2). Table 3 reports the energy and greenhouse gas emissions associated with the use of this source.

Table 2: Summary of costs and volumes of water that can be supplied by the Mount Lofty Ranges.

Option	Capacity (GL/year)	Capital cost ($/ML/year)	Operational cost ($/kL)
Water from Mount Lofty Ranges	121 (average year) - 30 (dry year)	0	0.24

Table 3: Summary of energy and GHGs and volumes of water that can be supplied by the Mount Lofty Ranges.

Option	Capacity (GL/year)	Embodied energy (MWh/ML/year)	Operational energy (MWh/ML)	Capital GHGs (tonnesCO_2-e/ML/year)	Operational GHGs (tonnesCO_2-e/ML)
Water from Mount Lofty Ranges	121 (average year) – 30 (dry year)	0	0.3	0	0.24

WATER FROM THE MURRAY RIVER

SOURCE AVAILABILITY

The Murray River provides on average 40% of Adelaide's water supply, but, in dry years, this percentage can reach 90% (Water for Good, 2010). SA Water's current water licence for public water supply for metropolitan Adelaide from the River Murray is for 650 GL over a rolling five year period or an average of 130 GL/year. However, more water can be provided from this source if additional water licences are purchased on the water market. Water purchases could be of a temporary (one year duration) or permanent nature with price varying according duration and reliability of supply in times of shortage (ie high or low security) as illustrated in Figure 5 and Figure 6.

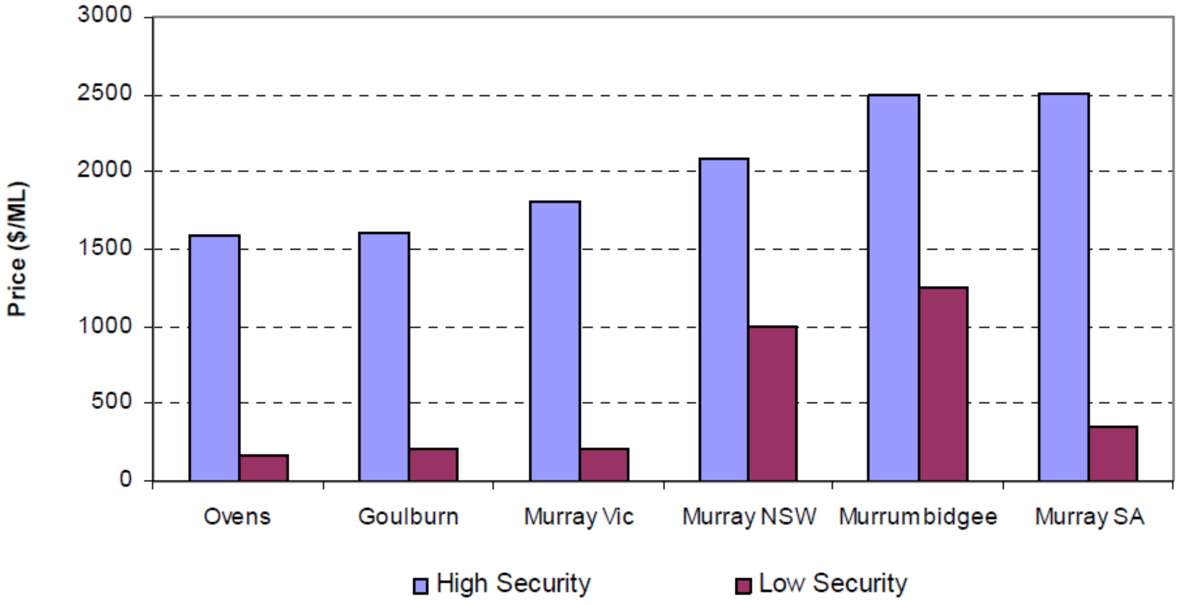


FIGURE 5: APPROXIMATE PRICES FOR PERMANENT, HIGH SECURITY WATER AND LOW SECURITY WATER (ENTITLEMENTS) AVERAGED OVER THE 2007-08 WATER SEASON FOR SIX MAJOR TRADING AREAS IN THE SOUTHERN MURRAY-DARLING BASIN (KACZAN ET AL. 2011).

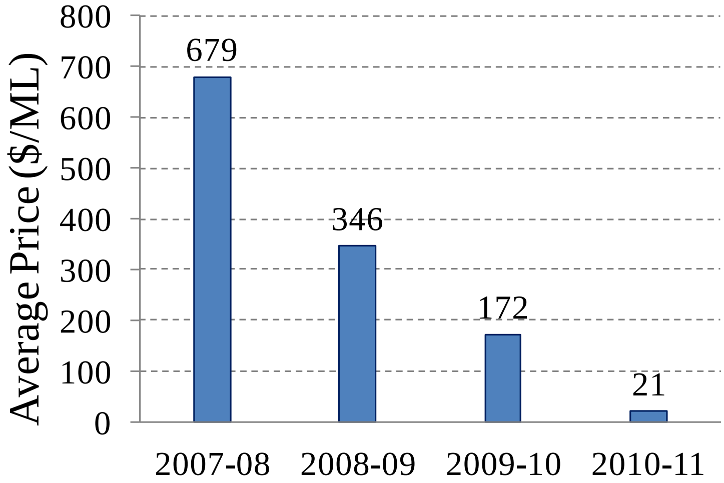


FIGURE 6: AVERAGE PRICES FOR TEMPORARY WATER ALLOCATION TRADES IN SOUTH AUSTRALIA (NATIONAL WATER COMMISSION, 2011).

The total diversions from the Murray River in 2007/08 reported by Kaczan et al. (2011) amounted to 2,738 GL (Figure 7). However, only 15.4% of this volume (423 GL) was delivered to South Australia. For future dry years it has to be taken into account that other users will purchase water allocations and that the price of water could increase enough so that water restrictions are a financially preferable option compared to purchase of additional water. It will be assumed that 190 GL/year more than the current average entitlement (i.e. 320 GL/year in total) can be supplied from the Murray River, based on an estimate of the capacity of the pipelines that transfer water from the River Murray to Adelaide. The estimate of the additional water supply from the Murray River (190 GL/year) does not take into account that other factors can limit the supply, such as the availability of storage. Moreover, environmental impacts and the actual availability of water in the Murray River have to be considered, especially in dry years.

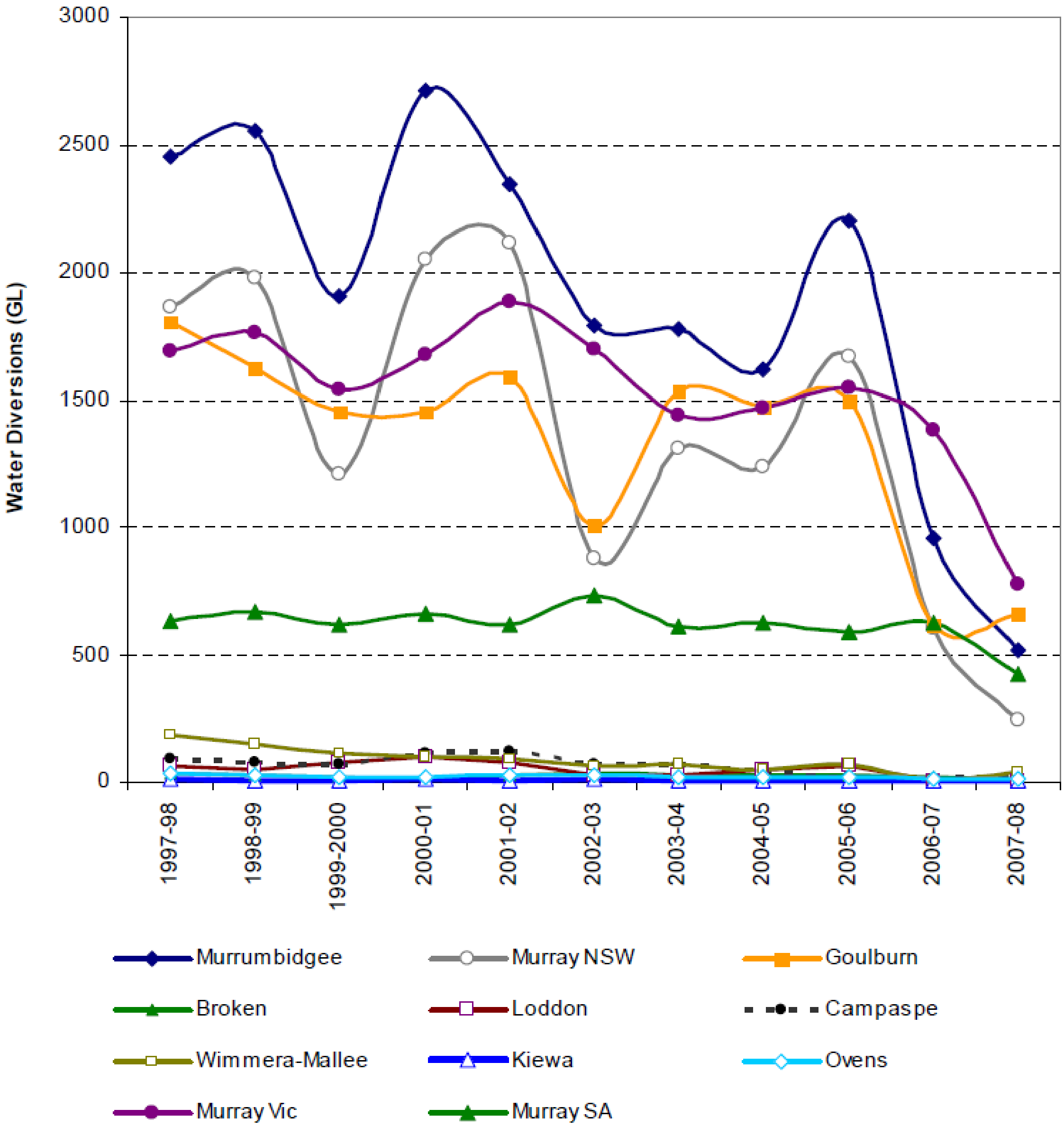


Figure 7: Approximate annual diversion volumes in 11 major trading areas in the southern Murray-Darling Basin (Kaczan et al. 2011).

Cost

As this source is currently used, the infrastructure required to transport the water is already built and hence its capital cost is considered to be a sunk cost. Therefore, the cost of supplying water from the River Murray only takes into account operational costs. The only exception is related to the pump replacement cost, estimated at the end of this section.

ATSE (2012) and Sustainable Focus and Clark (2008) estimate the average energy consumption due to pumping from the Murray River to be equal to 1.6 kWh/kL. ATSE (2012) also estimates that 0.3 kWh/kL are necessary for water treatment, resulting in a total energy consumption equal to 1.9 kWh/kL.

The energy price adopted for this source is equal to \$0.15/kWh as in ATSE (2012), resulting in a cost of pumping equal to \$0.29/kL. To this cost, the cost of chemicals and water purchase has to be added. ATSE (2012) estimates that the cost of supplying Adelaide using water from the Murray River is 0.44 \$/kL.

The average price of water allocation in the years 2007-08 to 2010-2011 is equal to \$0.30/kL. However, the price of water allocation is expected to be lower in years with abundant rainfall and more expensive in dry years. ATSE (2012) assumed an average price equal to \$0.25/kL. Given the variability of water allocation prices, it is proposed to use \$0.30/kL to estimate the cost of purchasing water in excess of the 130 GL/year licensed to SA Water from the Murray River for public water supply for metropolitan Adelaide.

It is also assumed that the additional water purchased from the Murray River can be delivered without the need for new infrastructure. The ATSE (2012) report highlights that the maximum capacity of the existing pipes is 10.28 GL/month for the Mannum-Adelaide pipeline, 14.9 GL/month for the Murray Bridge-Onkaparinga pipeline and 2.02 GL/month for the Swan Reach-Stockwell pipeline (used rarely). All together, the pipelines would be able to supply 320 GL/year. Moreover, the recent works for hydraulically connecting the Northern and Southern Adelaide water supply systems will be able to distribute the water to the whole of the Adelaide area. In fact, as reported by SA Water (2012), the Adelaide metropolitan area previously was separated in two different zones from a hydraulic point of view: the demand of the northern suburbs was satisfied by the Mannum-Adelaide-Hope Valley system, while southern Adelaide relied on the Murray Bridge-Onkaparinga-Happy Valley system (Figure 8). The North-South Interconnection System Project will allow for the transfer of large volumes of water between Adelaide's southern (including water from the desalination plant) and northern supply systems. As the interconnection project is well advanced, the capital cost (\$403 million) associated with the civil works will be considered as sunk costs.

The pump replacement costs are estimated on the basis of the peak daily capacity of the plants with the McGivney and Kawamura (2008) formula (Cost (\$)=3214.7*Q(ML/day)+60716). Taking into account the capacity of the three pipelines and their number of pump stations and converting the US\$ in 2008 to AUD in 2013, the pump replacement costs are estimated to be \$6.21m, \$6.64m and \$1.11m for the Mannum-Adelaide, Murray-Bridge Onkaparinga and Swan Reach-Stockwell pipeline, respectively. Note that the design life of these pumps is estimated to be 20 years. Therefore, every 20 years, \$13.96m will be incurred to replace pumps. Note that this is only an estimate affected by many uncertainties as the original pump replacement cost has been calibrated for the US market.

ENERGY AND GHG EMISSIONS

As indicated above the average energy consumption for pumping and treating water from the River Murray is 1.9 kWh/kL. The gross greenhouse gas emissions caused by the operation of pumps and water treatment can be estimated by applying the emission factors for South Australia. As reported in the introduction, the full cycle emissions will be considered. Therefore, an emission factor equal to 0.79 $kgCO_2$-e/kL (Department of Climate Change and Energy Efficiency, 2012b) will be used. The use of 1.9 kWh/kL, considered inclusive of pumping and treatment, results in a carbon footprint equal to 1.50 $tonneCO_2$-e/ML.

Furthermore, it is assumed that this same level of emissions per kL also applies to water purchased in excess of the current entitlement of SA Water (130 GL/year on average). GHG emissions related to the purchase of chemicals are not estimated here because of the lack of data.

FIGURE 8: MANNUM-ADELAIDE PIPELINE PATH (INDICATIVE) AND LOCATION OF THE DESALINATION PLANT.

SUMMARY

In conclusion, the levelised cost of supplying water from the Murray River is only related to the operational costs. It is suggested to use a cost equal to \$0.44/kL for the first 130 GL of water provided per year (Table 4). If additional water is required, the cost of the additional water purchase (\$0.30/kL) has to be added. This gives a total cost of \$0.74/kL. It is also assumed that the maximum volume that can be provided is 320 GL/year. This estimate is based on the capacity of the pipelines.

Based on the energy consumption for pumping and treatment, GHG emissions are estimated to be 1.5 $kgCO_2$-e/kL (Table 5).

Table 4: Summary of costs and volumes of water that can be supplied by the River Murray.

Option	Capacity (GL/year)	Capital cost ($/ML/year)	Operational cost ($/kL)
Pumping from River Murray	130 (current entitlement) +190 (additional pipe capacity) 320 (in total)	$13.96m every 20 years for pump replacement	0.44 (for current entitlement) 0.74 for each kL in excess of 130 GL/year (current entitlement)

Table 5: Summary of energy, GHGs and volumes of water that can be supplied by the River Murray.

Option	Capacity (GL/year)	Embodied energy (MWh/ML/year)	Operational energy (MWh/ML)	Capital GHGs ($tonnesCO_2$-e/ML/year)	Operational GHGs ($tonnesCO_2$-e/ML)
Pumping from River Murray	130 (current entitlement) +190 (pipe capacity) 320 (in total)	0	1.9	0	1.5

THE ADELAIDE DESALINATION PLANT

The desalination plant can provide up to 100 GL per year (about 2/3 of the current demand of Metropolitan Adelaide). The desalinated water is pumped to Happy Valley where it is blended with water from the Happy Valley water treatment plant before distribution to consumers.

CAPITAL COST

The capital costs of the desalination plant and interconnecting pipelines are described in the 2011 annual report of SA Water (South Australian Water Corporation, 2011) and equal $1.824 billion. The desalination plant and related facilities have already been built and therefore will be considered as an existing source in the optimisation process. However, for completeness, they are reported here.

To effectively supply the whole of metropolitan Adelaide in case of drought, pipelines and other infrastructure are necessary to connect the northern and southern supply networks. This infrastructure accounts for $403 million of the total cost and is expected to be completed soon. This cost also includes the construction of the required pumping stations to transfer the water from the south to the north in Adelaide (SA Water, 2012).

It can be assumed that the desalination plant and the pipeline systems will have a design life longer than the 25 years used in the economic analysis. The cost of the specific equipment for the desalination plant with a design life less than 25 years, such as the membranes for the reverse osmosis, will be included in the ongoing costs.

Capital Cost of Pumps to Transfer Desalinated Water to Happy Valley

Pumps to move water from the desalination plant to the tanks at Happy Valley will typically need to be replaced every 20 years. Arup (2012) provides some of the technical details that can be used to estimate the pump station power. The project will be able to deliver between 30 and 375 ML/day, the static lift is 140 m and the total lift at full flow is equal to 185 m. The mild steel cement lined pipe is 12 km long and has an internal diameter of 1.515 m and a pressure rating equal to 2.5 MPa.

Using these data, the power required at full capacity is estimated to be 9,846 kW. Arup reports that there are 8 pumps in the pumping station, therefore each pump should have a maximum power of about 1200 kW. Baulis et al. (2008) estimated that the replacement costs of these pumps will be around $30m, however, this cost overestimates the cost of pump replacement because it considers the construction of the whole pumping station. Using the formula from McGivney and Kawamura (2008) results in a cost of pump replacement equal to $1.7m every 20 years. This last value will be assumed in the report.

ONGOING COSTS

Ongoing costs for the desalination plant and related works are not available yet and, although a contract has been signed with AGL Energy Limited to provide renewable energy equivalent to that used by the desalination plant, the electricity price is not publicly available.

The estimated energy required to produce one kL of water with a desalination plant is about 5 kWh (Government of South Australia, 2004). In this same report the operating and maintenance costs are estimated to be equal to $39 million per year for a plant able to produce 50 GL/year. Therefore the cost of desalinated water should be $0.78/kL (in 2004 dollars) and this cost should also be inclusive of maintenance costs. This cost is $0.99/kL when converted to 2013 dollars. Note that costs are referred to March 2013 as this is the most recent value of the consumer price index CPI available (see Appendix D).

For the desalination plant, maintenance and other costs are relevant and could be incurred regardless of plant operation. Maintenance costs include the cost of replacing the membranes for the reverse osmosis. These membranes have a life much shorter than the project life (2-5 years compared to 25 years or more) and it is preferred to include them as ongoing costs. As reported by Hoang et al. (2009) the operational costs are nearly half of the capital costs. Although data in Figure 9 refer to a 100 ML/day (36.5 GL/year) plant, and therefore it is likely that operational costs for plants of different sizes are different, it can be seen that, among the operational costs, the sum of labour, chemicals and membrane costs is equal to the energy expenditure.

As reported by ABC News (2010), the South Australian plant will have a recurrent annual cost of about $130 million for electricity and other operating costs if run at full capacity. It should be noted that this value also contains fixed costs independent of production. If the labour costs computed using the percentages reported by Hoang et al (2009) are considered to be fixed, $28.26 million per year would have to be paid, regardless of the amount of water produced.

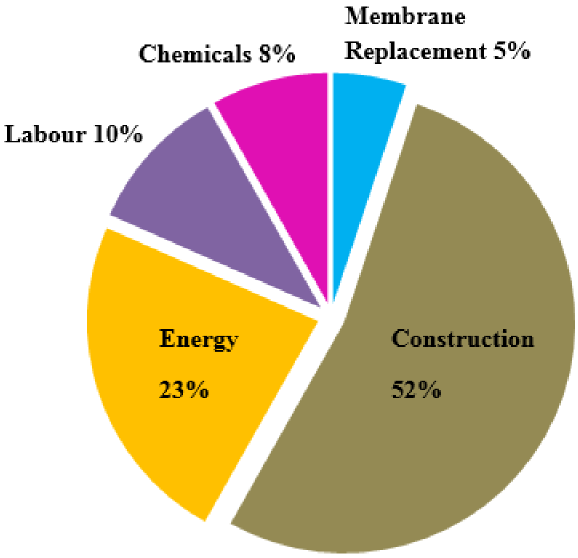


FIGURE 9: DISTRIBUTION OF COSTS IN A DESALINATION PLANT WITH CAPACITY EQUAL TO 100 ML/DAY (DATA FROM HOANG ET AL. 2009).

It is proposed to assume that the annual operational and maintenance costs for the desalination are $30 million, regardless of the operation of the desalination plant. It is also proposed to use an operational cost of $1/kL, based on the data from ABC News (2010). Note that the ABC News estimate is based on an electricity tariff equal to $0.13/kWh. Using $0.15/kWh does not change this cost considerably ($1.12/kL, see Appendix E). Because of the uncertainty in electricity prices and other factors, it is preferred to use $1/kL for consistency with other sources (ATSE, 2012). Note that this value includes the energy needed for pumping to the Happy Valley Water Treatment Plant.

ENERGY AND GHG EMISSIONS

As the construction works are already in place or being implemented, the only energy and greenhouse gas emissions considered for the desalination plant are the ones originating from the operation of the desalination plant.

The energy required for the desalination process and pumping to the Happy Valley Treatment Plant has been estimated equal to 5 kWh/kL (Government of South Australia, 2004). This quantum of energy has to be provided using renewable sources as stipulated by the contract with AGL Energy Limited.

For reporting purposes, the National Greenhouse and Energy Reporting System (NGERS) (Department of Climate Change and Energy Efficiency, 2012a) requires use of the average emission factor for the State to convert all energy use to GHGs, as it is not possible to distinguish the source of the energy once it enters the network.

It should be noted that the purchase of GreenPower^{TM} and the voluntary cancellation of Renewable Energy Certificates (RECs) generated by accredited GreenPower^{TM} generators is considered to be equivalent to the direct use of renewable energy under the Carbon Neutral Program Guidelines (Commonwealth of Australia, 2013). Therefore, the net carbon footprint may be calculated by deducting the portion of Scope 2 electricity emissions (ie indirect GHG emissions of a facility due to imported energy use, see Appendix B) equivalent to the amount of green power purchased from the gross emissions reported under the NGERS. In the following analysis, both gross and net GHG emissions will be estimated. Note that the full cycle (Scope 2 + Scope 3, see Appendix B) emission factor for electricity use will be used to compute the gross GHG emissions to be consistent with the estimates for the other facilities. Consideration of the electricity full cycle emission factor of 0.79 kgCO_2-e/kWh results in 3.95 kgCO_2-e/kL.

Biswas (2009) reports that, taking into account the whole life cycle of a desalination plant, 3.89 tonnes of CO_2-e would be produced to obtain 1 GL of desalinised water. The study does not include the GHGs caused by the production of capital equipment, including building, pipe infrastructure and machinery, but includes frequently consumed items, such as chemicals and membranes. The estimate also includes the transport of chemicals and membranes. Biswas showed that the generation of electricity for pumping, membrane operation and water delivery accounts for 92.1% of the total GHG emissions in the life cycle analysis. From this LCA analysis, it was estimated that other most relevant source of GHG emissions is the production of chemicals (7% of the total GHG). If the percentages suggested by Biswas (2009) are followed, the total GHG emissions of the desalinised water would amount to 4.29 kgCO_2-e/kL and the chemicals would amount to 0.30 kgCO_2-e/kWh. Values computed based on data from Mrayed and Leslie (2009) are similar (total GHG emissions equal to 4.21 kgCO_2-e/kL).

Considering the approximations and the different assumptions of other estimates, it is proposed to adopt a value of 4.29 kgCO_2-e/kL as the gross GHG emissions of the desalination plant. Note that the desalination plant also incurs costs when not in operation. However, as greenhouse gas emissions are mostly caused by the use of energy and chemicals, it is assumed that there will be no GHG emissions if the desalination plant is switched off.

The value assumed (4.29 kgCO_2-e/kL) can be compared with the data reported in the Annual Report of SA Water (South Australian Water Corporation, 2012) (Table 6). Knowing that only 1.8% of the total water produced was sourced by the desalination plant, the scope 2 emissions of the desalination are 3.78 kgCO_2-e/kL. The emission factor used by SA Water to estimate Scope 2 emissions should be equal to 0.67 (value for 2009-2010) or 0.65 (latest estimate), resulting in energy requirements of the desalination plant in the range 5.64-5.82 kWh/kL. This value is not too dissimilar to our assumed value of 5 kWh/kL and the difference can be explained by the fact that the desalination plant was not running at its maximum efficiency and by the fact that other factors (in addition to electricity, chemicals and membranes) could have been accounted for under Scope 2.

Table 6: Greenhouse gas emissions (tonnes CO2-e/year) and Estimated Energy Consumption (kWh/kL) in 2011-2012 for SA Water (South Australian Water Corporation, 2012)

Facility emission	Scope 1	Scope 2	Scope 3	Total emissions 2011-12
Adelaide desalination project (t CO_2-e)	3,563	14,180	78,377	96,121
Adelaide desalination project output (ML/year) 1.8% of 208,144ML	3,747			
Energy consumption for scope 2 = 0.65 (latest estimate) (kWh/kL)		5.82		
Energy consumption for scope 2 = 0.67 (2009-2010) (kWh/kL)		5.65		

Summary

The desalination plant will be able to produce up to 100 GL/year. Capital costs will not be considered in the analysis as the project has already being implemented. The operational costs consist of a fixed $30 million/year, regardless of the amount of water produced and of $1/kL to account for energy, chemical and membrane consumption (Table 7). Note that this cost includes pumping to the Happy Valley Treatment Plant.

The energy and gross greenhouse gas emissions of the desalination plant are estimated to be 5 kWh/kL and 4.29 kgCO2-e-kL (respectively) to account for electricity, chemicals and membranes (Table 8). If the GHGs produced by the consumption of electricity are deducted because green energy is purchased, the net GHG emissions are 0.34 kgCO2-e/kL and account for chemicals and membranes only. Note that emissions are produced only when the plant operates.

Table 7: Summary of costs and volumes of water that can be supplied by the desalination.

Option	Capacity (GL/year)	Capital cost ($/ML/year)	Operational cost ($/kL)
Desalination	100	$1.7m every 20 years for pump replacement	$1.00/kL plus $30m per year

Table 8: Summary of energy, GHGs and volumes of water that can be supplied by the desalination.

Option	Capacity (GL/year)	Embodied energy (MWh/ML/year)	Operational energy (MWh/ML)	Capital GHGs (tonnesCO_2-e/ML/year)	Operational GHGs (tonnesCO_2-e/ML)
Desalination	100	0	5	0	4.29 (gross emissions) 0.34 (net emissions accounting for green energy)

GROUNDWATER

SOURCE AVAILABILITY

According to ANRA (2009), the average use of groundwater sources for the whole of South Australia amounted to 419 GL/year. It was also estimated that the sustainable yield of groundwater for South Australia was 1146 GL/year. From the groundwater point of view, the Adelaide Metropolitan Region belongs to the area classified under the Mount Lofty-Flinders Ranges and it was estimated that 26 GL/year were used. Table 9 reports some characteristics of the groundwater resources in the region. In particular, the Adelaide Metropolitan T1 aquifer can be intersected at a depth in the range of 50-120 m and it has an estimated sustainable yield of 3.4 GL/year. The Adelaide Metropolitan T2 aquifer was not used much: the borehole extracted 200 ML/year, while the sustainable yield is 1.1 GL/year.

Approximately 3.5 GL/year were abstracted for agriculture and industry from the Northern Adelaide plains T1. This resulted in the formation of two cones of depression in the potentiometric surface and the area is now a Prescribed Wells Area to protect the value of the groundwater resource. However, it is estimated that 8 GL/year could be harvested in a sustainable way. ANRA (2009) reported that nearly 13.5 GL were abstracted annually from the Northern Adelaide Plains T2. As abstraction was concentrated in an area where salinity is below 1500 mg/L, a cone of depression developed and this aquifer is also now protected as a Prescribed Wells Area. Sustainable yields were not specified for this aquifer.

The Willunga embayment (or basin) is located approximately 50 km south of Adelaide and covers an area of approximately 320 km^2 (Figure 10). The Willunga Embayment GMU includes the major part of the McLaren Vale Prescribed Wells Area, which was proclaimed in 1990 to protect the value of the groundwater resource. The quality of the water is highly variable, with salinities in the range 350 mg/L to more than 50,000 mg/L.

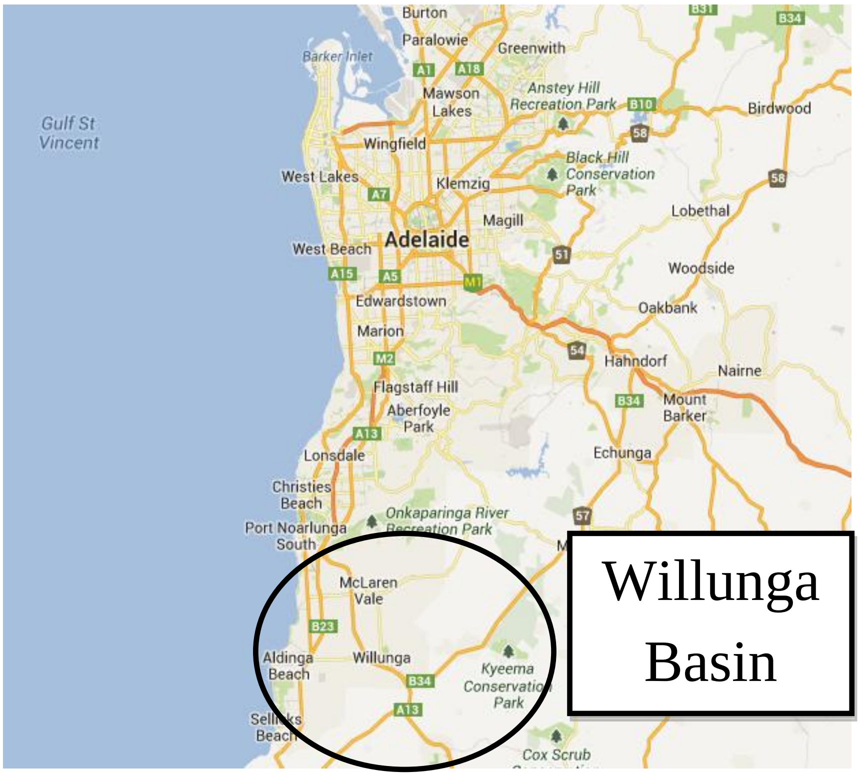


FIGURE 10: LOCATION OF THE WILLUNGA BASIN.

TABLE 9: GROUNDWATER CHARACTERISTICS (ANRA, 2009).

Groundwater management unit	Depth to top of aquifer (m)	Average salinity (mg/L)
Adelaide Metropolitan – T1	60	1,000
Adelaide Metropolitan – T2	190	1,500
Northern Adelaide Plains – T1	60	1,000
Northern Adelaide Plains – T2	120	1,000
Willunga Embayment	40	1,200

CAPITAL COST

The Government of South Australia (2004) estimated that up to 3 GL of water per year could be extracted from groundwater in the Metropolitan Adelaide Region: the capital and annual operational costs would be $2.4 million ($3.04m in 2013 dollars) and $0.84 million per year ($1.06m/year in 2013 dollars), respectively (Table 10). The operating costs would be equal to $0.35/kL, for a total of $0.43/kL in 2013 dollars.

TABLE 10: SUMMARY OF THE CAPITAL, OPERATIONAL AND MAINTENANCE COSTS (IN 2013 DOLLARS) FOR GROUNDWATER SUPPLY (GOVERNMENT OF SOUTH AUSTRALIA, 2004)

Source	Estimated available water per year (GL)	Estimated capital cost ($m)	Estimated annual operating/maintenance cost **($m)**	Estimated cost to the user * ($/kL)
Government of South Australia (2004)	3GL	3.04	1.06	1.39

* inclusive of treatment and distribution costs

Given the problems arising due to the over-exploitation of several aquifers and given that the Adelaide Metropolitan T2 is at significant depth, it is assumed that only 3 GL/year could be extracted from the Adelaide Metropolitan T1 aquifer. Considering that 60 m is the depth to the top of the aquifer, and that the extraction would cause a cone of depression, a minimum depth of the wells of 120 m is assumed.

Well construction costs depend on the depth and diameter of the well and on the nature of the geological strata encountered. Data for well construction (Peter Dillon, CSIRO Land and Water, pers. comm., 8/2/2013) estimated the cost of drilling, PVC casing, cementing at 200 m followed by drilling to 270 m in the Salisbury area at $90,000 per well. Equipping the well with a pump and the fibre glass rising main costs an additional $30,000 per well. Note that this cost can increase in friable aquifers by $10,000-20,000 per well to allow for stainless steel screens. In summary, it will be considered that the total cost for the construction of wells with a yield in the range 1-2 ML/day is about $120,000 per well, excluding bringing power to site and the costs of pipelines to or from the site.

Considering that 4-8 wells that are each able to deliver 1-2 ML/day will be necessary to extract 3 GL/year, the constructions of wells would cost $0.50 to $1.00million. However, this cost could be larger, depending on aquifer properties and yields.

The report *Water Proofing Adelaide* (Government of South Australia, 2004) estimated that $3.04 million (2013 dollars) would be necessary to increase the groundwater extraction by 3 GL/year. It is proposed to assume this value for the capital costs associated with the use of groundwater resources, as it is considered to be inclusive of well construction, treatment and distribution. Note that pump replacement has been estimated considering a yield of 3 GL/year and the formula by McGivney and Kawamura (2008): this results in $0.12m every 20 years.

OPERATIONAL COST AND ENERGY CONSUMPTION

Sustainable Focus and Clark (2008) estimates that an energy consumption of 0.7-1.2 kWh/kL would be necessary to treat the groundwater (reverse osmosis to treat brackish water is considered). The report also considers that this source will have a cost of $0.75-1.0/kL to users (0.84-1.12 $/kL, if inflated to 2013). This figure may be compared with the estimated cost to users reported in Water Proofing Adelaide ($1.10/kL in 2004 dollars, $1.39/kL, inflated to 2013).

The Government of South Australia (2004) reports that the operational and management costs of groundwater are \$0.84m/year to produce 3 GL/year in 2004 dollars. This results in \$0.35/kL in 2013 dollars. This estimate is based on an energy price equal to or lower than \$0.15/kL. Adopting a tariff of \$0.25/kWh would result in a cost equal to \$0.59/kL for the water. Starting from the estimation of the energy required for the treatment by Sustainable Focus and Clark (2008) (0.7-1.2 kWh/kL) and the cost of the chemicals (\$0.16/kL) results in \$0.34-0.46/kL.

Considering that some of the increase in the electricity price is already taken into account by inflating the 2004 values, it is proposed to use an operational and maintenance levelised cost equal to \$0.36/kL. This value is chosen because the Government of South Australia (2004) estimated the same water price to consumers for the supply from the Murray River and from groundwater.

Energy and GHG Emissions

In an analogous way to the previous cases, embodied energy and capital GHGs due to pump replacement will not be considered because of a lack of data. Capital GHG emissions caused by the construction of wells are also difficult to quantify, as the characteristics of each well (diameter, depth) are not known and also because it is not known how many new wells have to be constructed or if the existing ones can provide a large portion of the volume needed. Therefore this source of GHG emissions will also not be included.

Therefore the only source of greenhouse gas emissions will be the energy consumption, which is largely dependent on the groundwater depth. Assuming that the 3 GL/year are extracted from a depth equal to 120 m and a pump efficiency equal to 75%, the energy required for pumping would be 0.44 kWh/kL. The cost of water treatment has to be added to this quantity. As the survey carried out by Hoang et al. (2009) on the operation of desalination plants shows that on average, 0.7-1 kWh/kL are used to desalinate brackish water, a total operational energy equal to 1.14-1.44 kWh/kL would be necessary.

However, as not all of the water has to be pumped from such a depth and part of the water could have an acceptable salinity in relation to drinking standards, it is proposed to assume that 1.2 kWh/kL (the same as Sustainable Focus and Clark) are required to use groundwater sources. In this case, the full cycle emissions are 0.95 kgCO_2-e/kL.

Summary

It is estimated that only an additional 3 GL/year can be provided using groundwater sources. Capital costs amount to \$3.04 million. The operational costs are estimated to be \$0.36/kL (Table 11).

Carbon emissions are estimated to be equal to 0.95 kgCO_2-e/kL (Table 12). Note that emission related to well and pump construction are omitted.

Table 11: Summary of costs and volumes of water that can be supplied using groundwater.

Option	Capacity (GL/year)	Capital cost ($/ML/year)	Operational cost ($/kL)
Groundwater	3	1,014 + $0.12m every 20 years for pump replacement	0.36

Table 12: Summary of energy, GHGs and volumes of water that can be supplied using groundwater.

Option	Capacity (GL/year)	Embodied energy (MWh/ML/year)	Operational energy (MWh/ML)	Capital GHGs (tonnesCO_2-e/ML/year)	Operational GHGs (tonnesCO_2-e/ML)
Groundwater	3	0 (not estimated)	1.2	0	0.95

Stormwater Including Managed Aquifer Recharge

Capital Cost

South Australian Water Corporation (2011) provided the costs of two stormwater reuse schemes: the Barker Inlet Stormwater Reuse Scheme and the Adelaide Airport Stormwater Scheme (Table 13). The first project had a cost of $8.15 million and can harvest and deliver 300 ML of stormwater per year for use by industrial, commercial and irrigation customers in the Regency Park area. The Adelaide Airport Stormwater Scheme can harvest and deliver 270 ML of stormwater per year for irrigation to replace potable water used in and around the airport. The capital cost of the second project is estimated to be $9.8 million (SA Water and Government of South Australia, 2012).

Table 13: Summary of the capital, operational and maintenance costs for stormwater harvesting (non potable use).

Option	Estimated available water per year (GL)	Estimated capital cost ($2011·$10^6$)	Estimated capital cost ($2013·$10^6$)	Capital costs ($2013/ML/year)
South Australian Water Corporation (2011) - Barker Inlet Stormwater Reuse Scheme	0.3	8.15	8.41	28,022
South Australian Water Corporation (2011) - Adelaide Airport Stormwater Scheme	0.27	9.8	9.93	36,790

Philp et al. (2008) reviewed some of the existing stormwater harvesting schemes in Australia (Table 14). Note that the 2013 dollars are converted from the date of the report of Philp et al. (2008).

TABLE 14: COST OF STORMWATER HARVESTING PRACTICES (PHILP ET AL. 2008).

Project	Loc.	Estim. savings (ML/y)	Total capital cost ($2008)	Annual recurrent costs ($2008)	Capital costs ($2013/ML/y)	Recurrent costs ($2013/kL)
SYDNEY SMITH PARK, WESTMEAD	NSW	12	731,827	45,000	68,065	4.19
BEXLEY MUNICIPAL GOLF COURSE, BEXLEY	NSW	66	594,197	18,000	10,048	0.30
BLACK BEACH FORESHORE PARK, KIAMA	NSW	12	174,900	17,000	16,267	1.58
MANLY STORMWATER TREATMENT AND USE	NSW	19	359,780	39,000	21,134	2.29
POWELLS CREEK RESERVE, NORTH STRATHFIELD	NSW	2	379,183	30,000	211,699	16.74
SCOPE CREEK, CRANEBROOK	NSW	6	562,452	44,000	104,623	8.18
SOLANDER PARK, ERSKINEVILLE	NSW	2.7	544,798	46,000	225,199	19.01
TARONGA ZOO, MOSMAN	NSW	36.5	2,200,000	55,000	67,270	1.68
RIVERSIDE PARK, CHIPPING NORTON	NSW	12	68,234	5700	6,346	0.53
HORNSBY SHIRE COUNCIL NURSERY AND PARKS DEPOT	NSW	0.72	329,000	28,000	509,985	43.40
CATANI GARDENS STORMWATER CAPTURE AND USE, FITZROY	VIC	12	527,250	-	49,038	-
SORRENTO STORMWATER USE	VIC	70	$578,000	-	9,216	-
STORMWATER USE FOR THE CHARLTON COMMUNITY	VIC	22	155,000	-	7,863	-
MERNDA VILLAGES ASR	VIC	150	1,105,000	-	8,222	-
ALBERT PARK STORMWATER USE PROJECT	VIC	200	674,000	-	3,761	-
TRINITY GRAMMAR BILLABONG RESTORATION	VIC	30	365,000	-	13,579	-
STAWELL STORMWATER ALTERNATIVE NATURAL SOLUTIONS (SWANS)	VIC	25	540,000	5,000	24,107	0.22
ALTONA GREEN PARK	VIC	4	250,000	-	69,755	-
ALTONA LEISURE CENTRE	VIC	3.5	98,000	-	31,250	-
CITY OF SALISBURY INTEGRATED	SA	7,500	4500000	-	670	-

Project	Loc.	Estim. savings (ML/y)	Total capital cost ($2008)	Annual recurrent costs ($2008)	Capital costs ($2013/ML/y)	Recurrent costs ($2013/kL)
WATER MANAGEMENT PLAN						
MULGA CREEK CATCHMENT WETLAND DEVELOPMENT, BROKEN HILL	NSW	8.2	600,000	-	81,664	-
CITY OVAL DRAINAGE RETENTION SYSTEM BOX HILL PROJECT	VIC	12.5	740,000	-	66,072	-
BEECHWORTH RECREATION RESERVES STRATEGY	VIC	11	721,000	-	73,154	-
WODONGA’S SUSTAINABLE SPORTS GROUND	VIC	90	870,000	-	10,789	-
CRANBOURNE TURF CLUB IRRIGATION	VIC	30	800,000	-	29,762	-
BENDIGO HARNESS RACING TRACK WATER HARVESTING	VIC	15	412,000	-	30,655	-
MAWSON LAKES	SA	1121	10500000	470,000	10,454	0.47
BARRY BROTHERS WATER USE	VIC	12	100,000	-	9,301	-
AVERAGE					**63,209**	**8.22**

Wallbridge & Gilbert (2009) provide more information about the costs associated with stormwater use, although the focus in this case is aquifer storage and recovery (ASR) using stormwater. The report highlights that it would be possible to harvest an extra 42 GL/year of stormwater in addition to the 18 GL/year already harvested in Adelaide. This would require an investment of the order of $600-700 million to upgrade the existing stormwater facilities and to build new ones. The estimated cost does not include operational or maintenance costs and does not include costs associated with land acquisition, establishment or maintenance of the stormwater drainage system and distribution to users. Only the larger schemes are taken into account in the report (larger than 250 ML/year), but there could be cost-effective opportunities for smaller schemes, too. The report takes into account the fact that the stormwater has to be treated so as to reach an adequate quality to be suitable for aquifer recharge. It is also important to note that, depending on the end use of the harvested water, post treatment may be required. Three types of treatment have been considered in Wallbridge & Gilbert (2009): wetlands, bioretention and mechanical treatment. This last type of treatment has only been considered in locations where there are space limitations. Table 15 reports the costs separated by location.

Table 15: Summary of the capital costs of stormwater harvesting for catchments in the Adelaide region (Wallbridge and Gilbert, 2009).

CATCHMENT	Potential annual yield (GL/year)	Capital cost (2009 $m)	Capital cost (2013 $m)	Capital Cost * (2013 $/ML/year)
Gawler River	6.02	66.5	72.9	15,143
Smiths Creek	3.49	39.5	43.3	15,515
Adams Creek	3.53	14.5	15. 9	5,631
Greater Edinburgh Parks	1.99	31	34.0	21,354
Little Para River	2.24	25	27.4	15,299
Dry Creek	8.23	44	48.3	7,329
Barker Inlet	4.08	49	53.7	16,463
Magazine Creek	1.79	33	36.2	25,272
Port Road	1.52	12.5	13.7	11,273
Grange area	1.25	16.5	18.1	18,095
Torrens River	6.69	75.5	82.8	15,470
Mile End Drain	0.85	7.5	8.2	12,095
Brownhill/ Keswick	4.23	36	39.5	11,667
Sturt River	6.19	84	92.1	18,602
Field River	2.61	30.5	33.4	16,019
Christie Creek	1.32	16.5	18.1	17,135
Onkaparinga River	2.04	26	28.5	17,471
Pedler Creek	1.24	10.5	11.5	11,608
Willunga	0.48	5	5.5	14,279
Total	**59.79**	**623**	**683.2**	**14,284**

* based on recovery = 80% of injection

It should be noted that the potential annual yield values shown in Table 15 are based on the potential harvest (and injection in the groundwater). The actual amount of water withdrawn could be less or slightly larger than this quantity. To improve the state of the groundwater, many regulators have proposed a recovery efficiency (the volume of water that can extracted related to the volume of water injected) equal to 0.9 (Ward and Dillon, 2011). However, Ward and Dillon also specify that the recovery efficiency in South Australia has been limited to 0.8 to avoid possible salinity increases above acceptable limits.

The report from Dillon et al. (2009) contains a cost breakdown for twelve ASR projects (nine of them are located in South Australia and the remaining three in Victoria) with yields in the range 75 ML/year and 2000 ML/year (corresponding to 0.2 to 5.5. ML/day). This is reported in Table 16. As reported, the capital costs of stormwater ASR projects ranged from $4,100 to $10,000 per ML/yr ($4,496 – $10,967 if inflated to 2013). These values are consistent with the costs reported in the Wallbridge & Gilbert report (2009) for the capital costs of constructing ASR facilities in the Adelaide region (4th column of Table 15).

TABLE 16: COST BREAKDOWN OF ASR PROJECTS (DILLON ET AL. 2009).

Project component	Component cost as % of total cost
Investigation	11
Capital costs of water harvesting	25
Capital costs of water treatment, ASR, distribution	39
Total capital costs	64
Operation, maintenance and management	26
Total	100

The cost of stormwater harvesting can be compared with the costs estimated in the Goyder Institute's Managed Aquifer Recharge and Stormwater Use Options (MARSUO) project (Dandy et al. 2013). The MARSUO project provides some detailed information about the stormwater harvesting cost related to a specific catchment in the Adelaide region, the Parafield Stormwater Harvesting Scheme. The catchment has an area of about 1,590 ha and is currently used to recover and store stormwater. Therefore it has already some of the facilities necessary for these operations, such as wells, pumps, treatment storages and monitoring systems. The whole project covers 11.2 ha (City of Salisbury, 2003) and the total capital cost of the project amounted to $13 million (Matthew Coldwell, Salisbury Water, pers. comm., March 9, 2012). Of this, $6m was for the harvesting facilities including basins, wetland and ASR and $7m was for the associated distribution system. The estimated cost of the harvesting facilities without ASR is $4m. As the estimated average annual yield of this scheme with ASR is 1.1 GL/year, this results in a capital investment equal to $6,818/ML/year for the harvesting facilities (if the 80% aquifer efficiency recovery is taken into account). This value is at the low end of the range of capital costs/ML/year given in Table 18.

Treatment and Distribution Costs

As the costs for the construction of the harvesting facility, wells and wetland are estimated in Table 15, it is necessary to estimate the costs associated with the construction of the additional facilities required for treating and distributing the water. Considering the costs and the yields estimated for the Parafield scheme in the MARSUO project, it is proposed to adopt the costs reported in Table 17 to account for the capital costs for the pipe system, treatment, storage and additional pumping facilities required for treatment and distribution.

For the third pipe residential systems, these costs are based on an assumed cost of $1800 per house for Greenfield sites and $4000 per house for brownfield sites (B.Naumann, City of Salisbury, pers. comm., November 30, 2012). It is assumed that the average household use of harvested stormwater for a third pipe network for options 5-8 is 100 kL/year.

TABLE 17: CAPITAL COSTS ($/ML/YEAR) FOR TREATMENT AND DISTRIBUTION IN ADDITION TO THE CONSTRUCTION OF HARVESTING FACILITIES, WELLS AND WETLAND.

Option	Description	Yield (ML/year)	Capital Cost ($m)	Capital costs ($/ML/year)
Irrigation of open spaces	1. Harvesting and wetland	370	7.00	18,919
	2. Harvesting and wetland + ASR	880	7.00	7,955
	3. Harvesting and wetland + ASR + disinfection	880	7.20	8,182
	4. Harvesting and wetland + ASR + blending with treated wastewater + disinfection*	*2100*	13.92	6,629
Non potable house use	5. Harvesting and wetland + disinfection	*370*	*15.57(Greenfield)* *23.71(Brownfield)*	*42,081 (Greenfield)* *64,081 (Brownfield)*
	6. Harvesting and wetland + ASR + disinfection	*880*	*24.57 (Greenfield)* *43.93 (Brownfield)*	*27,920 (Greenfield)* *49,920 (Brownfield)*
	7. Harvesting and wetland + blending with treated wastewater + disinfection*	*1000*	*30.61 (Greenfield)* *52.61 (Brownfield)*	*30,610 (Greenfield)* *52,610 (Brownfield)*
	8. Harvesting and wetland + ASR + blending with treated wastewater + disinfection*	*2100*	*51.46 (Greenfield)* *97.35 (Brownfield)*	*24,505 (Greenfield)* *46,357 (Brownfield)*
Potable use	9. Harvesting and wetland + ASR + disinfection + direct injection	*880*	*8.02*	*9,114*
	10. Harvesting and wetland + transfer to Little Para Reservoir**	*1034*	*4.83*	*4,671*
	11. Harvesting and wetland + ASR + transfer to Little Para Reservoir**	*827*	*4.62*	*5,586*
	12. Harvesting and wetland + ASR + disinfection + transfer to Little Para Reservoir**	*827*	*5.25*	*6,348*

* not including the capital cost of the DAFF treatment plant
** not including the capital costs of the existing treatment facility at Little Para Reservoir

From Table 17 it can be seen that the options that do not involve aquifer storage and recovery (ASR) (options 1, 5, 7) have a lower yield, because of the absence of a large storage facility. Note that the yields of options 4, 7 and 8 include blending with recycled wastewater. The large capital costs associated with options 5-8 are due to the cost of building a third pipe network. Option 9 involves the costs associated with the harvesting of stormwater, the treatment to potable standards and direct injection to the water mains. Alternatively, harvested stormwater could be pumped to the Little Para Reservoir (about 11 km away): in Options 10, 11, 12, with treatment to potable standards being provided by the existing Little Para treatment plant.

OPERATIONAL AND MAINTENANCE COST

Operational and maintenance costs for a managed aquifer recharge (MAR) project are estimated from the analysis of the MARSUO project. In particular, costs for electricity, chemicals, monitoring and maintenance have been accounted for. It has to be noted that monitoring costs depend on the water use: from $0.12/kL for irrigation to $0.43/kL for injection of potable water into the mains. A summary of the operational and maintenance costs is given in Table 18.

For ASR options, the operational costs are influenced by the depth and thickness of the aquifer as well as its hydraulic properties and the depth to the potentiometric surface of the aquifer. As these properties vary over the Adelaide Metropolitan area, the values for the injection and extraction pump heads used in the MARSUO project have been assumed as indicative values, i.e. the pumping head for injection is assumed equal to 30 m, while the pumping head for extraction is assumed equal to 60 m.

TABLE 18: OPERATIONAL AND MAINTENANCE COSTS ($/KL) FOR THE VARIOUS OPTIONS OF STORMWATER MANAGEMENT IN THE MARSUO PROJECT, DISTRIBUTION INCLUDED.

Option	Description	Average Annual Yield (ML/year)	Operational and Maintenance costs ($/kL)
Open space irrigation	1. Harvesting and wetland treatment	370	0.45
	2. Harvesting and wetland + ASR	880	0.42
	3. Harvesting and wetland + ASR + disinfection	880	0.43
	4. Harvesting and wetland + ASR + blending with treated wastewater + disinfection	*2100*	0.63
Non potable house use	5. Harvesting and wetland + disinfection	*370*	0.88
	6. Harvesting and wetland + ASR + disinfection	*880*	0.69
	7. Harvesting and wetland + blending with treated wastewater + disinfection	*1000*	0.81
	8. Harvesting and wetland + ASR + blending with treated wastewater + disinfection	*2100*	0.70
Potable use	9. Harvesting and wetland + ASR + disinfection + direct injection	*880*	1.26
	10. Harvesting and wetland + transfer to Little Para Reservoir	*1034*	0.79
	11. Harvesting and wetland + ASR + transfer to Little Para Reservoir	*827*	0.94
	12. Harvesting and wetland + ASR + disinfection + transfer to Little Para Reservoir	*827*	1.16

Further information on the operational and maintenance costs of MAR projects have been found in Chalmers and Grey (2004). Although the data are related to Western Australia, they seem to be in line with the costs reported above. The operating and maintenance unit water costs from the Forrestdale MAR system (400 lots), where water is used for garden watering on residential properties, amounted to $5200/year for energy cost for bores and transfer pumping, $50,000/year for operations and maintenance and $27,500/year (50%) for administration costs. The total operational and maintenance costs are $82,800/year or $0.67/kL ($104,935/year and $0.85/kL, respectively, if inflated to 2013).

Another example is the study for the MAR scheme to inject and recover 2.3 GL/year (6.3 ML/day) of stormwater from the Leederville Aquifer for the Wungong Urban Water Project at Brookdale. The total unit costs are estimated to be in the range $0.94-1.41/kL (excluding distribution – but capital, operating and maintenance costs are included). If inflated to 2013 values, these costs are in the range $1.19-1.79/kL. The capital costs were estimated to be $1-1.4 million with operating costs between $0.36-0.60 million per year ($1.27-1.77 million and $0.46-0.76 million in 2013 dollars, respectively). This results in O&M costs equal to 0.33 $/kL: this value is similar to the value given in Table 18 for option 2 (open space irrigation with aquifer recharge, $0.42/kL) if the increases in electricity price are considered.

EMBODIED ENERGY AND CAPITAL GHG EMISSIONS

Embodied energy and capital emissions are associated with the well and wetland construction. Considering the number of ASR wells required, a well diameter equal to 0.2 m, using a PVC-U 200/I2S1 for casing (embodied energy equal to 836.6 MJ/m from Ambrose et al. (2002)) and a well depth equal to 150 m, it is possible to estimate the capital GHGs related to well construction (

Table 19). Given the wetland volume, estimated using a 2 m depth, it is also possible to estimate the GHG emissions caused by its excavation. Other assumptions are related to the soil density (1.25 tonnes/m^3), the energy requirements for the excavation (0.1 MJ/kg from Alcorn and Wood (1998) for sand) and the emissions from the fuel used for the excavation (diesel: 69.2 $kgCO_2$-e/GJ for heavy trucks from Department of Climate Change and Energy Efficiency, 2012a,b).

The average values of total embodied energy and greenhouse gas emissions for all projects in

Table 19 are 5.131 MWh/ML/year and 1.502 tonnes CO_2-e/ML/year (respectively). These values have been computed considering a diesel emission factor (0.25 kgCO_2-e/kWh) for the wetland construction and well excavation and the full cycle emission of electricity (0.79 kgCO_2-e/kWh) for the well pipe construction.

Table 19: Estimate of capital GHG emissions for some of the stormwater schemes analysed by Wallbridge and Gilbert (2009) for the Adelaide region.

Scheme	Recovered Yield* (GL/year)	Excavation energy (MWh)	Well construction energy (MWh)	Total embodied energy (MWh)	Total capital GHGs (tCO_2-e)
Gawler River	4.82	26,701	2,346	29,048	8442
Smiths Creek	2.79	11,458	1,011	12,469	3626
Adams Creek	2.82	19,601	1,299	20,900	5874
Greater Edinburgh Parks	1.59	12,500	722	13,222	3665
Little Para River	1.79	11,806	722	12,527	3492
Dry Creek	6.59	30,253	2,274	32,528	9272
Barker Inlet	3.27	15,625	1,660	17,285	5159
Magazine Creek	1.43	9,375	650	10,025	2831
Port Road	1.22	6,875	397	7,272	2016
Grange area	1.00	590	397	987	450
Torrens River	5.35	6,875	3,610	10,485	4467
Mile End Drain	0.68	868	361	1,229	492
Brownhill & Keswick	3.39	11,816	1,480	13,269	4073
Sturt River	4.95	16,347	2,888	19,235	6275
Field River	2.09	24,583	180	24,764	6262
Christie Creek	1.05	6,319	0	6,319	1574
Onkaparinga River	1.63	11,458	0	11,458	2855
Pedler Creek	0.99	4,340	180	4,521	1219
Willunga	0.38	1,736	1,083	2,819	1259
TOTAL	**48.8**	**229,128**	**21,260**	**250,389**	**73,300**
AVERAGE**	**-**	**4.695**	**0.436**	**5.131**	**1.502**

*considering 80% aquifer efficiency recovery
** (MWh/ML/year tonnesCO_2-e/ML/year)

The embodied energy and the capital greenhouse gas emissions related to the distribution of the recovered stormwater are based on the results of the MARSUO project (Dandy et al. 2013). In particular, the embodied energy for the construction of the distribution pipeline in Parafield (2,783 MWh, options 1-8), the embodied energy of the pipelines to transport water to Greenfield where it will be mixed with recycled stormwater (4,151 Mwh, Options 4, 7,8) and the embodied energy of tanks (83 MWh, options 1-3,9-12; 419 MWh, options 4, 6, 8; 336 MWh, options 5, 7) have been estimated and included in Table 22.

Third Pipe Network

Some of the options considered (Options 5, 6, 7 and 8) require a third pipe to deliver non-potable water to users. As the energy and greenhouse gas emissions associated with the third pipe system are not considered in the estimation of the embodied energy and capital GHG emissions evaluated above, they will be estimated in this section.

Estimating the embodied energy and GHG emissions that arise from the construction of the pipe system to deliver non-potable water requires an estimate of the distance of the houses from the source, of the flow provided and of the pipe material. However, as an accurate estimate is not possible without a detailed design, the greenhouse gas emissions associated with the pipe construction will be estimated based on SA Water's technical guidelines on pipes for mains (SA Water, 2011). Considering a pipe maximum velocity equal to 2 m/s and a peaking factor equal to 2, diameters in the range 200-500 mm would be needed in most cases (to be able to provide 1-6 GL/year). However, the pipe sizes reduce with distance from the source: for this reason, an average pipe diameter equal to 150 mm will be assumed. Note that the third pipe does not have to provide water for fire fighting and does not have to be a looped network. Using the data reported by Ambrose et al. (2002), PE100 180/12.5 (internal diameter equal to 151.8 mm) has an embodied energy equal to 536.2 MJ/m.

The house sizes and their positioning also play a role in defining the cost of the third pipe. An average lot size equal to 400 m^2 will be assumed (allowing for 27 x 15 m blocks), leading to an average length of pipe of 15 m per household.

Using these inputs, and an average consumption of 100 kL/year/household, the embodied energy of constructing a third pipe system for internal and external use would be 22.342 MWh/ML/year and its greenhouse gas emissions would be 17.650 tonnesCO_2-e/ML per year. Note that these estimates are based on a PE100 180/12.5, a consumption equal to 100 kL/year/household and 1.1 GL/year ASR scheme: different material or a different average pipe size due to a larger yield would result in different embodied energy and greenhouse gas emissions. GHGs generated by maintenance have not been considered and GHGs caused by the excavation for the 3rd pipe have been neglected.

Options 9 – 12 require a pipe to reach the injection point in the water distribution system (Option 9) or to reach the Little Para Reservoir (Options 10-12). In the first case, the embodied energy is equal to 301MWh (assuming a PVC-U 250 of length 1 km). For the other options the embodied energy is 4041 MWh (PVC-U 300 with length equal to 11 km).

Operational Energy and GHG Emissions

Dillon et al (2009) estimated the energy consumption from the operation of aquifer stormwater recharge to be 0.1 kWh//kL, corresponding to 0.079 kgCO_2-e/kL. The report does not analyse the capital GHG emissions, but it suggests that they should be much smaller than the capital GHG emissions of a desalination plant.

Leslie (2007) estimated the greenhouse gas emissions of the aquifer storage and recovery (ASR) scheme at the University of New South Wales to be 0.45 tonnes CO_2-e/ML: Of this, 0.40 tonnesCO_2-e/ML is due to power consumption while 0.05 tonnesCO_2-e is associated with the use of the materials. It has to be noted that this stormwater does not require treatment and pumping into the aquifer.

Operational energy and GHGs used in this study are based on the estimate of the energy and emissions provided by the MARSUO project (Dandy et al. 2013): Table 20 gives the operational energy and GHGs emissions of new and existing facilities. The embodied energy and capital GHGs of the new pipe infrastructure for option 9 are 0.34 MWh/ML/year and

0.27 tonnesCO_2-e/ML/year, respectively, while, for options 10, 11 and 12 embodied energy and capital GHGs are 4.91 MWh/ML/year and 3.88 kg CO_2-e/kL/year. Note that the operational GHGs estimated for the irrigation of open spaces (0.50 tonnes CO_2-e/ML) agrees reasonably well with the value estimated by Leslie (2007) (0.40 tonnes CO_2-e/ML for energy consumption) if it is considered that Leslie did not accounted for the energy required for injection.

TABLE 20: OPERATIONAL ENERGY AND GHGS FOR THE VARIOUS OPTIONS OF STORMWATER HARVESTING AND MANAGEMENT

Option	Description	O&M Energy (MWh/ML)	O&M GHGs (tonnesCO_2-e/ML)
Open space irrigation	1. Harvesting and wetland treatment	0.27	0.22
	2. Harvesting and wetland + ASR	0.63	0.50
	3. Harvesting and wetland + ASR + disinfection	0.63	0.50
	4. Harvesting and wetland + ASR + blending with treated wastewater + disinfection	0.89	0.70
Non potable house use	5. Harvesting and wetland + disinfection	1.51	1.19
	6. Harvesting and wetland + ASR + disinfection	1.86	1.47
	7. Harvesting and wetland + blending with treated wastewater + disinfection	1.65	1.30
	8. Harvesting and wetland + ASR + blending with treated wastewater + disinfection	1.78	1.41
Potable use	9. Harvesting and wetland + ASR + disinfection	1.39	1.08
	10. Harvesting and wetland + Little Para Reservoir	1.05	0.83
	11. Harvesting and wetland + ASR + Little Para Reservoir	1.35	1.06
	12. Harvesting and wetland + ASR + treatment + Little Para Reservoir	1.80	1.41

SUMMARY

To evaluate the capital cost of building wetland and stormwater harvesting schemes, it is proposed to use the costs evaluated by Wallbridge and Gilbert (2009) and reported in Table 15 to consider the costs of wells and wetland/biofiltration construction. Costs for pumping stations, treatment plants and distribution system are based on the Parafield stormwater harvesting scheme and have to be added to the cost of the wetland and stormwater harvesting scheme. (These costs have been estimated as a capital cost in $/ML/year in Table 17 and are summarised in Table 21). Note that options 1, 5, 7 and 10 do not involve aquifer storage and recovery (ASR), while options 4, 7, 8 involve blending with recycled wastewater and therefore their cost effectiveness depends on the distance of the recycling facility. Note that costs of options 10, 11 and 12 is based on a distance of about 11 km to the nearest reservoir (for option 9, it is assumed that 1 km of pipe is sufficient to reach a suitable injection point in the potable water mains). The capital costs for providing stormwater for potable uses are in general less lower than for the other options, as they can use the existing distribution system. The option without ASR for potable use has also a larger yield than the other options without

ASR, because the volume of water that exceeds the demand can be stored in the reservoir: this further reduces the capital cost per ML/year.

A summary of the energy and greenhouse gas emissions is given in Table 22.

TABLE 21: SUMMARY OF COSTS AND VOLUMES OF WATER THAT CAN BE SUPPLIED USING STORMWATER.

Option	Capacity (GL/year)	Capital cost ($/ML/year)	Operational cost ($/kL)
Wetland without ASR	48.8 Harvesting	Values given in Table 15	
	48.8 Distribution		
	Irrigation of public open space	18,919	0.45
	Greenfield third pipe system for non-potable use	42,081	0.88
	Brownfield third pipe system for non-potable use	64,081	0.88
Wetland without ASR (cont.)	Blending with treated wastewater then greenfield third pipe system for non-potable use	24,505	0.81
	Blending with treated wastewater then brownfield third pipe system for non-potable use	46,357	0.81
	Transfer to reservoir for potable use**	4,671	0.79
Wetland with ASR	48.8 Harvesting	Values given in Table 15	
	48.8 Distribution		
	Irrigation of public open space	7,955	0.42
	Disinfection and irrigation of public open space	8,182	0.43
	Blending with treated wastewater and irrigation	6,629	0.63
	Greenfield third pipe system for non-potable use	27,920	0.69
	Brownfield third pipe system for non-potable use	49,920	0.69
	Blending with treated wastewater then greenfield third pipe system for non-potable use	24,505	0.70
	Blending with treated wastewater then brownfield third pipe system for non-potable use	46,357	0.70
	Direct injection for potable use*	9,114	1.26
	Transfer to reservoir for potable use**	5,586	0.94
	Treatment and transfer to reservoir for potable use**	6,348	1.16

* based on pipe length of 1 km
** based on pipe length of about 11 km

TABLE 22: SUMMARY OF ENERGY, GHGS AND VOLUMES OF WATER THAT CAN BE SUPPLIED USING STORMWATER.

Option	Capacity (GL/year)	Embodied energy (MWh/ML/year) [Capital GHGs (tonnesCO_2-e /ML/year)]	Operational energy (MWh/ML) [Operational GHGs (tonnesCO_2-e/ML)]
Wetland without ASR	48.8 Harvesting	5.131 [1.502]	
	48.8 Distribution		
	Irrigation of public open space	7.746 [5.958]	0.27 [0.22]
	Greenfield third pipe system for non-potable use	30.772 [23.655]	0.61 [0.49]
	Brownfield third pipe system for non-potable use	30.772 [23.655]	0.61 [0.49]
	Blending with treated wastewater then greenfield third pipe system for non-potable use	29.612 [23.151]	0.76 [0.60]
	Blending with treated wastewater then brownfield third pipe system for non-potable use	29.612 [23.151]	0.76 [0.60]
	Transfer to reservoir for potable use**	4.006 ** [4.070]**	1.04 [0.83]
Wetland with ASR	48.8 Harvesting	5.131 [1.502]	
	48.8 Distribution		
	Irrigation of public open space	3.257 [3.702]	0.63 [0.50]
	Disinfection and irrigation of public open space	3.257 [3.702]	0.63 [0.50]
	Blending with treated wastewater and irrigation	3.501 [3.124]	0.89 [0.70]
	Greenfield third pipe system for non-potable use	25.981 [21.379]	0.97 [0.77]

Option	Capacity (GL/year)	Embodied energy (MWh/ML/year) [Capital GHGs (tonnesCO_2-e /ML/year)]	Operational energy (MWh/ML) [Operational GHGs (tonnesCO_2-e/ML)]
Wetland with ASR (cont.)	Brownfield third pipe system for non-potable use	25.981 [21.379]	0.97 [0.77]
	Blending with treated wastewater then greenfield third pipe system for non-potable use	25.843 [20.774]	0.89 [0.70]
	Blending with treated wastewater then brownfield third pipe system for non-potable use	25.843 [20.774]	0.89 [0.70]
	Direct injection for potable use*	0.437 [1.475]*	1.39 [1.08]
	Transfer to reservoir for potable use**	5.008 [5.158]**	1.35 [1.06]
	Treatment and transfer to reservoir for potable use**	5.008 [5.158]**	1.80 [1.41]

* based on pipe length of 1 km
** based on pipe length of about 11 km

WASTEWATER REUSE

CAPITAL COST

In the *Waterproofing Adelaide* report (Government of South Australia, 2004), it is estimated that 10 GL/year, in addition to the 20 GL/year already used, could be provided from the reuse of wastewater. Although the cost is highly variable, depending on the site, *Waterproofing Adelaide* reports an estimated cost to consumers in the range of $1-2/kL ($1.27-2.53/kL if adjusted to 2013).

According to the South Australian Water Corporation (2011), the Southern Urban Reuse Project (now constructed) was expected to cost $62.6 million ($64.6m in 2013 dollars) and had the objective of providing recycled water to residential areas to the South of Adelaide. These capital costs were inclusive of an 800 ML earthen storage, ultra filtration building, including mechanical and electrical works, ETSA power supply, telecommunication upgrade, site civil works, reclaimed water pump station, feed water storage lagoon, filtered water storage lagoons and recycled water pump station. The project was designed to supply 1.6 GL/year of treated wastewater for non-potable use in new housing developments in Adelaide's southern suburbs (Farrell and Caica, 2011). The Christies Beach Wastewater Treatment Plant currently provides about 11 GL/year of treated wastewater for horticultural purposes. The upgrade of the plant will cost $272 million and will be able to produce about 16 GL/year of treated water (South Australian Water Corporation, 2011).

Other significative projects have been developed including the Glenelg to Adelaide Parklands Recycled Water Project. This project cost $76.248 million (Australian Government, 2012) ($77.29m in 2013 dollars) and included additional treatment facilities and pipelines. The project is designed to provide 3.8 GL/year of recycled wastewater for reuse. The 32 km pipeline from Glenelg to Adelaide Parklands and around the parklands ranges in diameter from 250–750 mm, and provides recycled wastewater from the Glenelg Wastewater Treatment Plant to the Adelaide Parklands and city gardens (Lyndsie Mewett 2010).

Table 23 gives the capital costs of recycling wastewater estimated using these data. Note that none of these schemes produces water for potable purposes. It is expected that additional treatment and associated capital costs would be needed if potable use is considered.

TABLE 23: ESTIMATION OF CAPITAL COSTS FOR RECYCLED WASTEWATER.

Intervention	Cost (2013 $m)	Yield (GL/year)	Capital cost ($m/ML/year)
Southern Urban Reuse Project	64.6	1.6	40,375
Glenelg to Adelaide Parklands Recycled Water Project	77.3	3.8	20,342
Christies Beach Project	280.6	5.48*	51,204

*in addition to the current 30 ML/day

Table 24 gives the current capacities of the wastewater treatment plants in Adelaide. It is assumed that up to 58.55 GL per year of recycled wastewater can be supplied with the current recycling capacities, but this could be increased to 98.55 GL/year if the Bolivar and Glenelg WWTPs were to be upgraded to produce water of suitable quality for reuse.

TABLE 24: CAPACITIES OF THE MAJOR WASTEWATER TREATMENT PLANTS.

WWTP	Current plant capacity (ML/year)	Current recycling capacity (ML/year)
Bolivar	60,225	38,325
Glenelg	21,900	3,800
Christies Beach	16,425	16,425
TOTAL	98,550	58,550

OPERATIONAL AND MANAGEMENT COST

Currently, SA Water collects and treats about 95 GL of wastewater in Adelaide and about 100 GL statewide every year (Water for Good, 2012). Unfortunately the costs of recycling are not reported by the National Water Commission (2013) and only the sewage treatment operating costs are reported. The operational cost of treating the sewage is 1.13 $/kL on average (Table 25).

TABLE 25: ESTIMATION OF OPERATIONAL COSTS FOR TREATING SEWAGE (DATA FROM THE NATIONAL WATER COMMISSION, 2013).

Indicator	2006–07	2007–08	2008–09	2009–10	2010-11	2011-12
Total volume of sewage collected (ML)	88,961	83,502	83,379	85,106	89,696	88,573
Connected properties (000s)	475	480	487	494	500	507
Operating costs ($/property)	172	174	211	195	184	171
Total operating cost ($m)	81.4	83.3	102.6	96.4	92.0	86.8
$/kL	0.92	1.00	1.23	1.13	1.03	0.98
$/kL (2013$)	1.07	1.11	1.35	1.21	1.06	0.99

Marsden Jacob Associates (2006b) reports some of the estimated levelised costs for wastewater reuse schemes (see Appendix A for the explanation of the levelised costs). These costs includes the capital costs and assumptions about the design life of the facility and the discount rate. Table 26 shows these costs in 2013 dollars. It should be noted that residential use has a levelised cost that is larger than the other uses ($3.45/kL on average for residential use; $1.13/kL for irrigation, industrial, municipal use).

Given the difficulty in calculating the total unit costs of recycled water, PMSEIC (2003) adopted the rule of thumb that the total cost would be more than double the operating costs. However, these costs are difficult to estimate, as there is a discrepancy from what the users pay and the real cost of producing and delivering recycled water. For example, the operating costs for the Rouse Hill scheme in Sydney were anticipated to be in the order of $4/kL ($5.19/kL in 2013 dollar) , however, as an incentive, it was due to be sold at $0.27 per kL. The PMSEIC reported the operating costs for the Sydney Olympic Park to be $1.60/kL (2003 data). If inflated to 2013, this cost amounts to $2.08/kL.

It is proposed that a cost of $2.00/kL be used to account for the operational costs of wastewater reuse projects.

TABLE 26: LEVELISED COST OF RECYCLED WATER (MARSDEN JACOB ASSOCIATES, 2006B).

Location	Use of recycled water	Levelised cost estimate ($/kL)	Levelised cost estimate (2013$/kL)
Western Sydney Recycled Water Initiative	Environmental flow replacement, residential and agriculture	5.80	6.91
Rouse Hill, NSW (existing)	Residential	3.00-4.00	3.58-4.77
Melbourne Eastern STP		>3.00	>3.58
Sydney Water Indirect Potable Reuse	Indirect Potable	2.23-2.61	2.66-3.11
Olympic Park, NSW (existing)	Residential	1.60+	1.91+ (operating costs only)
Redcliffe City opportunities, QLD	Irrigation and Residential	2.50	2.97
Springfield, QLD (existing)	Residential	1.45	1.72
SA opportunities	Industrial and municipal	1.40	1.69
High quality industrial water	Industrial	0.85 - 1.40	1.01-1.69
Redcliffe City opportunities, QLD	Irrigation	0.80	0.95
Logan City opportunities, QLD	Parks and gardens	0.80	0.95
Toowoomba opportunities, QLD	Agriculture	0.45	0.54

ENERGY AND GHG EMISSIONS

Embodied energy and capital GHG emissions due to the construction of civil works will not be estimated because of the absence of data. However, it is believed that they do not have a large influence on the total energy and emissions.

Energy consumption and associated GHG emissions were estimated by Mrayed and Leslie (2009): they estimated that 1.2tonnesCO_2-e/ML are caused by power consumption, membranes and chemicals. This value is valid for a plant with a capacity equal to 100 ML/day and a feed pressure for the reverse osmosis equal to 140 m. Note that this pressure is much lower than the one required by the desalination plant and note also that there is no energy recovery for the wastewater recycling plant. The power consumption is 0.595 MWh/ML and results in emissions of 0.47 tonnesCO_2-e/ML if the full cycle emission factor for electricity is considered. The GHG emissions caused by the use of chemicals is similar to that of the desalination option, although the wastewater treatment produces slightly larger emissions (0.246 tonnesCO_2-e/ML instead of 0.22 tonnesCO_2-e/ML) to account for the need for hydrogen peroxide (not needed in the desalination process). Note that this wastewater treatment is based on a reverse osmosis process, as is the case for the desalination plant, however, a lower feed pressure is required. The GHG emissions caused by the use of membranes are 0.054 tonnesCO_2-e/ML. Taking into account this information the GHG emissions associated with the wastewater reuse result in a total of 0.77 tonnesCO_2-e/ML.

Sustainable Focus and Clark (2009) report an energy consumption for the wastewater reclamation option in the range 0.8-1.0 MWh/ML: this results in 0.63- 0.79 tonnesCO_2-e/ML.

The presentation by Leslie (2007) shows that recycling in Malabar (Sydney) uses 1.2 MWh/ML for treating the water (3.8 and 1.8 MWh/ML are then necessary to provide water to Warragamba and Prospect, respectively). If 0.79 tonnesCO_2-e/MWh is used to convert the energy to greenhouse gas emissions, the carbon footprint of water reuse is 0.95 tonnesCO_2-e/ML.

Kenway et al. (2008) report that the average intensity for primary wastewater treatment is 0.36-1.34 GJ/ML (average 0.8 GJ/ML), 0.93-2.96 GJ/ML if secondary treatment is added (1.65 GJ/ML on average) and 1.41-39.6 GJ/ML for tertiary treatment (3.25 GJ/ML on average). Data are based on Sydney Water and Brisbane Water input. Considering the scope 2 plus 3 emission factor for electricity results in an average of 0.18, 0.36 and 0.71 tonnes CO_2-e/ML, respectively. These values are summarised in Table 27.

The greenhouse gas emission provided in the SA Water annual report (South Australian Water Corporation, 2012) can be used to estimate the emissions from a wastewater treatment plant. Note that it has been assumed that only 56% of the total water delivered (159 GL/year) will go in the wastewater system (data from Kenway et al. (2009) for the period 2006-07). Note also that 26.4% of the wastewater treated is recycled: this could require additional energy/chemicals, but it cannot be exactly estimated because of a lack of data. With these assumptions, 1.10 tonnesCO_2-e/ML is used to treat the wastewater (Table 28). This figure is not too far from the one presented by the other authors if the uncertainty regarding the volume of wastewater treated is taken into account. It is expected that this value is an overestimate caused by the small volume involved. Data from Kenway et al. (2009) report an energy intensity for the wastewater system in Adelaide equal to 2469 GJ/GL (0.69 MWh/ML): this results in 0.45 tonnesCO_2-e/ML if the scope 2 emission factor (0.65

tonnesCO_2-e/MWh) is considered and in 0.54 tonnesCO_2-e/ML if the full cycle emission factor is considered. Considering that emissions for chemicals and membranes need to be added, it is proposed to use 0.84 tonnesCO_2-e/ML.

TABLE 27: ESTIMATED ENERGY CONSUMPTION AND GREENHOUSE GAS EMISSIONS FOR WATER RECYCLING.

Author	Energy (MWh/ML)	GHG (tonnesCO_2-e/ML)
Mrayed and Leslie (2009)	0.60	0.77 (including chemicals and membranes)
Sustainable Focus and Clark (2009)	0.8-1.0	0.63- 0.79
Leslie (2007)	1.2*	0.95*
Wilkinson (2007)	0.17-0.81*	0.11-0.53*
Kenway et al. (2008) (average value in brackets)	0.1-0.4 (0.22) primary 0.26-0.82 (0.46) prim+sec. 0.39-11.00 (0.90) sec+tert	0.08-0.29 (0.18) primary 0.20-0.65 (0.36) prim+sec. 0.31-8.69 (0.71) sec+tert

*distribution excluded

TABLE 28: GREENHOUSE GAS EMISSIONS (T CO2-E) IN 2011-2012 FOR SA WATER (SOUTH AUSTRALIAN WATER CORPORATION, 2012)

Facility emission	Scope 1	Scope 2	Scope 3	Total emissions 2011-12
Bolivar WWTP (t CO_2-e)	2,9912	24,191	4,661	58,765
Glenelg WWTP (t CO_2-e)	3,940	2,525	486	6,953
Christies Beach WWTP (t CO_2-e)	3,377	5,600	6,102	15,080
Aldinga WWTP (t CO_2-e)	585	1,443	328	2,357
Total (t CO_2-e)	**37,814**	**33,759**	**11,577**	**83,155**
Average kgCO2-e/kL	**0.50**	**0.45**	**0.15**	**1.10**

SUMMARY

The current capacities of the wastewater treatment plants are given in Table 24. This indicates that the current plant capacity is 58.55 GL /year and this could be increased to 98.55 GL/year if the Bolivar and Glenelg plants are upgraded and sufficient demand exists for treated wastewater.

It is proposed to use a capital cost equal to $20,342/ML/year for the upgrade of plant capacity above the current recycling capacities (based on the Glenelg scheme in Table 23) and an operational cost equal to $2.00/kL (Table 29). The cost of the Glenelg scheme is used as it is thought to be more representative of future wastewater reuse schemes. It includes the cost of a distribution scheme for non-residential use.

Embodied energy and capital emissions are not estimated because of the absence of data; operational energy and emissions are estimated to be equal to 0.69 MWh/ML and 0.84tonnesCO_2-e/ML (Table 30), respectively. Note that the GHG estimate includes energy, chemicals and membranes.

TABLE 29: SUMMARY OF COSTS AND VOLUMES OF WATER THAT CAN BE SUPPLIED BY WASTEWATER REUSE

Option	Capacity (GL/year)	Capital cost ($/ML/year)	Operational cost ($/kL)
Wastewater reuse	40 GL /year in addition to the current capacity of 58.55 GL/year	20,342	2.00

TABLE 30: SUMMARY OF ENERGY, GHGS AND VOLUMES OF WATER THAT CAN BE SUPPLIED BY WASTEWATER REUSE

Option	Capacity (GL/year)	Embodied energy (MWh/ML/year)	Operational energy (MWh/ML)	Capital GHGs (tonnes CO_2-e/ML/year)	Operational GHGs (tonnesCO_2-e/ML)
Wastewater reuse	40 GL /year in addition to the current capacity of 58.55 GL/year	-	0.69	-	0.84

RAINWATER TANKS

CAPITAL COST

Rainwater tanks differ from the previous options because they operate at the household level to reduce the demand that has to be supplied by the mains water distribution system. The purchase of a rainwater tank is left to the individual household, which can usually take advantage of rebates. The cost analysis below does not take into account these rebates, as they represent an expense for the Government in any case.

Capital costs of rainwater tanks vary depending on the size and shape of the tank, with 'slim' water tanks being more expensive than cylindrical ones of the same size. The Government of South Australia (2004) estimated that the volume of water saved in a year in South Australia is in the order of 25 GL for a total capital cost of $900 million (considering the spread of rainwater tanks in 2004). This results in a capital cost of $36,000/ML/year in 2004 dollars ($45,624/kL/year referred to 2013 dollars). However, the report does not specify if the water provided by the rainwater tanks is used indoor or outdoor and it is not clear if the rainfall pattern is taken into account.

A more recent estimate of the costs of rainwater tanks can be found in the report of Marsden Jacob Associates (2009) for Perth. In this report, 2 kL and 5 kL tanks are considered as an average and a large residential water tank, respectively. Capital costs depend on the water use and on the type of house: installation costs are larger if plumbing is needed in the domestic pipes and in existing houses. Table 31 summarises the costs provided by Marsden and Jacob Associates (2009): these costs include plumbing and the cost of the pump.

The analysis from Baulis et al. (2008) using information from one rain tank distributor in Adelaide shows that the costs of rainwater tanks can be approximated by a linear relationship with the size of the tank:

$$C = 0.1744 \cdot x + 2731.6$$

where C is the cost of the rainwater tank in $ (data for 2007) and x the volume of the rainwater tank in litres. This cost is inclusive of installation (footing and plumbing work) and of the pump necessary to water the garden and/or to use the rainwater for toilet flushing. For a tank sizes of 2 kL and 5 kL, the cost predicted is $3080 and $3600, respectively ($3,588 and $4,197 if inflated to 2013). These costs are in line with the ones proposed by Marsden Jacob Associates (2009) for an existing house with an indoor use.

TABLE 31: CAPITAL COSTS ($) FOR RAINWATER TANKS (MARSDEN JACOB ASSOCIATES, 2009). COSTS INFLATED TO 2013 ARE REPORTED IN BRACKETS.

	2 kL tank		5 kL tank	
Water use	New house	Existing house	New house	Existing house
Outdoor use only	1,450-2,250 (1,590-2,467)	1,450-2,250 (1,590-2,467)	1,900-2,700 (2,084-2,961)	1,900-2,700 (2,084-2,961)
Outdoor + indoor use	2,750 (3016)	3,250 (3,564)	3,200 (3,509)	3,700 (4058)
Outdoor + indoor use + hot water systems	Not evaluated	Not evaluated	3,200 (3,509)	3,900 (4,277)

Tam et al. (2010) report the capital cost for rainwater tanks (inclusive of installation) for different cities. Table 32 reports the data for Adelaide. It can be seen that these costs are lower than the previous ones. The fact that the pump is not required for the outdoor use could explain some of the discrepancies; other differences can be related to the type of buildings considered (new or existing), which is not specified in the report.

TABLE 32: TOTAL COST OF INSTALLING RAINWATER TANKS (TAM ET AL. 2010).

Tank size	Tank cost ($)	Pump cost ($)	Plumbing cost ($)	Installation cost ($)	Total capital cost for outdoor use only (no pump) ($)	Total capital cost for outdoor and indoor use ($)
2 kL	829	355	730	550	2109	2464
5 kL	1389	355	730	550	2669	3024
10 kL	1925	355	730	550	3205	3560

The design life of the rainwater tanks is assumed to be 25 years for the Marsden Jacob Associates report (2009), after which the tank has to be replaced. The report estimated that only 10% of the installation and plumbing costs are required every 25 years.

In Baulis et al. (2008) the design life of a rainwater tank is assumed to be 40 years, as the HDPE tank is guaranteed for 20 years (BlueScope Steel Australia, 2002). A design life of 20 year is used by Tam et al. (2010). A design life of 25 years is considered a good representative estimate based on the values used in the above studies. The design life of pumps is usually assumed to be 20 years. However, the small pumps used for rainwater tanks are less efficient and receive less maintenance than pumps in water distribution systems. Tam et al. (2010) and Marsden Jacob Associates (2009) assumed that would be necessary to replace the pump every 10 years.

Based on Marsden Jacob Associates (2009), it is proposed to assume the tank costs shown in Table 31, that $355 will be paid every 10 years to replace the pump and that 10% of the installation and plumbing costs will be paid every 25 years.

ONGOING COST

Ongoing costs for rainwater tanks are mostly due to pumping. In addition to energy costs, maintenance costs for the pump and the tank itself need to be considered. Marsden Jacob Associates (2009) estimate the ongoing costs to be in the order of a few dollars a year to a maximum of one hundred dollars per year. Marsden Jacob Associates used $20/year ($21.93 if inflated to 2013) as the annual maintenance cost for tank desludging, pump servicing (excluding pump replacement), gutter maintenance and/or chlorine disinfection. Only $0.025/kL or $0.05/kL are required for pumping for outdoor only or indoor and outdoor water use, respectively (Marsden Jacob Associates, 2009). If inflated, these values are $0.027/kL and $0.055/kL, respectively.

Tam et al. (2010) used the following assumptions in evaluating the cost effectiveness of rainwater tanks: (i) $0.05/kL for ongoing operating and maintenance costs; (ii) $20/year for additional maintenance costs. Tam et al.'s report also shows that rainwater tanks would not be cost effective for Adelaide, as the average price of other water sources was in the range $0.42-1.09 kL, while, considering different sizes of rainwater tanks and different roof areas provides a cost in the range $1.57-2.19/kL for outdoor water use and $1.69-2.34/kL if rainwater is also used indoors. These costs per kL are significantly lower than the unit cost estimated from Marsden Jacob Associates (2009) for Perth, where the cost of water from rainwater tanks is in the range $4-13/kL (cost estimated using a 6% discount rate).

The Government of South Australia (2004) estimated operational and maintenance costs of rainwater tanks to be $0.3 million to save 25 GL of water per year. This would lead to a cost of $0.012/kL ($0.015/kL if inflated to 2013).

Note that all previous reports assumed that the operational costs due to energy consumption are very small. However, the cost related to the energy consumption of pumps for rainwater tanks can be much larger, as shown by Retamal et al. (2009). These authors surveyed different configurations of rainwater tanks for (mostly) residential use. The energy intensity of each case study varied from 0.9 kWh/kL to 4.9 kWh/kL (1.5 kWh/kL on average). The energy intensity is not only affected by the configuration of the system. In fact, three of the case studies had similar tank configurations and an 890 Watt fixed speed pump, but showed different energy intensity: the lowest intensity 0.9 kWh/kL was when the water use was characterised by long and high flow events (for example, by watering the garden) and the highest energy intensity (2.3 kWh/kL) occurred with short and low flow events.

Based on the Retamal et al (2009) results, it is proposed to assume an energy intensity equal to 1.2 kWh/kL if the rainwater tank yield is used outdoor only and 1.45 kWh/kL if the rainwater tank yield is used outdoor and indoor (excluding the hot water connection).

Assuming an electricity price equal to 0.25 $/kWh, the operational cost of the pump associated with the rainwater tank is $0.3/kL for outdoor use only and $0.36/kL for outdoor plus indoor water use.

Rainwater Tank Yield

In order to evaluate the cost effectiveness of rainwater tanks, it is necessary to estimate tank yield. This task is complicated because it has to take into account the annual rainfall and its temporal pattern, as well as water use (e.g. in summer, when garden watering is necessary, the rainwater tank can be empty; if it rains and the rainwater is already full, the additional rain is lost). As rainwater tanks rely on rainfall, climate change can have a significant impact on tank yield.

Coombes and Kuczera (2003) report an average tank yield for Adelaide equal to about 21 kL/year for a 2 kL tank connected to 100 m^2 roof area (including a hot water connection). Similar values (16.36-16.77 kL/year, excluding the hot water connection) are reported by Lane et al. (2012). Marsden and Jacob Associates report a tank yield equal to 22 kL/year (assumed connection to indoor and hot water system and a 50 m^2 roof area).

Appendix A of the document prepared by the Department of Planning and Local Government (2010) shows the harvesting curve for a 2 kL tank with a roof area of 100 m^2 as a function of the demand. These values are computed using the rainfall pattern of specific locations and considering a constant indoor demand. Using the same software used by the Department of Planning and Local Government (2010) (Rain Tank Analyser, 2009) it is estimated that the tank yield is about 14 kL/year/property if the tank is used only for irrigation purposes (100 m^2 garden assumed) and about 32 kL/year/property if the water from the tank is used also for laundry and toilet. Note that these results are obtained assuming a total consumption equal to 523 L/day/property (National Water commission, 2010) and that 40% of this quantity (209 L/property/day) is used for gardening and 27% (141 L/property/day) is used for toilet flushing and laundry (Government of South Australia and SA Water, 2013). Note also that the data of the National Water Commission (2010) clearly show a reduction in the volume of water supplied by water mains, most likely due to water restrictions, the adoption of water efficient appliances and in general a more water efficient behaviour. The most conservative estimates of 2009-2010 have been adopted.

Considering that the yield estimates for Adelaide vary from 9 kL/year to 14 kL/year for outdoor use and from 17 kL/year to 32 kL/year for outdoor and indoor use, it will be assumed that the annual yield is 10 kL/year for outdoor and 22 kL/year per property and indoor and outdoor use, respectively. Note that these yields are estimated for a 2 kL tank.

The total yield estimated by different authors for a 5 kL tank for outdoor water use and indoor and outdoor water use in Adelaide is shown in Table 33. Based on the values shown, it is decided to assume a yield equal to 19 kL/year for 5 kL tanks used for outdoor use only and 44 kL/year if water from the 5 kL tank is used also indoors.

TABLE 33: ESTIMATED YIELD OF 5 KL RAINWATER TANK IN ADELAIDE FOR 100M^2 OF CONNECTED ROOF AREA (UNLESS OTHERWISE SPECIFIED).

Rainwater Tank Yield (kL/year/tank)		
Source	**Outoor use only**	**Indoor and Outdoor use**
Rain Tank Analyser (2009)	~19	~44
Combes and Kuczera (2003)	-	~23
Combes and Kuczera (2003)*	-	~53-63 (depending on number of residents)
Marsden and Jacob Associates (2007)	19 and 47 for 50m^2 and 200m^2 of roof area, respectively	22 and 73 for 50m^2 and 200m^2 of roof area, respectively

*for 200m^2 of connected roof area

Levelised Cost

Table 34 shows a comparison of the levelised costs in 2013$. These costs have been reported so as to compare the available literature. It has to be noted that the cost of the rainwater tanks for indoor and outdoor water use is lower than that of the rainwater tanks for outdoor water use only, because of the larger yield in the second case (Marsden Jacob and Associates, 2009).

Using the data provided in the report, an estimate for Adelaide is made considering that the yield for a 2 kL tank is 22 kL/year for indoor and outdoor use and 10 kL/year for outdoor use. The estimate is based on the cost of tank installation (provided in Table 31) and a present value of the $20/year maintenance cost (inflated to 2013) for 25 years (about $280). The operational costs (about 30-36 cents per kL) are a small percentage of the total levelised cost, which is in the range $12 – $22/kL. Note that the total levelised cost reduces to $8.41 – 15.65/kL if the largest savings from Rain Tank Analyser (2009) are considered. Only if the total yield is considered to be 97 kL/year, as in Tam et al. for a 100 m^2 roof, are the levelised costs more similar to the ones presented by these authors ($1.81-2.52/kL for outdoor use and $3.02/kL-$3.46/kL for outdoor and indoor water use in new and existing buildings).

TABLE 34: TOTAL COST OF INSTALLING AND OPERATING RAINWATER TANKS.

Authors	Levelised cost (2013 $/kL)
Government of South Australia (2004)	3.44
Tam et al. (2010)	1.76-2.21* 1.89-2.40** (depending on the connected roof size)
Marsden Jacob Associates (2009) for a 2kL tank (for Perth)	8.82-19.21* 6.88-13.76**
Marsden Jacob Associates (2007) data for a 2kL tank, 200 m^2 connected roof, for Adelaide – cost to owner	2.68* (no pump required) 4.15**
ATSE (2012)	1.43-3.37
Estimated for a 2kL tank connected to 100m^2 of roof area (using 10* or 22** kL/year yield)	14.93-21.80* 12.08-14.03**

* Outdoor water use
** Outdoor and indoor water use

Total Water Savings Estimation

In addition to rainwater tank cost, it is also important to estimate the number of households that can install this device. In fact, because of water restrictions and the success of rebates on water savings appliances, rainwater tanks are more popular in South Australia than in any other state, with 49% of South Australian houses being provided with water by rainwater tanks, compared to 26% nationally (Australian Bureau of Statistics (ABS), 2011a). It has to be noted that rainwater tanks are more common outside Adelaide, where 83% of households have a rainwater tank.

Appendix F presents the methodology followed to estimate the water savings due to rainwater tanks. Considering that many rainwater tanks have already been installed since 2004, the water savings for a 2 kL tank are estimated to be 1.3 GL/year for outdoor use only and 2.9 GL/year if the rainwater is used outdoor and indoor. Assuming that the number of buildings that can install a 5 kL rainwater tank is the same as in the 2 kL tank case, the total yield is 2.5 GL/year for outdoor rainwater use and 5.8 GL/year for outdoor and indoor use.

ENERGY AND GHG EMISSIONS

Kenway et al. (2008) report the embodied energy of PVC and concrete tanks estimated by Pullen (1999) (Table 35). Analysing these data it can be seen that the embodied energy (EE) in a PVC tank can be expressed as

$$EE\ (GJ) = 0.2899 * Vol(kL) + 3.5605$$

where *Vol(kL)* is the tank volume in kilolitres.

The formula provided fits the input with R^2 equal to 0.997 and results in EE of 4.14 GJ for a 2 kL tank. Note also that the life of a PVC tank is assumed to be 25 years (Pullen assumed 50 years, but for much larger tanks), the resulting emissions are 36.34 kgCO_2-e/year/tank (full cycle electricity emission factor adopted).

Baulis et al. (2008) estimated the embodied energy of HDPE tanks: the embodied energy due to the tank construction is estimated to be

$$EE\ (MJ) = -14.0 * Vol(kL)^2 + 1344.8 * Vol(kL) + 2020.4$$

In this case, the embodied energy is equal to 4800 MJ and the emissions are 1.0533 kgCO_2-e for a 2 kL tank. If this carbon footprint is spread over 25 years, the GHGs are 42.13 kgCO_2-e/year/tank. This larger emission will be considered in the following. For a 5 kL tank, the embodied energy is equal to 8700 MJ and the emissions are 1,909 kgCO_2-e, equivalent to 76.37 kgCO_2-e/year/tank if spread over 25 years.

TABLE 35: EMBODIED ENERGY IN PVC AND CONCRETE TANKS (PULLEN, 1999).

Tank size (kL)	PVC membrane lined steel			Reinforced concrete		
	EE (GJ)	Life (years)	Annualised GJ/a (EE/years)	EE (GJ)	Life (years)	Annualised GJ/a (EE/years)
34	13	50	0.3	42	75	0.6
68	24	50	0.5	58	75	0.8
113	36	50	0.7	78	75	1

An energy consumption of 1.2 kWh/kL for outdoor use and 1.45 kWh/kL for outdoor and indoor use will be used. Considering an emission factor equal to 0.79 kgCO_2-e/kWh, this results in 0.95 kgCO_2-e/kL for outdoor use and 1.15 kgCO_2-e/kL for outdoor and indoor use. Note that it is assumed that all tanks will be provided with a pump, even when rainwater is used only outdoors, despite the fact that, in some cases, the tank could be used without a pump. Note also that GHG emissions from maintenance and pump replacement are ignored.

SUMMARY

Table 36 summarises the results discussed in the previous sections: depending on the rainwater use (only for garden watering or for outdoor use and toilet and laundry use), the 2 kL rainwater tanks could save 1.3 GL/year or 2.9 GL/year, respectively. The water savings associated to 5 kL tanks increase to 2.5 and 5.8 GL/year, respectively. This estimate only considers the additional water savings that can be provided by this appliance. The levelised cost of rainwater tanks varies depending on the roof area connected, on the quantity of water used (and its pattern) and on the rainfall quantity and pattern. Estimates are based on a 2 kL tank connected to 100 m^2 of roof area or on a 5 kL tank connected to 100 m^2 of roof area.

Energy and greenhouse gas emissions have been estimated using the same number of potential houses for the installation of rainwater tanks and an energy consumption equal to 1.2 kWh/kL for the pump for outdoor water use and 1.45 kWh/kL for outdoor and indoor water use (Table 37). Note that it is assumed that all tanks are equipped with a pump, although some rainwater tanks for outdoor use only could not have one. In this case, their operational GHGs would be zero, as possible emissions for maintenance are not accounted for.

TABLE 36: SUMMARY OF COSTS AND VOLUMES OF WATER THAT CAN BE SUPPLIED BY RAINWATER TANKS.

Option	Capacity (GL/year)	Capital cost ($/ML/year)	Operational cost ($/kL)
Rainwater tanks (Design life: 25 years) (2kL tank)	2.9 for indoor & outdoor use (22 kL/year/tank) 1.3 for outdoor use only (10 kL/year/tank) (based on 2kL tank connected to 100m^2 roof)	139,412 -164,743 ($3,016 – 3,564/tank) for indoor&outdoor 163,954 – 254,386 ($1,590 – 2,467/tank) for outdoor 10% of the construction costs to be added every 25 years. Pump replacement ($355/pump) every 10 years	$0.36/kL for indoor&outdoor $0.3/kL for outdoor + $22/year for maintenance
Rainwater tanks (Design life: 25 years) (5kL tank)	5.8 for indoor & outdoor use (44 kL/year/tank) 2.5 for outdoor use only (19 kL/year/tank) (based on 5kL tank connected to 100m^2 roof)	$81,100 -93,789 /ML/year ($3,509 – 4,058/tank) for indoor & outdoor use $111,744 – 158,769 /ML/year ($2084 – 2,961/tank) for outdoor use only 10% of the construction costs to be added every 25 years. Pump replacement ($355/pump) every 10 years	$0.36/kL for indoor & outdoor use $0.3/kL for outdoor use only + $22/year for maintenance

TABLE 37: SUMMARY OF ENERGY AND GHGS AND VOLUMES OF WATER THAT CAN BE SUPPLIED BY RAINWATER TANKS.

Option	Capacity (GL/year)	Embodied energy (MWh/ ML/year)	Operational energy (MWh/ML)	Capital GHGs (tonnes CO_2-e/ ML/year)	Operational GHGs (tonnes CO_2-e/ML)
Rainwater tanks (Design life: 25 years) (2kL tank)	2.9 for indoor & outdoor use (22 kL/year/tank) 1.3 for outdoor use only (10 kL/year/tank)	61.632 for indoor& outdoor use 137.487 for outdoor use only (1.333/tank)	1.45 for outodoor & indoor use 1.2 for outdoor use only	48.689 for indoor & outdoor 108.615 for outdoor (1.053 tonnes CO_2-e/tank)	1.15 for outdoor & indoor water use 0.95 for outdoor water use
Rainwater tanks (Design life: 25 years) (5kL tank)	5.8 for indoor & outdoor use (44 kL/year/tank) 2.5 for outdoor use only (19 kL/year/tank)	54.924 for indoor& outdoor use 127.424 for outdoor use only (2.417/tank)	1.45 for outodoor & indoor use 1.2 for outdoor use only	43.390 for indoor & outdoor 100.665 for outdoor (1.909 tonnes CO_2-e/tank)	1.15 for outdoor & indoor water use 0.95 for outdoor water use

DEMAND MANAGEMENT

Encouraging or forcing a reduction in water demand, if successfully applied, will result in a decrease in the amount of water needed. This is an alternative to increasing water supply by finding new water sources or increasing the volume of water withdrawn from existing sources. There are several demand management options with different characteristics in terms of cost, effectiveness and public acceptability.

Some of the most common forms of water demand management include increasing water price, applying water restrictions, forcing or offering rebates for the use of water efficient appliances and informing customers about the importance and cost of water and methods for reducing water consumption. All of these interventions have different costs and different associated water savings (Olmstead and Stavins, 2008). It has to be noted that, given that the access to water is one of the basic needs, water pricing options have to be regulated so as to assure equity and access to the resource.

In all types of water management interventions, the estimation of the water savings that are achieved is complicated by several factors, which also vary in place and time. The effectiveness of price management depends on the elasticity of water demand, i.e. a measure of the effect that a price change has on demand. This is a function of the actual water price and of user income (high-income users tend to be less sensitive to changes in price). More information about the price elasticity of the demand for water can be found in Appendix G.

In the following section, the cost and benefits of water restrictions and water efficient appliances will be discussed. Note that water price management will not be analysed, as it is not considered a viable option to further reduce water consumption, due to Government policy based on setting prices to achieve full cost recovery. For South Australia, the current tariff consists of a quarterly supply charge of $73.25 per property, a price of $2.42/kL for the first 30 kL used, a price of $3.45/kL for a consumption in the range 30-130 kL and a price of $3.73/kL for each additional kilolitre. All volumes are measured on a quarterly basis (Weatherill et al. 2012). The water tariff implements larger costs for larger volumes of water consumed, so as to promote water conservation.

COST OF WATER RESTRICTIONS

Mandatory water-use restrictions usually limit or control outdoor and industrial water use and are often associated with other conservation or information programs, so that it is difficult to distinguish the individual contribution of each. Note also that water restrictions are not always effective: Turner et al. (2010) report the results obtained using smart water meters in Hervey Bay (QLD). The shifting of sprinkler bans from 8am-4pm to 6am-8pm did not reduce significantly the amount of water used, but only changed the shape of the demand curve by shifting the peak demands before and after the sprinkler ban period (a slight increase of the peak demand was also observed).

Moreover, there are examples where imposing water restrictions had negative effects. When water restrictions are effective, one consequence is the financial loss to the water utility, caused by reduced consumption as well as a loss of amenity to water consumers. Given a period of water restrictions during the drought of 2006 to 2009, PMSEIC (2007) reported that there is a limit to the extent to which demand management approaches can further reduce overall water demand without being intrusive and damaging to the economy.

Water restrictions can impose costs on various sectors of the community including the following:

- The water utility that suffers loss of revenue as well as additional administrative costs
- Residential consumers who suffer losses because of time restrictions on outdoor watering
- Industrial and commercial consumers who suffer economic loss due to reduced production

The following analysis will concentrate on items (1) and (2) as water restrictions generally limit the outdoor use of water and only very stringent restrictions limit the use of water for industrial and commercial purposes.

The economic cost of water restrictions on residential consumers can be explained by considering the demand function. Figure 11 represents this function for a typical household, where d_0 is the demand in the absence of water restrictions and d_r is the demand when water restrictions are applied. Note that the same reduction in demand can be obtained by increasing the water price from p_0 to p_r.

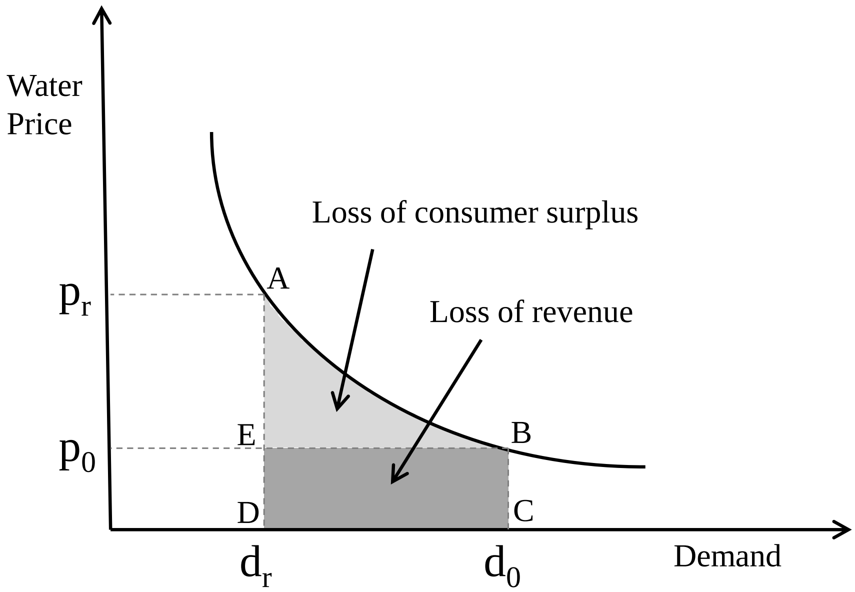


FIGURE 11: DEMAND RELATIONSHIP FOR A HYPOTHETICAL HOUSEHOLD (FROM KUCZERA AND NG, 1994).

The total economic loss due to water restrictions depends on the reduction in willingness to pay. This is represented by the grey areas in Figure 11; the area EBCD represents a loss of revenue for the water utility, because the demand has been reduced from d_0 to d_r; the area ABE is the loss of consumer surplus (Kuczera and Ng, 1994).

Dandy (1992) analysed the economic cost of restrictions on outdoor water use. Following Narayanan et al (1985), Dandy (1992) identified the following three cases of restrictions on outdoor water use: quantity restrictions, moderate time restrictions and stringent time restrictions.

Quantity restrictions limit the total quantity of water that can be used by each individual household and may be analysed using the information contained in Figure 11.

Moderate time restrictions (e.g. limiting the use of sprinklers to certain times of the day), increase the cost of input of labour for the watering process and therefore cause the demand curve for outdoor water to shift downward. The situation is shown in Figure 12 (from Dandy, 1992). The imposition of moderate time restrictions causes the demand curve to shift from D_1 to D_2. The outdoor water use drops from q_{10} to q_{20}. The reduction in willingness to pay for this household is the shaded area shown in Figure 12.

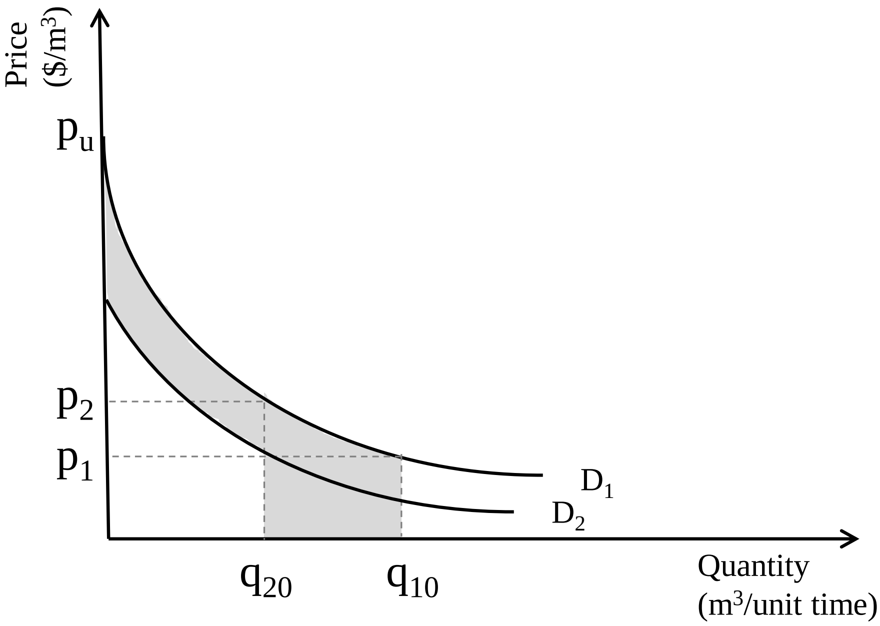


FIGURE 12: REDUCTION IN WILLINGNESS TO PAY DUE TO MODERATE TIME RESTRICTIONS (FROM DANDY, 1992).

The effect of stringent time restrictions is shown in Figure 13 (from Dandy 1992). The demand curve has shifted down due to the increased cost of labour. However, the time available for watering is so limited that only a quantity q_{30} can be applied and, effectively, quantity rationing applies. The loss in willingness to pay is shown by the shaded area and will be greater than the effect of an equivalent price increase or purely quantity rationing.

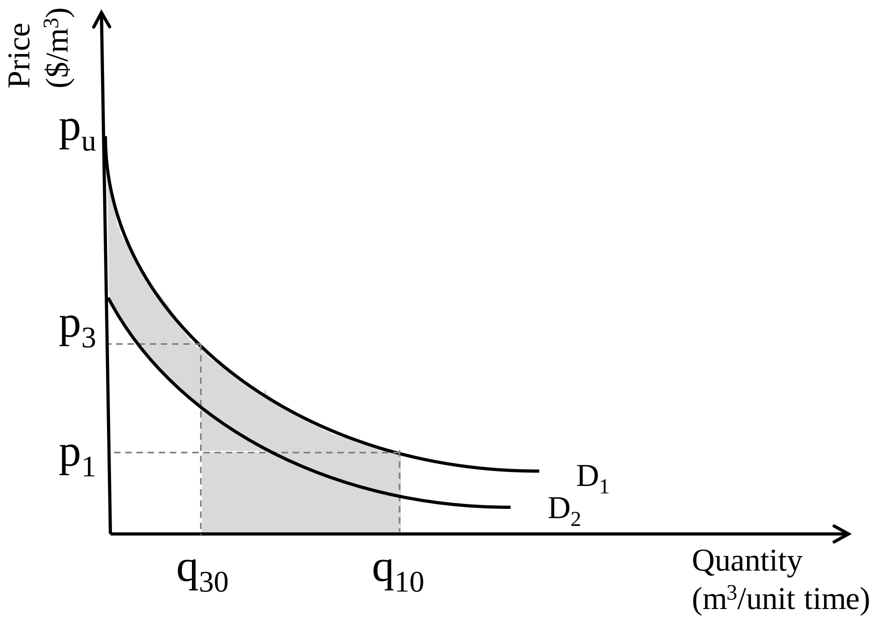


FIGURE 13: REDUCTION IN WILLINGNESS TO PAY DUE TO STRINGENT TIME RESTRICTIONS (FROM DANDY, 1992).

Most water restrictions in urban areas are of the time restriction type due to the difficulty of applying pure quantity restrictions. It will be assumed that all restrictions considered will be stringent time restrictions and that the cost (or loss of willingness to pay) can be estimated using an equivalent quantity restriction. As shown in Figure 13 this approach will tend to underestimate economic cost as it does not take into account the shift in the demand curve for outdoor water use caused by the restrictions.

For stringent time restrictions the effective reduction in the quantity used will vary between households as every household will have its own demand curve, patterns of water use and availability to water the garden in restricted times. If we treat these restrictions as an equivalent quantity restriction (as shown in Figure 11), this means that the reduction in the quantity used (d_0 minus d_r) will differ between households and hence the 'shadow price' of the water (p_r) will also differ. Dandy (1992) shows that this means that the economic costs of the restrictions are greater than the economic cost of an equivalent price increase.

The following equations can be used to estimate the cost of water restrictions on outdoor residential water use:

$$E[\Delta W] = p_1 Q_{1o} \left\{ \left(\frac{\bar{\varepsilon}}{1+\bar{\varepsilon}} \right) \left[1 - (1-\bar{r})^{\frac{(1+\bar{\varepsilon})}{\bar{\varepsilon}}} \right] \right\} \quad \text{when } \bar{\varepsilon} \neq -1 \qquad (1)$$

$$E[\Delta W] = -p_1 Q_{1o} [\ln(1-\bar{r})] \quad \text{when } \bar{\varepsilon} = -1 \qquad (2)$$

where $E[\Delta W]$ is the expected value of the total reduction in willingness to pay, p_1 is the current price of the water for the outdoor consumption Q_{1o} in the absence of restrictions, $\bar{\varepsilon}$ is the mean price elasticity of water demand for all households and $\bar{r}$ is the mean fractional reduction in outdoor consumption in response to water restrictions for all households.

These equations are based on the following assumptions:

- The shift in the demand curve for outdoor water use in response to stringent time restrictions may be neglected
- All residential consumers have identical demand curves for outdoor water use
- The price elasticity of demand for outdoor water use for all consumers is constant

As these assumptions are not likely to hold in practice, the cost estimated using these equations represent a lower bound on the true value of the economic cost.

Water restrictions generally don't limit indoor water use. Furthermore, the limitations on industrial use are usually minor unless severe restrictions are imposed. The loss of revenue to the water utility is included in the above equations.

The loss of willingness to pay is not the only factor influencing the economic cost of water restrictions: 'administration' costs of restrictions can also be significant as shown by Chong et al. (2009). For example, \$5 million was spent by Sydney Water in 2003-2006 to process exemptions and \$5.9 million was spent for monitoring in 2005-06. In the ACT, the cost per year of advertising and monitoring water restrictions were in the range \$1-2.7 million/year depending on the water restriction stage. Costs for advertising were $800,000 and $850,000 for Perth and Brisbane City Council respectively, while monitoring and enforcement was about $400,000 for both.

Chong et al. (2009) attempted to estimate the cost of water restrictions for householders, industry, government and water utilities for Perth, Canberra and Sydney (and a few other smaller cities). Results for Perth and Canberra are shown in Table 38. To analyse the sensitivity of some of the parameters, the estimates include: i) modelling the total residential water use (higher estimate of consumer welfare loss) or modelling outdoor residential water use only (lower estimate of consumer welfare loss); ii) the use of price-demand elasticities between -0.3 (greater estimate of consumer welfare loss) and -1.7 (lesser estimate of consumer welfare loss). Note that this value is larger than the typical values adopted in literature (-0.25 to -0.35), but has been assumed to account for the fact that the outdoor demand could be much more price elastic than the total demand, especially in drought periods. As shown by Kuczera and Ng (1994), outdoor demand is more elastic than indoor demand; however, values for Newcastle are likely to differ from those in Adelaide because of differences in climate. As water restrictions are usually applied to outdoor water uses, the applicability of Kuczera and Ng's values for total consumption is likely to be limited. Other assumptions in the model by Chong et al. (2009) are related to use of the top tiered prices (Sydney $1.17/kL, Perth $1.12/kL, ACT $1.11/kL and the estimation of a constant indoor water use equal to 160L/person/day for all cities.

It is difficult to translate the values reported in Table 38 to Adelaide, because of climate differences, possible house type differences and the many assumptions made in the original computations. Moreover, actualising the 2007 values accounting only for changes in the CPI is not considered reliable, as the estimates of water restriction costs are based on a water price equal to $1.1-1.2/kL (which was the highest tier at the time), but currently, the water price in Adelaide is in the range $2.42-3.73/kL (much higher than what would be estimated using changes in the CPI).

The cost of water restrictions on residential consumers in Adelaide will be estimated using equation (1) given above. The price elasticity of demand for outdoor water use is assumed to lie in the range -0.8 to -1.5 based on values given in Appendix G. The cost of restrictions will be estimated assuming an average annual household water consumption of 180kL of which 40% (or 72 kL) is outdoor use. It is assumed that all of the reduction in consumption occurs in outdoor use, so that a 10% reduction in overall consumption implies a 25% reduction in outdoor consumption. This gives the range of costs shown in Table 39. These values include the loss of revenue to the water utility. The costs associated with water conservation marketing and promotion are estimated as an average between the costs bore by the water utility of Western Australia ($800,000/year) and the average of the costs bore by the ACT ($1.3m/year) in 2009 dollars and result in an estimate of $1.15m/year in 2013 dollars.

TABLE 38: ESTIMATE OF ECONOMIC COST OF WATER RESTRICTIONS IN AUSTRALIA (CHONG ET AL. 2009).

City	Typology	Cost	Notes
Perth	Household	$28-161 /year/household	Frequency, severity and duration of WRs not taken into account. Likely to be overestimated for short/light WRs.
	Industry	Not substantial	Based on consultation with irrigation industry
	Utilities	$800,000/year	
ACT	Household	$11-120 /year/household	$239/household would be paid to move from a continuous level 3 or above WR to a situation with no likely restrictions
	Industry	$0.5m/year under stage 1 to $4.5m/year under stage 5	
	Utilities	$1.2-1.4m/year	

TABLE 39: ESTIMATE OF ECONOMIC COST OF WATER RESTRICTIONS IN ADELAIDE.

Type	Reduction in total consumption	Cost
Households	10%	$68 to $74/household/year
Households	20%	$153 to $187/household per year
Water utility		$1.15m/year

Effectiveness of Water Restrictions

The estimate of the effectiveness of water restrictions has been analysed by several sources. However, as these measures are often implemented in conjunction with other water management options, it is difficult to estimate the specific contribution of each intervention. Chong et al. (2009) analysed the water savings associated with water restrictions in Australia up to 2007 (Table 40): these savings varied according to the stage of water restrictions and on location: results show a minimum demand reduction equal to 6% and a maximum reduction equal to 34% (maximum savings of 24% have been recorded for Adelaide).

However, as effectiveness is usually expressed as a percentage of normal demand, attention has to be paid to demand changes. Depending on how dated past data on water restrictions are, many changes could have occurred in demand: the introduction of more water efficient appliances and an increase in water saving behaviour could have permanently reduced it. An extreme example is the case of water restrictions that completely prohibit any outdoor water use. If town A usually consumed 1 GL/year, of which 50% was used outdoor, water restrictions would save up to 0.5 GL/year. However, if outdoor water use is eliminated (for example, there are currently no gardens), water demand is already 0.5 GL/year: applying the same water restrictions as in the past will not decrease the demand at all in this case.

Appendix H estimates the changes in water consumption due to water restriction in Adelaide. However, due to the lack of data on the effect of water restrictions on current consumption, it is proposed to assume an effectiveness of the water restrictions in the range 10%-20% compared to unrestricted demand. Note that this percentage is based on the data reported in

Chong et al. (2009) reporting water savings in the order of 6%-24% and does not take into account that, since 2006, the water use could have been reduced (thus, overestimating the possible savings).

Cost of Water Efficient Appliances

Encouraging the use of water efficient appliances can reduce water demand without introducing changes in user habits and therefore it could be considered preferable to water restrictions. The purchase of water efficient appliances can be subsidised or made mandatory (usually in case of new buildings and renewals). During times of water scarcity, rebates are usually offered to speed up the reduction in the demand. Often, rebates are directed to householders as residential consumption is a large portion of the total consumption in a city. However, it is worth noting that other users' consumption could be relevant too: from the analysis in Appendix H, the amount of water used for non-residential uses in Adelaide (commercial, industrial, public use and non-revenue water) is about 40%. Therefore introducing rebates or other subsidies to improve the water efficiency of other users could have a significant effect. Several successful examples of water savings in the industrial and commercial sector are reported in Water Services Association of Australia (2009).

Table 40: Effectiveness of water restrictions in various cities in Australia (Chong et al. 2009).

Location	Restriction level	Savings target level (%)	Estimated savings (%)
Sydney	1: No sprinklers or watering systems (excludes drip systems).	7	13
	2: No sprinklers or watering systems (excl. drippers). Hosing 4pm–10am 3 days/week.	12	16
	3: No sprinklers or watering systems. Drippers & hosing allowed 4pm– 10am 2 days/week.	15	17
ACT	1: Sprinklers and watering systems 7–10am and 7–10pm 3 days/week. Trigger hoses and buckets anytime.	15	14
	2: No sprinklers or watering systems except drippers. Drippers, trigger hoses and buckets 7–10am and 7–10pm 3 days/week.	25	13
	3: No sprinklers or watering systems. Dripper exemption currently applies. No lawn watering. Trigger hoses and buckets 7–10am and 7–10pm 3 days/week.	40	33
	2: No sprinklers or watering systems except drippers. Drippers, trigger hoses and buckets 7–10am and 7–10pm 3 days/week.	13	13
	3: No sprinklers or watering systems. Dripper exemption currently applies. No lawn watering. Trigger hoses and buckets 7–10am and 7–10pm 3 days/week.	40	33
	2: No sprinklers or watering systems except drippers. Drippers, trigger hoses and buckets 7–10am and 7–10pm 3 days/week.	13	11
Melbourne	1: Manual watering systems 6–8am and 8–10pm 3 days a week. Automatic watering systems midnight –4am odds/evens. Trigger hoses anytime.	n/a	7.8
	2: No lawn watering. Watering systems 3 days/week: manual 6–8am and 8–10pm; auto midnight–4am. Trigger hoses anytime.	n/a	10.7
Geelong	1: Manual watering systems 6–8am and 8–10pm 3 days a week. Automatic watering systems midnight–4am odds/evens. Trigger hoses anytime.	n/a	8

Location	Restriction level	Savings target level (%)	Estimated savings (%)
	2: No lawn watering. Watering systems 3 days/week: manual 6–8am and 8–10pm; auto midnight–4am. Trigger hoses anytime.	n/a	20
Adelaide	2: Sprinklers (excl drippers) 3 days/week 8pm–8am.	n/a	6
	3: sprinklers 1 day/wk for 3 hours either 5–8am or 8–11pm. Trigger hoses & drippers 8pm–8am.	n/a	24
Brisbane	2: No sprinklers or unattended watering devices. Hoses odds/evens 7pm–7am.	15	25
	3: No sprinklers or hoses. Buckets and cans anytime.	20	30
	4: No sprinklers or hoses. Buckets and cans 3 days/week 4–8am or 4–8pm.	25	34

Appendix I presents the methodology used to estimate the cost and water savings of water efficient appliances (WEA). The following presents the results of the analysis.

Estimating the cost of Water Efficient Appliances

Lane et al. (2012a, 2012b) analysed the rebates and subsidies offered to residential users in Australia in the period 2003-2011. The levelised costs of several water efficient appliances were determined by considering the cost to the consumer (inclusive of the rebate), the cost to the policymaker (rebate and administrative costs) and the cost to society. The cost to society includes the cost of the water efficient device (including the subsidy), the cost of installation and the administration costs.

Water savings were estimated considering the current distribution of water appliances based on a 2004 residential end use survey conducted in Newcastle (Thyer et al. 2009), except for the estimate of pool cover savings (Lane et al. 2012b). Note that it is assumed that indoor water use in Adelaide is similar to that of Newcastle, while outdoor use is different because of the different climate. It is important also to note that the washing machine savings have been estimated considering the change from a top loading to a front loading washing machine only. The fact that differences in the water efficiency of the appliances are not considered could explain some of the differences with other estimates.

Data from Lane et al. (2012b) have been used to compute the levelised costs of low flow showerheads, dual flush toilets and washing machines over a period of 25 years and using an interest rate of 6% p.a. so as to compare these levelised costs with the costs estimated for the other options (Table 41). Considering the water that these appliances can save, their levelised cost is in the range $0.80-13.00/kL (in the computation, maintenance cost has not been considered).

It has to be noted that most of these appliances are often replaced because of old age or malfunctioning. Therefore, a fairer comparison would take into account only the additional cost of buying a water efficient device instead of a normal one, so as to estimate the value of the rebate that would make preferable the purchase of a water efficient device. However, most appliances on the market are water efficient, so that it is difficult to have a reliable comparison. In addition, the analysis by Lane et al. showed that the presence of rebates did not influence the choice of 20% of the households who claimed a rebate.

Table 41: Levelised costs of water saving appliances estimated using n=25 years and i=6% p.a.

Water efficient appliance (WEA)	Low flow showerhead	Front loader washing machine	Dual flush toilet	Pool cover
Life of WEA (years)	10	8	10	8
Cost of purchase ($)	60	630	600	600
Cost of installation ($)	16	164	153	547
Water savings (kL/year/household)	13.8	20.2	8.4	36
Levelised cost ($/kL)	0.81	6.98	13.12	5.65

The estimated water savings differ significantly from the ones reported by the Government of South Australia and SA Water (2013) (Table 42). However, it has to be noted that the estimates in Table 42 are based on a comparison with water 'inefficient' devices, while Lane et al. considered the actual distribution of the appliances in the houses, e.g. some houses have already dual flush toilets (11/6L, 9/4L).

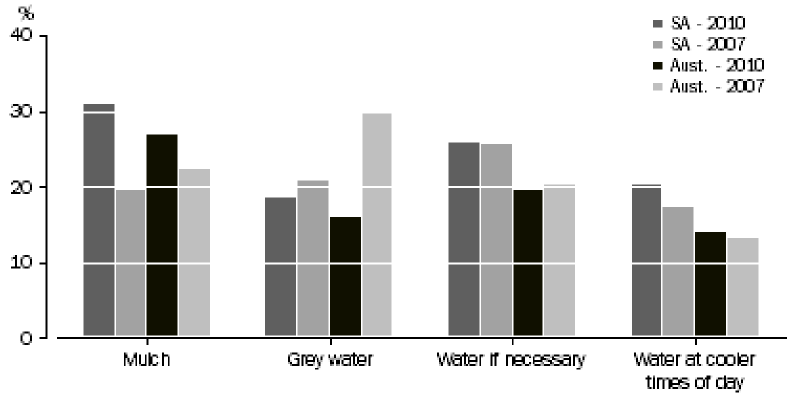
Table 42: Savings of water efficient appliances (Government of SA and SA Water, 2013).

Appliance type	Best practice flow rate	Non water saving fixture	Water savings per person (kL/yr)
Toilet	4.5/3 L dual flush (avg 3.3 L/flush)	11 L/flush	11
Hand basin	4.5 L/min	18 L/min	20
Shower (10 min)	7 L/min	18 L/min	40
Shower (4 min)	7 L/min	18 L/min	16

To estimate the total savings that could be achieved through the use of water saving appliances, it is necessary to estimate how many households can benefit from these devices. Dolnicar and Hurlimann (2010) surveyed the water attitudes of Australians and reported that the percentage of houses with water efficient washing machines was 50-75%, 43% of houses had tap timers installed, 76% had low flow taps and 74% of the gardens had water resistant plants. As the two questions related to the use of water efficient washing machines show a discrepancy, the most conservative estimate of the possible savings (75% of houses have already a water efficient device installed) will be used.

Data related to the spread of water efficient devices are reported also by ABS (2011a). A comparison of the water saving measures adopted outside and inside the house in the 12 months preceding March 2010 and March 2007 shows that water savings have improved inside the house and slightly decreased in the garden. ABS (2011a) reports that 70% of Australian households with a garden reported water saving activities in 2010, compared to 78% in 2007. However, specific activities have increased: the use of mulch (31% in 2010 and

19% in 2007), only water if necessary (26% in 2010 and 25% in 2007), water at cooler times of day (20% in 2010 and 17% in 2007) (Figure 14). At March 2010, water-efficient shower heads were installed in 65% of households (up from 37% in 2001) and 89% of households had a dual flush toilet (up from 72% in 2001). Moreover, in March 2010, 14% of the household had a water efficient washing machine installed.



Source: ABS, Environmetal Issues : Water use and Conservation, Australia, March 2010 (cat. no. 4602.0.55.003)
ABS, Environmetal Issues : Peoples Views and Practices, March 2007 (cat. no. 4602.0)

FIGURE 14: MAIN STEPS OF WATER CONSERVATION IN GARDENS (FROM ABS, 2011A)

Considering the previous percentages, 11% of the households could introduce a dual flush toilet and 35% of the households could install water efficient shower heads. As reported by Lane et al. (2012), over the five year H_2OME program, approximately 1 in 3 tenants claimed a rebate for the purchase of a new washing machine. If households that purchased a water efficient washing machine without claiming a rebate are excluded, 66% will still benefit from the introduction of a water efficient device.

It is important to note that the analysis by Lane et al. (2012) shows that owners are more likely to adopt water savings measures than tenants. The estimation of the possible savings (and of the optimal rebate) should take into account this information. According to the ABS (2011b), in 2009-10 about 69.8% of the dwellings were occupied by owners.

The Government of South Australia (2004) estimated that up to 48 GL/year could have been saved through water saving appliances (Table 43). A large part of these savings was expected for outdoor use (30 GL/year). The second column presents the value updated considering the fraction of householders who have already adopted these appliances.

The costs of tap timers and low flow taps can be estimated considering their price and the possible water savings. A brief survey of the cost of 4 WELS star taps shows that their cost is on average $360 (range $169-623) (data from Harvey Norman website, accessed 11/1/2013); the cost of tap timers ranges from $8 for the most basic ones to $289 for complex multifunction ones (average $59) (Bunnings Warehouse, 2013). Considering the water savings reported by the Government of South Australia (2004) and the current spread of these devices (data from Dolnicar and Hurlimann, 2010), the possible savings for low flow taps and tap timers are 0.4 GL/year and 2.2 GL/year, respectively.

TABLE 43: SAVINGS ACHIEVABLE IN ADELAIDE BY USING WATER EFFICIENT APPLIANCES.

Water savings	Estimated by Gov. of South Australia (2004) (GL/yr)	Estimated by data from Lane et al. (2012b) and spread of water efficient appliances (GL/yr)
Washing machines	6.7	2.4
Tap timers	3.9	n/a
Low flow showerheads	3.3	2.3
Low flow taps	1.6	n/a
Dual flush toilet	3.2	0.4
Native gardens & water efficient garden appliances	30	n/a
Total	48.7	5.2

Table 44 summarises the costs estimated for the purchase and installation of water efficient appliances (note that maintenance costs are not considered). Note that the water savings are estimated using the values in the third column of Table 43 because they are considered to be more accurate. Computing the water savings starting from the data of the Government of South Australia (2004) would have resulted in possible water savings equal to 1.7 GL/year and 1.2 GL/year for washing machines and low flow shower heads, respectively. Note that for low flow taps and tap timers, a design life equal to 10 years and an installation cost of $16 have been assumed.

TABLE 44: COST OF WATER EFFICIENT APPLIANCES.

	Washing machines	Tap timers	Low flow showerheads	Low flow taps	Dual flush toilet
Design life (years)	8	10	10	10	10
Cost of purchase ($/appliance)	630	59	60	360	600
Cost of installation ($/appliance)	164	16	16	16	153
Total Cost ($/appliance)	794	75	76	376	753
Water savings (kL/year/household)	20.2	8.15	13.8	3.34*	8.4
Number of house that could install the WEA (‘000)	119.7	272.9	167.6	114.9	52.7
Maximum possible savings (GL/year)	2.4	2.2	2.3	0.4*	0.4

*assuming that 2 taps per house are replaced

ENERGY AND GHG EMISSIONS

The carbon footprints of demand management options are difficult to quantify. In the following, to be consistent with the cost estimates, the ‘browning’ of a city due to water restriction will be neglected. Moreover, also the carbon footprint related to the 'advertisement' of water restrictions, e.g. notices of water restriction could be printed and posted to customers, will be neglected due to the absence of data.

As price management was not considered a viable option, its potential greenhouse gas emissions (or reduction in greenhouse emissions) will be neglected.

Water restrictions and water efficient appliances reduce water demand and, as less water needs to be pumped and treated, less energy will be consumed, resulting in a decrease in the total greenhouse gas emissions. However, this effect is already incorporated by the fact that, for example, less water needs to be pumped from the Murray River and the total emissions from this source will be reduced.

Reducing water demand can have two additional environmental benefits: less energy is required to heat the water (when hot water is needed) and less energy is required to treat the resulting wastewater. Because water restrictions are usually applied to outdoor uses, which usually do not require hot water and for which used water is not collected in the waste water system, these benefits will only be described in the case of water efficient appliances (Figure 15).

First, the water savings of the appliance need to be estimated. If the appliance uses or provides hot water, it is necessary to estimate how much hot water is used: for example, a shower will generally be used to provide hot water 100% of the time, but a tap can be open to have hot or cold water. It is also important to estimate at what temperature the water will be delivered, at what temperature the hot water heater is set and at what temperature the mains water is, so that it is possible to estimate how much energy is required for water heating. Note that assumptions on the efficiency of the water heater will be required. In order to convert this energy to greenhouse gas emissions it is necessary to estimate (or assume) which source of energy is used (in the case of domestic use, this is usually electrical energy or natural gas) and select the appropriate emission factor.

Once water has been used, it is collected and transported to a wastewater treatment plant. To estimate the GHG emission reduction caused by reduced water consumption, it is necessary to estimate the fraction of the water that will reach the treatment plant: for outdoor uses, like gardening, this percentage is close to zero, while it is 100% for toilet use. At this point, it is necessary to estimate how much energy and how many chemicals are used in the treatment plant and which energy source is used for the treatment process. Knowledge of the emission factor and the amount of energy needed for the treatment makes possible to compute the reduction in the GHG emissions.

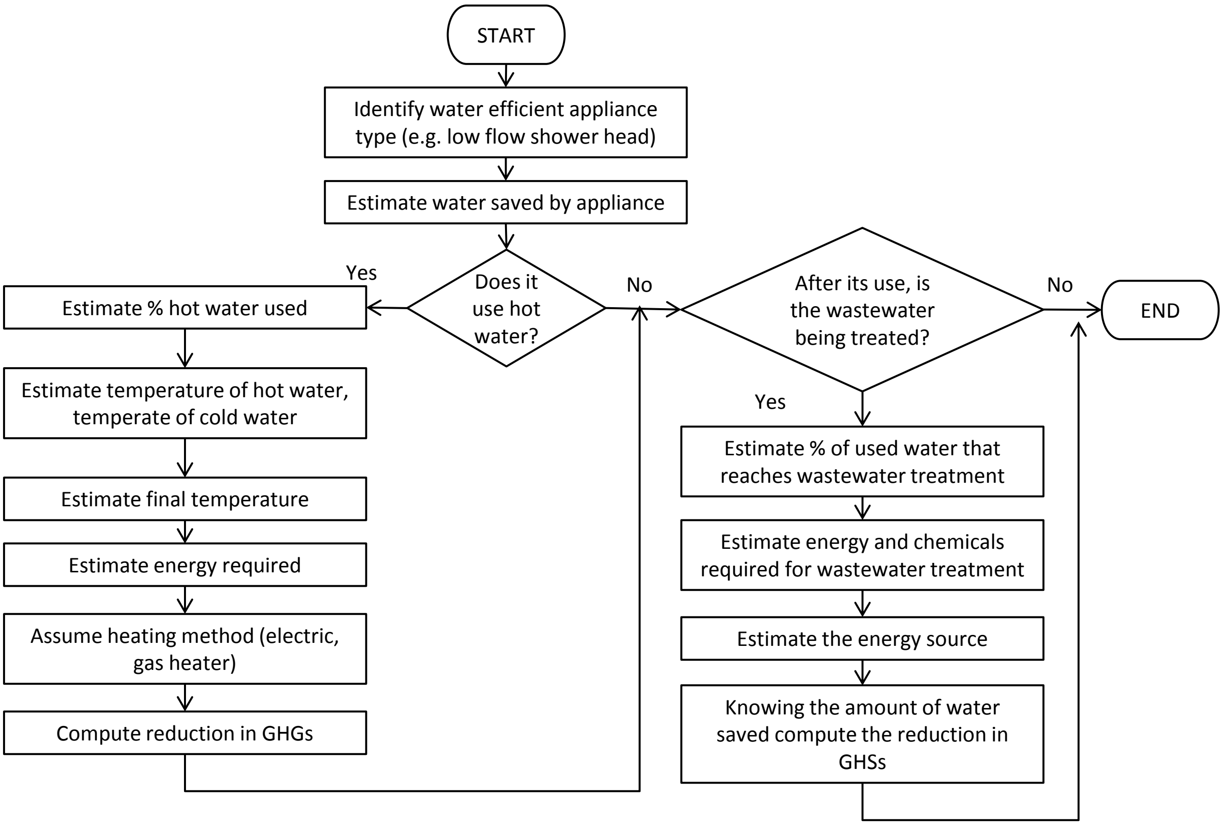


FIGURE 15: FLOWCHART FOR ESTIMATING THE CARBON FOOTPRINT REDUCTION DUE TO THE INTRODUCTION OF WATER EFFICIENT APPLIANCES.

Reduction of energy and GHGs for reduced water heating

As mentioned in the previous section, reducing the amount of water needed for indoor use has an additional benefit related to energy consumption inside the house. If less water is used for showering, less energy to heat the water will be used, resulting in a decrease in greenhouse gas emissions[1]. Note that, because outdoor use and some of the indoor uses do not require hot water, the carbon footprint of these uses will be considered equal to zero. This is because it is assumed that water efficient appliances will have similar embodied energy to non-water-efficient ones and that households will replace existing appliances in any case: the only choice is if the new appliance will be water efficient or not.

Kenway et al. (2008) report that water heating is responsible on average for 27% of the total residential emissions (Figure 16). Note also that the estimation of the GHG emissions depends on the source of energy considered. Appliances that use electrical energy are responsible for greater emissions, as there are larger losses in generation and transmission.

Hot water demands are influenced by flow rate, the number of people in the house, the type of appliances installed, but also by family income and cultural background. Moreover, energy

[1] Note that the reduction in energy consumption related to the decreased use of hot water has not been considered in the cost estimation.

consumption and related GHG emissions depend on fuel type, mains water temperature and the temperature set for the hot water, heater type and its efficiency rating and by water and heat losses. Hot water volume storage and its insulation also impact energy requirements.

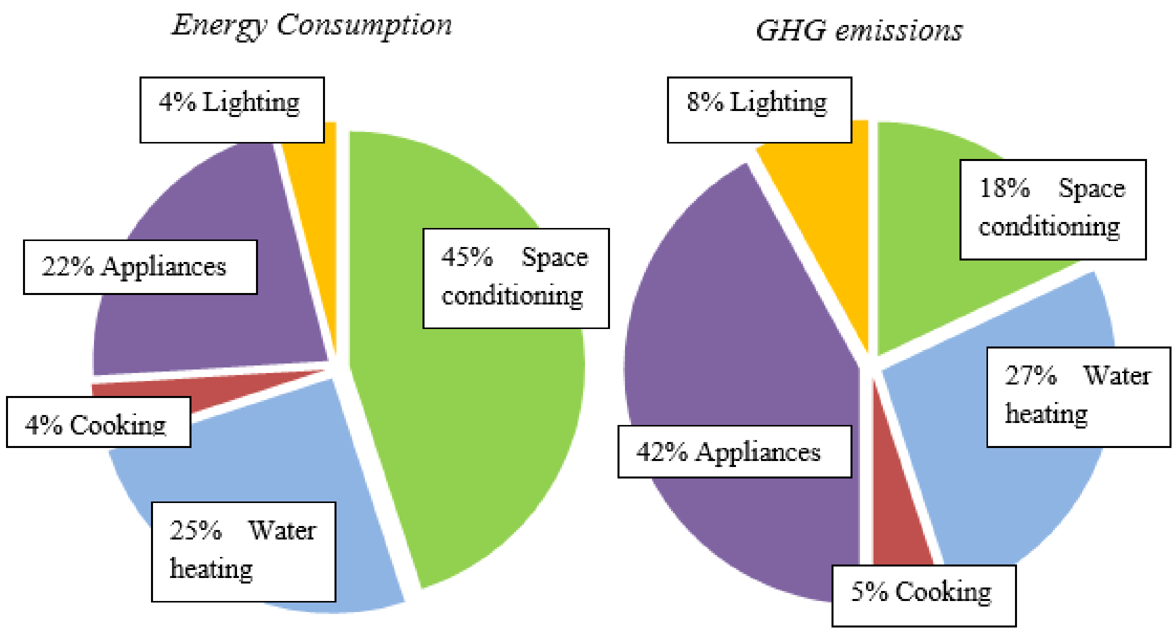


FIGURE 16: INDOOR RESIDENTIAL ENERGY CONSUMPTION AND GHG EMISSIONS PER SPECIFIC USE (FROM KENWAY ET AL. 2008).

The estimate of the energy savings related to the use of water efficient appliances is based on the estimate of the indoor water use. Kenway et al. (2008) based this assumption on the proportion of water for indoor use on data provided by utilities. As this information was not available, a mean of Sydney and Melbourne usage patterns was used. In particular, the indoor water consumption for each specific end use was based on the analysis from George Wilkenfield and Associates (GW&A) (2004). Assumptions about the percentage of water used by each end use are shown in Figure 17 (GWA, 2004) (see Table 45 for an example of the volumes of end-use demand requiring water heating).

Based on information supplied by Sustainability Victoria, Kenway et al. (2008) estimated the impact of two demand management strategies on residential water demand for hot water and associated energy and GHG emissions. Two scenarios (high and low water use) were analysed assuming three persons per household, 0.9 average daily showers per person over the year; hot water temperature of 60°C and cold water temperature of 15°C, shower temperature of 40°C (56% hot water). Note also that energy losses were not considered, thus energy usage was underestimated. However, it is assumed that the losses are equal for water efficient and non water-efficient systems.

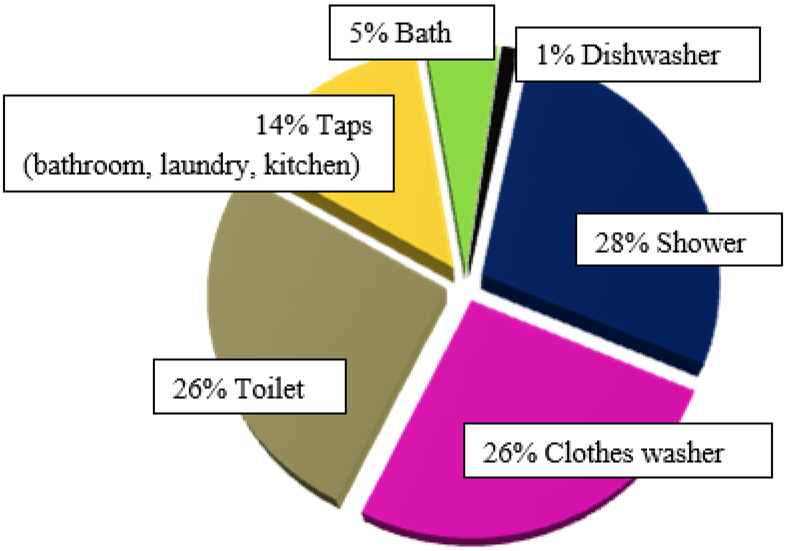


FIGURE 17: INDOOR RESIDENTIAL WATER DEMAND CONSUMPTION PER END USE (FROM KENWAY ET AL. 2008).

TABLE 45: VOLUMES OF COLD AND HOT WATER USED BY EACH APPLIANCE.

Appliance	Cold water (L/household/day)	Hot water (L/household/day)
Taps (kitchen, laundry, bathroom)	19	20
Shower	41	46
Bath	7	8
Clothes washer	61	15
Dishwasher	4	1
Toilet	78	-
Total	210	90

Results presented by Kenway et al. (2008) show that the use of WELS 3 Star roses for the shower (instead of normal ones) saves about 29.07 kWh/kL for each house (this is an average between the estimation of high and low water consumption behaviour). This would result in 22.96 kgCO_2-e/kL saved for an electric water heater. However, 50% of the houses in South Australia have a gas water heater (ABS, 2004).

The full cycle emissions of natural gas are 61.73 kgCO_2-e/GJ, equal to 0.22 kgCO_2-e/kWh (data from the Department of Climate Change and Energy Efficiency, 2012b). Note that the greenhouse gas emissions from scope 1 and scope 3 have been added. Gas water heaters have a lower emission factor than electricity (6.46 kgCO_2-e/kL) and, considering a proportion of gas-electricity water heaters equal to 50%-45% (ABS, 2004), their use results in an average emission savings equal to 14.28 kgCO_2-e/kL.

Kenway et al. (2008) also analysed the savings caused by the replacement of a top loader WELS 2-star washing machine with a WELS 4-star front loader washing machine. In this case, the energy savings amount to 254 kWh/year for a corresponding saving of 10 kL of water. This results in 25.4 kWh/kL and in 20.07 kgCO_2-e/kL saved.

Reductions in energy and GHGs from the installation of tap timers and low flow taps will not be estimated because of the lack of data and the variability of the water temperature for taps for different uses.

Reduction of GHGs for reduced wastewater treating

Reducing water demand will also cause a reduction in the volume of wastewater that has to be treated, with a further reduction in greenhouse gas emissions. In this case, it is assumed that 56% of saved water will not be treated (to account for the fact that only 56% of the water supplied ended up in the wastewater treatment in 2006-2007 - estimate from Kenway et al. data). It will be also considered that 0.69 kWh/kL are used for treatment (Kenway et al. 2008), resulting in 0.54 kgCO_2-e/kL. It has been decided to use a value lower than the one for the recycling option, because it is assumed that wastewater will be only treated and not recycled.

Therefore, for each option that decreases water usage, an emission factor equal to -0.54 kgCO_2-e/kL will be considered (or added to the previous emission savings).

Water restrictions reduce outdoor consumption: this is usually associated with cold water and, because a large part of outdoor use consists of watering the garden, the water does not reach wastewater treatment. Therefore, it is proposed to assume that they have no impact on energy or greenhouse gas emissions. If a high level water restrictions that also limit indoor water use are considered, the impact on energy and greenhouse gas emissions will need to be considered.

SUMMARY

Table 46 summarises the results of the water demand management options. Note the capital costs for water restriction is an average of the costs reported in Table 39 and that the values reported in brackets for the water efficient appliances refer to the design life (DL) of the appliance and WHS refers to the water savings per household.

Note that the negative sign of some emissions is caused by the fact that less wastewater needs to be treated and/or less water needs to be heated.

TABLE 46: SUMMARY OF COSTS AND VOLUMES OF WATER THAT CAN BE SAVED BY USING DEMAND MANAGEMENT OPTIONS.

Option	Capacity (GL/year)	Capital cost ($m/ML/year)	Operational cost ($/kL)
Water restrictions	10% of current total demand 20% of current total demand Advertising and administrative costs	$71/year per household $170/year per household $1.15m/year for water utility	-
Washing machines	2.4 (WSH: 20.2 kL/year/household)	$794/appliance (DL: 8 years)	-
Tap timers	2.2 (WSH: 8.15 kL/year/household)	$75/appliance (DL: 10 years)	-
Low flow showerheads	2.3 (WSH: 13.8 kL/year/household)	$76/appliance (DL: 10 years)	-
Low flow taps	0.4 (WSH: 3.34 kL/year/household – 2 appliances per house are installed)	$752 for 2 appliances (DL: 10 years)	-
Dual flush toilet	0.4 (WSH: 8.4 kL/year/household)	$753/appliance (DL: 10 years)	-

WSH: water savings per household; DL: design life

TABLE 47: SUMMARY OF ENERGY, GHGS AND VOLUMES OF WATER THAT CAN BE SAVED BY USING DEMAND MANAGEMENT OPTIONS.

Option	Capacity (GL/year)	Embodied energy (kWh/ ML/year)	Operational energy (MWh/ML)	Capital GHGs (tonnes CO_2-e/ ML/year)	Operational GHGs (tonnes CO_2-e/ML)
Water restrictions	8-32 GL/year (6%-24% of current demand)	-	0	-	0
Washing machines	2.4 (WSH: 20.2 kL/year/household)	-	-26.1	-	-20.61
Tap timers	2.2 (WSH: 8.15 kL/year/household)	-	-0.69	-	-0.54
Low flow showerheads	2.3 (WSH: 13.8 kL/year/household)	-	-29.76	-	-14.82
Low flow taps	0.4 (WSH: 3.34 kL/year/household – 2 appliances per house are installed)	-	-0.69	-	-0.54
Dual flush toilet	0.4 (WSH: 8.4 kL/year/household)	-	-0.69	-	-0.54

WSH: water savings per household; DL: design life

SUMMARY

In this report, a number of possible water sources to supply the Adelaide Region were analysed. In particular, the volume of water available, the capital and operating costs, energy and greenhouse gas emissions associated with each option have been estimated. These estimates are subject to uncertainty and depend on the specific conditions under which the supply option is implemented.

Table 48 and Table 49 provide a summary of the costs that are considered representative of the water supply sources examined. The energy and greenhouse gas emissions of these options are given in Table 50 and Table 51. It is important to note that these values are only estimates and the application of these options could be more or less expensive (or produce more or less GHGs) depending on the specific location of the option.

The purpose of this report was to provide data for the simulation model of the Greater Adelaide system being developed as part of the Goyder Institute's 'Optimal Water Resources Mix for Metropolitan Adelaide' (OWRM) Project. Although the sources could be ranked in terms of cost, energy and greenhouse gas emissions based on the data presented, that ranking will be carried out as part of the modelling and optimisation studies for the OWRM project as it depends on obtaining a mix of sources that best achieve the cost, energy, security of supply, environmental and social objectives defined for the study.

The following section describes the limitations and the uncertainties associated with the costs, energy and GHG emissions presented in this report.

LIMITATIONS

The only capital costs that are included in this study are the costs of new infrastructure. The capital costs of existing infrastructure (as of March 2013) are not included as this has been spent already and can't be recovered. Essentially it is a 'sunk cost'.

Operational costs have been included for both existing and new facilities. For existing infrastructure the operational costs consist only of operating costs. These operating costs depend on the volume of water that is supplied from these sources in the future. Ongoing maintenance costs for existing infrastructure will be incurred regardless of the new options chosen and so they has not been including in the cost analysis.

The new facilities that are considered in the study include new stormwater harvesting schemes, upgrades of wastewater treatment facilities and distribution networks for the treated stormwater and wastewater. Operational costs for new facilities include both operating and maintenance costs. Maintenance costs have been estimated as an average cost per kL produced rather than as a fixed cost per year. Hence they will be zero in any year that a facility has zero output. In reality there will be fixed maintenance costs unrelated to the volume of water produced and hence this may potentially lead to different optimisation outcomes. As it is unlikely that any facility will have zero output in future years, this error in estimation is acceptable given the other uncertainties in the cost estimates.

The exception is the Adelaide Desalination Plant that could be operated at low levels of output (after the initial proving period) in most years and will only be run at high levels of output during drought years. The assumed operating cost of the Adelaide desalination plant is $30m per year plus $1 /kL produced. Thus there is a fixed cost of $30m per year regardless of output. This is a constant that is included in the cost estimates of all options and so, does not make any difference to the choice between options.

The uncertainty in the results depends on a number of factors. All operational costs are affected by the assumed electricity tariff Assumptions have been made regarding the yield/capacity of the supply options and the capital and operational costs. Capital costs are affected by the uncertainty of the costs of implementing the option (e.g. implementing a stormwater reuse scheme in a specific location) and the uncertainty associated with the yield/capacity of the option. For example, costs and total water savings for the water distribution mains due to the use of rainwater tanks and demand management options are largely affected by the estimated number of houses that will adopt a rainwater tank (as well as its size) and the number of houses that will adopt a water efficient appliance (water savings in this case are also affected by the assumption related to the current water appliances). Note also that, even the yield of the most common sources such as the Mount Lofty Ranges are affected by some uncertainty related to the climate change.

It has to be noted that some options could affect each other, especially in relation to the amount of water that can be saved or provided. In this report, inter-relationships between the options have not been considered. For example, the estimate of water savings achievable using water efficient appliances and the water savings due to the use of rainwater tanks have been computed separately, considering only the effect of implementing the single option. However, adopting these two interventions together may reduce the total water savings in some cases: if the rainwater tank provides water for toilet flushing and laundry and, in addition, water-efficient appliances reduce the required volume, the extra water in the tank can be wasted if it is not needed for other uses. Another example is related to wastewater reuse: if water consumption is reduced, it is expected that the amount of wastewater that is available to be recycled will reduce. However, estimating these influences is difficult and subject to many additional uncertainties. Therefore, the costs and benefits of each option were considered separately.

In conclusion, all values reported in

Table 48 to Table 51 are subject to uncertainty. However, costs and energies for Mount Lofty Ranges, Murray River and Desalination plant are considered to be less affected as there is more information available and the references are more recent and from South Australia. Values reported for other water sources are affected by a larger uncertainty as

- values have been estimated using sources outside South Australia (e.g. wastewater reuse), or outside Australia (pump replacement costs)
- costs are largely affected by the capacity/yield of the intervention, which is difficult to estimate for the rainwater tanks and demand management options.
- costs and energy largely depend on the specific location of the construction, as do the stormwater reuse options, where space availability and geological and aquifer properties can limit the options available.

Other assumptions are clearly stated in the specific section of each water source. In order to give a qualitative estimate of the uncertainty associated with the values reported in

Table 48 to Table 51, the following classification is used:

- Values are considered to have *high reliability* (labelled with the superscript *h* in the following tables) if they are sourced from direct observation or estimated through the use of a calibrated model of the actual system.
- Values are considered to have a *medium reliability* (labelled with the superscript *m*) if they are based on observations or estimates made for closely related systems or developed from literature values from other systems, but there are multiple sources of information available.
- Values have a *low reliability* (labelled with the superscript *l*) if they are derived from literature values that have been developed for other systems and there is a single or only few sources available.

It would be possible to reduce the uncertainty associated with the costs, energy and GHG values reported in this work. However, whether it is worthwhile reducing this uncertainty and how much effort is required depends on the degree of uncertainty required in the results, how easy it is to reduce this uncertainty and on which water sources will be used predominantly.

Note that the degree of reliability associated with the values given in this report is considered to be acceptable given that the aim of the study is to demonstrate the framework developed in the project 'Optimal Water Resources Mix for Metropolitan Adelaide' rather than come up with specific recommendations for the Metropolitan system.

Table 48: Summary of costs and volume of water supplied/saved by different options.

Option	Capacity (GL/year)	Capital cost* ($'000/ML/year)	Operational cost ($/kL)
Water from Mount Lofty Ranges	121 (average year) [(h)] 30 (dry year) [(h)]	0**	0.24 [(h)]
Pumping from Murray River	130 (current entitlement) [(h)] +190 (additional pipe capacity) [(m)] 320 (in total) [(m)]	$13.96m every 20 years for pump replacement [(l)]	0.44 (for current entitlement) [(h)] 0.74 for each kL in excess of 130 GL/year (current entitlement) [(m)]
Desalination	100 [(h)]	$1.7m every 20 years for pump replacement [(l)]	$1.00/kL plus $30m per year [(h)]
Groundwater	3 [(l)]	$1.0/ML/year [(l)] + $0.12m every 20 years for pump replacement [(l)]	0.36 [(m)]
Stormwater: Wetland without ASR	48.8 Harvesting [(h)]	Values given in Table 15 [(h)]	
	48.8 Distribution [(h)]	($/ML/year)	
	Irrigation of public open space	18.9 [(l)]	0.45 [(l)]
	Greenfield third pipe system for non-potable use	42.1 [(l)]	0.88 [(l)]
	Brownfield third pipe system for non-potable use	64.1 [(l)]	0.88 [(l)]
	Blending with treated wastewater then greenfield third pipe system for non-potable use	30.6 [(l)]	0.81 [(l)]
	Blending with treated wastewater then brownfield third pipe system for non-potable use	52.6 [(l)]	0.81 [(l)]
	Transfer to reservoir for potable use	4.7 **** [(l)]	0.79 [(l)]

Option	Capacity (GL/year)	Capital cost* ($'000/ML/year)	Operational cost ($/kL)
Stormwater: Wetland with ASR	48.8 Harvesting [(h)]	Values given in Table 15	
	48.8 Distribution [(h)]	($/ML/year)	
	Irrigation of public open space	8.0 [(l)]	0.42 [(l)]
	Disinfection and irrigation of public open space	8.2 [(l)]	0.43 [(l)]
	Blending with treated wastewater and irrigation	6.6 [(l)]	0.63 [(l)]
	Greenfield third pipe system for non-potable use	27.9 [(l)]	0.69 [(l)]
	Brownfield third pipe system for non-potable use	49.9 [(l)]	0.69 [(l)]
	Blending with treated wastewater then greenfield third pipe system for non-potable use	24.5 [(l)]	0.70 [(l)]
	Blending with treated wastewater then brownfield third pipe system for non-potable use	46.4 [(l)]	0.70 [(l)]
	Direct injection for potable use	9.1 *** [(l)]	1.26 [(l)]
	Transfer to reservoir for potable use	5.6 **** [(l)]	0.94 [(l)]
	Treatment and transfer to reservoir for potable use	6.3 **** [(l)]	1.16 [(l)]

* unless otherwise specified.
** It is assumed that the capacity of Mount Lofty Ranges, Murray River and Desalination plant cannot will increased and therefore the embodied energy and capital emissions of this options are assumed to be equal to zero.
*** based on pipe length of 1 km
**** based on pipe length of about 11 km
WSH: water savings per household; DL: design life.
h, m, l: indicate high, medium and low reliability of the values, respectively.

TABLE 49: SUMMARY OF COSTS AND VOLUME OF WATER SUPPLIED/SAVED BY DIFFERENT OPTIONS (CONTINUED).

Option	Capacity (GL/year)	Capital cost ($'000/ML/year)	Operational cost ($/kL)
Wastewater reuse	98.55 *(h)*	20.3 *(l)*	2.00 *(l)*
Rainwater tanks (Design life: 25 years) (2kL tank)	2.9 for indoor & outdoor use (22 kL/year/tank) *(l)* 1.3 for outdoor use only (10 kL/year/tank) *(l)* (based on 2kL tank connected to 100m^2 roof)	139.4 -164.7 *(l)* ($3.0 – 3.6*10^3 /tank) for indoor & outdoor use *(h)* 164.0 – 254.4*(l)* ($1,6 – 2,5*10^3 /tank) for outdoor use only *(h)* 10% of the construction costs to be paid every 25 years. *(m)* Pump replacement ($355/pump) every 10 years *(m)*	$0.36/kL for indoor & outdoor use *(l)* $0.3/kL for outdoor use only *(l)* + $22/year for maintenance *(m)*
Rainwater tanks (Design life: 25 years) (5kL tank)	5.8 for indoor & outdoor use (44 kL/year/tank) *(l)* 2.5 for outdoor use only (19 kL/year/tank) *(l)* (based on 5kL tank connected to 100m^2 roof)	81.1 -93.8 *(l)* ($3.5 – 4.1*10^3 /tank) for indoor & outdoor use *(h)* 111.7 – 158.8 *(l)* ($2.1 – 3.0*10^3 /tank) for outdoor use only *(h)* 10% of the construction costs to be added every 25 years. *(m)* Pump replacement ($355/pump) every 10 years *(m)*	$0.36/kL for indoor & outdoor use *(l)* $0.30/kL for outdoor use only *(l)* + $22/year for maintenance *(m)*
Water restrictions	10% of current total demand *(l)* 20% of current total demand *(l)* Advertising costs	$71/year/ household *(l)* $170/year/household *(l)* $1.15m/year for water utility *(l)*	-
Washing machines	2.4 *(l)* (WSH: 20.2 kL/year/household) *(l)*	$794/appliance *(m)* (DL: 8 years)	-
Tap timers	2.2 *(l)* (WSH: 8.15 kL/year/household) *(l)*	$75/appliance *(m)* (DL: 10 years)	-
Low flow showerheads	2.3 *(l)* (WSH: 13.8 kL/year/household) *(l)*	$76/appliance *(m)* (DL: 10 years)	-
Low flow taps	0.4 *(l)* (WSH: 3.34 kL/year/household. Two appliances per house are installed) *(l)*	$752 for 2 appliances *(m)* (DL: 10 years)	-
Dual flush toilet	0.4 *(l)* (WSH: 8.4 kL/year/household) *(l)*	$753/appliance *(m)* (DL: 10 years)	-

(WSH: water savings per household; DL: design life.)
h, m, l: high, medium and low reliability of the values, respectively.

TABLE 50: SUMMARY OF ENERGY, GROSS GHGS AND VOLUME OF WATER SUPPLIED/SAVED BY DIFFERENT OPTIONS.

Option	Capacity (GL/year)	Embodied energy (MWh/ML/year) [Capital GHGs (tonnesCO2-e/ ML/year)]	Operational energy (MWh/ML) [Operational GHGs (tonnesCO2-e/ML)]
Water from Mount Lofty Ranges	121 (h) (average year) – 30 (dry year) (h)	0* [0]	0.3 (h) [0.24] (h)
Pumping from Murray River	130 (current entitlement) (h) +190 (pipe capacity) (m) 320 (in total) (m)	0* [0]	1.9 (h) [1.5] (h)
Desalination	100 (h)	0* [0]	5 (h) [4.29 (gross emissions) (h) 0.34 (m) (net emissions accounting for green energy)] (m)
Groundwater	3 (l)	Not estimated	1.2 (l) [0.95] (l)
Stormwater: Wetland without ASR	48.8 Harvesting (h)	5.131 (l) [1.502] (l)	
	48.8 Distribution (h)		
	Irrigation of public open space	7.746 (l) [5.958] (l)	0.27 (l) [0.22] (l)
	Greenfield third pipe system for non-potable use	30.772 (l) [23.655] (l)	0.61 (l) [0.49] (l)
	Brownfield third pipe system for non-potable use	30.772 (l) [23.655] (l)	0.61 (l) [0.49] (l)
	Blending with treated wastewater then greenfield third pipe system for non-potable use	29.612 (l) [23.151] (l)	0.76 (l) [0.60] (l)
	Blending with treated wastewater then brownfield third pipe system for non-potable use	29.612 (l) [23.151] (l)	0.76 (l) [0.60] (l)
	Transfer to reservoir for potable use***	4.006 *** (l) [4.070]*** (l)	1.04 (l) [0.83] (l)
	48.8 Harvesting (h)	5.131 (l) [1.502] (l)	

Option	Capacity (GL/year)	Embodied energy (MWh/ML/year) [Capital GHGs (tonnesCO2-e/ ML/year)]	Operational energy (MWh/ML) [Operational GHGs (tonnesCO2-e/ML)]
	48.8 Distribution (h)		
Stormwater: Wetland with ASR	Irrigation of public open space	3.257 (l) [3.702] (l)	0.63 (l) [0.50] (l)
	Disinfection and irrigation of public open space	3.257 (l) [3.702] (l)	0.63 (l) [0.50] (l)
	Blending with treated wastewater and irrigation	3.501 (l) [3.124] (l)	0.89 (l) [0.70] (l)
	Greenfield third pipe system for non-potable use	25.981 (l) [21.379] (l)	0.97 (l) [0.77] (l)
	Brownfield third pipe system for non-potable use	25.981 (l) [21.379] (l)	0.97 (l) [0.77] (l)
	Blending with treated wastewater then greenfield third pipe system for non-potable use	25.843 (l) [20.774] (l)	0.89 (l) [0.70] (l)
	Blending with treated wastewater then brownfield third pipe system for non-potable use	25.843 (l) [20.774] (l)	0.89 (l) [0.70] (l)
	Direct injection for potable use	0.437 (l) [1.475]** (l)	1.39 (l) [1.08] (l)
	Transfer to reservoir for potable use	5.008 (l) [5.158]*** (l)	1.35 (l) [1.06] (l)
	Treatment and transfer to reservoir for potable use	5.008 (l) [5.158]*** (l)	1.80 (l) [1.41] (l)

* It is assumed that the capacity of Mount Lofty Ranges, Murray River and Desalination plant cannot will increased and therefore the embodied energy and capital emissions of this options are assumed to be equal to zero.
** based on pipe length of 1 km
*** based on pipe length of about 11 km
h, *m*, *l*: indicate high, medium and low reliability of the values, respectively.

TABLE 51: SUMMARY OF ENERGY, GROSS GHGS AND VOLUME OF WATER SUPPLIED/SAVED BY DIFFERENT OPTIONS.

Option	Capacity (GL/year)	Embodied energy (MWh/ML/year) [Capital GHGs (tonnesCO_2-e/ ML/year)]	Operational energy (MWh/ML) [Operational GHGs (tonnesCO_2-e /ML)]
Wastewater reuse	98.55 (h)	Not Estimated [Not Estimated]	0.69 (m) [0.84] (m)
Rainwater tanks (Design life: 25 years) (2kL tank)	2.9 for indoor & outdoor use (l) (22 kL/year/tank) (l) 1.3 for outdoor use only (l) (10 kL/year/tank) (l)	61.632 for indoor & outdoor use (l) [48.689 for indoor & outdoor use] (l) 137.487 for outdoor use only (l) [108.615 for outdoor use only] (l) (1.333/tank) (h) [(1.0533 tonnesCO2-e/tank)] (h)	1.45 for indoor & outdoor use (l) [1.15 tonnesCO2-e/ML for indoor & outdoor water use] (l) 1.20 for outdoor use only (l) [0.95 tonnesCO2-e/ML for outdoor water use only] (l)
Rainwater tanks (Design life: 25 years) (5kL tank)	5.8 for indoor & outdoor use (l) (44 kL/year/tank) (l) 2.5 for outdoor use only (l) (19 kL/year/tank) (l)	54.924 for indoor& outdoor use (l) [43.390 for indoor & outdoor use] (l) 127.424 for outdoor use only (l) [100.665 for outdoor use only] (l) (2.417/tank) (h) [(1.909 tonnesCO_2-e/tank)] (h)	1.45 for indoor & outdoor use (l) [1.15 tonnesCO_2-e/ML for indoor & outdoor water use] (l) 1.20 for outdoor use only (l) [0.95 tonnesCO_2-e/ML for outdoor water use only] (l)
Water restrictions	10% of current total demand (l) 20% of current total demand (l) Advertising costs	Not Estimated [Not Estimated]	Not estimated [Not estimated]
Washing machines	2.4 (l) (WSH: 20.2 kL/year/household) (l)	Not Estimated [Not Estimated]	-26.1 (l) [-20.61] (l)
Tap timers	2.2 (l) (WSH: 8.15 kL/year/household) (l)	Not Estimated [Not Estimated]	-0.69 (l) [-0.54] (l)
Low flow showerheads	2.3 (l) (WSH: 13.8 kL/year/household) (l)	Not Estimated [Not Estimated]	-29.76 (l) [-14.82] (l)
Low flow taps	0.4 (l) (WSH: 3.34 kL/year/household – 2 appliances per house are installed) (l)	Not Estimated [Not Estimated]	-0.69 (l) [-0.54] (l)
Dual flush toilet	0.4 (l) (WSH: 8.4 kL/year/household) (l)	Not Estimated [Not Estimated]	-0.69 (l) [-0.54] (l)

WSH: water savings per household; DL: design life.
h, m, l: indicate high, medium and low reliability of the values, respectively.

REFERENCES

ABC News (2010). '$130m annual cost to run desal plant', http://www.abc.net.au/news/2010-12-01/130m-annual-cost-to-run-desal-plant/2358158 updated Wed Dec 1, 2010 12:51pm AEDT, accessed 15/11/2012.

ABS (2010). '4610.0 - Water Account, Australia, 2009-10.' http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/4610.0Chapter442009-10, last updated 24/9/2012, accessed 25/2/2013

ABS (2004). '4618.4 - Domestic Use of Water and Energy, South Australia, Oct 2004', Latest ISSUE Released at 11:30 AM (CANBERRA TIME) 14/04/2005, http://www.abs.gov.au/ausstats/abs@.nsf/0/86C76FD73C383272CA256FE20074B784?OpenDocument, accessed 21/2/2013.

ABS (Australian Bureau of Statistics) (2011a). 'Feature article: Household water consumption and conservation actions', 1345.4 – SA Stats, Jan 2011, http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/1345.4Feature%20Article1Jan%202011, accessed 10/1/2013.

ABS (2011b). '4130.0 - Housing Occupancy and Costs, 2009-10. Feature article: First home buyers in Australia', http://abs.gov.au/ausstats/abs@.nsf/Latestproducts/4130.0Feature %20Article12009-10?opendocument&tabname=Summary&prodno=4130.0&issue=2009-10&num=&view=, accessed on 10/1/2013.

ABS (Australian Bureau of Statistics) (2013). 'Using the CPI', http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/6440.0Main+Features302011, last accessed 31/5/2013.

ABS Census (2011). '1022 Census quick stats', http://www.censusdata.abs.gov.au/ census_services/getproduct/census/2011/quickstat/4gade, accessed 11/1/2013.

Alcorn A., and Wood, P. (1998). 'New Zealand building materials embodied energy coefficients database, Volume II – Coefficients. Appendix A.', Centre for Building Performance Research, Victoria University of Wellington. Report prepared for the Building Research Association of New Zealand, Wellington, November.

Ambrose, M.D., Salomonsson, G.D. and Burn, S. (2002). 'Piping Systems embodied energy analysis.' CSIRO, October.

ANRA (Australia Natural Resources Topic) (2009). 'Water resources - Overview - South Australia', http://www.anra.gov.au/topics/water/overview/sa/index.html, last updated 13/5/2009, accessed 6/12/2012.

Arup (2012). 'Adelaide desalination plant transfer pipeline system', http://www.arup.com/Home/Projects/Adelaide_Desalination_Plant_Transfer_Pipeline_System.aspx, accessed 4/12/2012.

ATSE (2012). 'Sustainable water management – Securing Australia's future in a green economy', Australian Academy of Technological Sciences and Engineering.

Australian Government (2012). 'Glenelg to Adelaide Park Lands water recycling project', http://www.environment.gov.au/water/policy-programs/urban-water-desalination/glenelg-adelaide-project.html, last updated 29/7/2011, last accessed 17/7/2013.

Australian Greenhouse Office AGO, (2006). 'AGO Factors and methods workbooks, Australian Greenhouse Office, Department of the Environment and Heritage, December

Baulis, J., Lloyd, L., Paton, F. and Staniford, B. (2008). ‘Multi-Objective Optimisation of Urban Water Supply Systems at the Regional Scale Incorporating Sustainability’, Final report, The School of Civil, Environmental and Mining Engineering, The University of Adelaide, October.

Biswas W.K. (2009). ‘Life cycle assessment of seawater desalination in Western Australia’, World Academy of Science, Engineering and Technology 56, 369-375.

BlueScope Steel Australia, (2002) ‘Rainwater Tanks Ease Pressure On State Water Supplies’, http://www.bluescopesteel.com.au/go/news/rainwater-tanks-ease-pressure-on-state-water-supplies, 30 September, accessed 15/11/2012.

Bunnings warehouse (2013). http://www.bunnings.com.au/products_category_watering-devices_1593.aspx?filter=categoryname--Tap+Timers&page=3, accessed on 11/1/2013.

Chalmers L., and Gray S. (2004). ‘Stormwater management manual for Western Australia: Structural Controls’, Department of Environment, February.

Chong J., Herriman, J., and White S. (2009). ‘Review of water restrictions’, prepared by Sustainable Futures and ACIL Tasman Pty Ltd for National Water Commission, Commonwealth of Australia.

City of Salisbury. (2003). ‘Stormwater harvesting and utilisation in the City of Salisbury.’

Commonwealth of Australia (Department of Industry, Innovation, Climate Change, Science , Research and Tertiary Education) (2013) Carbon Neutral Program Guidelines, National Carbon Offset Standard , ISBN 978-1-921299-02-5, June 2013.

Coombes P.J. and Kuczera G. (2003). ‘Analysis of the performance of rainwater tanks in Australian capital cities’, 28th International Hydrology and Water Resources Symposium, 10-14 November, Wollongong NSW, The Institution of Engineers, Australia.

Dandy, G. (1992). ‘Assessing the economic cost of restrictions on outdoor water use.’ Water Resources Research, 28(7), 1759-1766.

Dandy G., Nguyen T. and Davies C. (1997). ‘Estimating residential water demand in the presence of free allowances’, Land Economics, 73(1), 125-139.

Dandy, G.C., Ganji, A., Kandulu, J., Hatton MacDonald, D., Marchi, A., Maier, H. and Schmidt, C. E. (2013). ‘Managed Aquifer Recharge and Stormwater Use Options: Net Benefits Report’, Goyder Institute for Water Research. MARSUO Project Final Report.

Department of Climate Change and Energy Efficiency (2012a).’National greenhouse and energy reporting system measurement’, Australian Government, July

Department of Climate Change and Energy Efficiency (2012b). ‘Australian national greenhouse accounts’, Australian Government, July

Department of Planning and Local Government (2010). ‘Water sensitive urban design technical manual for the greater Adelaide region’, Government of South Australia, Adelaide.

Dillon P., Pavelic P., Page D., Beringen H., and Ward J. (2009). ‘Managed aquifer recharge: An introduction’, Waterlines Report Series No, 13, February 2009, work undertaken by the CSIRO on behalf of the National Water Commission.

Dolnicar S. and Hurlimann A. (2010). ‘Australian’s water conservation behaviours and attitudes,’ Australian Journal of Water Resources, 14 (1), 43-53.

DWLBC report (2008). ‘Adelaide metropolitan area groundwater modelling project’, department of Water, Land and Biodiversity Conservation, Government of South Australia, May.

Farrell, D. and Caica, P. (2011). ‘ Southern suburbs tap into recycled water’, DF11/024, 27 June.

Fearnside, P. M. (2002). ‘Time preference in global warming calculations: A proposal for a unified index.’ Ecol. Econ., 41(1), 21–31

Gaudin S. (2006). ‘Effect of price information on residential water demand’, Appl. Econ., 38, 383-393.

Government of South Australia. (2004) ‘Water Proofing Adelaide. Exploring the issues - a discussion paper’, Government of South Australia, Action Salinity & Water Australia and WaterCare it’s in your hands.

Government of South Australia and SA Water (2013). 'Save water in your home overview', http://www.sawater.com.au/sawater/yourhome/savewaterinyourhome/, last updated 15/11/2012, last accessed 7/1/2013.

GW&A (2004). 'Regulation Impact Statement: Proposed National System of Mandatory Water Efficiency Labelling and Standards for Selected Products.' Department of the Environment and Heritage, Australia

Harvey Norman (2013). http://www.harveynorman.com.au/appliances/kitchen-bbq/sinks-taps, accessed 11/1/2013.

Hoang, M., Bolto, B., Haskard, C., Barron, O., Gray, S. and Leslie, G. (2009). 'Desalination in Australia', CSIRO, Water for a Healthy Country Flagship Report series ISSN: 1835-095X.

Kaczan D., Qureshi M.E. and Connor J. (2011). 'A summary of water trade and price data for the southern Marray-Darling Basin', CSIRO: Water for a Healthy Country National Research Flagship, Canberra. 20 pp.

Kenway, S.J., Priestley, A., Cook, S., Seo, S., Inman, M., Gregory A. and Hall, M. (2008). 'Energy use in the provision and consumption of urban water in Australia and New Zealand.' CSIRO: Water for a Healthy Country National Research Flagship, December.

Kuczera G., and Ng W.S. (1994). ' Use of economic losses due to restrictions in water supply headworks planning.' Water Down Under '94, Adelaide, Australia, 21-25 November.

Lane A., Ling R., Murphy C., Usher I.B., Thyer M.A. and Dandy G.C. (2012a). 'Optimum use of subsidies for reducing domestic water consumption', OzWater'12, 8-10 May, Sydney.

Lane A., Ling R., Murphy C., Usher I.B., Thyer M.A. and Dandy G.C. (2012b). ' Optimum use of subsidies for reducing domestic water consumption', Final report, The School of Civil, Environmental and Mining Engineering, The University of Adelaide, October.

Leslie, G. (2007). ' Developing alternative urban water supplies,' IEAust Sth Highlands Division Mittagong, October 25

Lyndsie Mewett (2010). 'Water pipelines: drought proofing down under', The Australian Pipeliner, January, http://pipeliner.com.au/news/water_pipelines_drought_proofing_ down_under/012068/, accessed 16/11/2012.

Marsden Jacob Associates (2004). 'Estimation of long run marginal cost (LRMC)', prepared for the Queensland Competition Authority, 3 November.

Marsden Jacob Associates (2006a). 'Securing Australia's Urban Water Supply: Research notes for selected case studies', Research notes prepared for Department of the Prime Minister and Cabinet, 20 November.

Marsden Jacob Associates (2006b).'Securing Australia's urban water suppliers: opportunities and impediments', Department of Prime Minister and Cabinet, Australian Government, November.

Marsden Jacobs Associates (2007). 'Cost effectiveness of rainwater tanks in urban Australia' Waterlines series, National Water Commission, March.

Marsden Jacobs Associates (2009). 'The cost effectiveness of residential rainwater tanks in Perth', report prepared for Water Corporation and the Department of Water, April.

McGivney, W.T., and Kawamura, S. (2008). 'Cost Estimating manual for Water treatment facilities', John Wiley & Sons, Inc. 205 pp.

Mrayed, S. and Leslie, G. (2009). 'Examination of Greenhouse footprint for both Desalination and Water recycling processes', Ozwater09. Melbourne, Australia, 2009.

Narayanan, R., Larson, D.T., and Hughes, T.C. (1985). 'Effectiveness of drought policies for municipal water management', Water Resour. Bull., 21(3), 407-416.

National Water Commission, (2010). 'National Performance Report 2009–10_Part B Urban water utilities', Australian Government.

National Water Commission (2011). 'Australian water markets report 2010-11', Australian Governement, http://archive.nwc.gov.au/library/topic/markets/australian-water-markets-report-2010-11, accessed 11/2/2013.

National Water Commission (2013). 'National performance report 2011-12. Urban water utilities', Australian Government, National Water Commission. March. Data from Part B, downloaded from http://www.nwc.gov.au/publications/topic/nprs/urban-2011-2012 on 19/7/2013.

Olmstead S.M., Hanemann W.M., and Stavins R.N. (2007) 'Water demand under alternative price structures', J. Environ. Econ. Manage., 54(2), 181-198.

Olmstead S.M., and Stavins R.N. (2008) 'Comparing price and non-price approaches to urban water conservation', NRM Natural Resources Management, downloadable from http://www.feem.it/Feem/Pub/Publications/WPapers/default.htm

Philp M., McMahon J., Heyenga S., Marinoni O., Jenkins G., Maheepala S. and Greenway M. (2008). 'Review of stormwater harvesting practices', October, Urban Water Security Research Alliance, Technical Report No. 9.

PMSEIC (Prime Minister's Science, Engineering and Innovation Council) (2003). 'Recycling water for our cities', 28 November.

PMSEIC (Prime Minister's Science, Engineering and Innovation Council) (2007). 'Water for our cities: building resilience in a climate of uncertainty', June.

Pullen, S.F. (1999). 'Consideration of Environmental Issues when Renewing Facilities and Infrastructure.' 8th International Conference on Durability of Building Materials and Components, Vancouver, June.

Rain Tank Analyser (2009) 'raintankBETAv2', Division of Information Technology, Engineering and the Environment University of South Australia, http://w3.unisa.edu.au/water/uwrg/publication/ raintankanalyser.asp, last updated 7 September 2009, last accessed 7/2/2013)

Retamal M., Glassmire J., Abeysuriya K., Turner A. and White S. (2009) 'The water-energy nexus: Investigation into the energy implications of household rainwater systems', prepared for CSIRO, Institute for Sustainable Futures, University of Technology, Sydney.

SA Water (2011). 'Allowable pipe size, class and materials for water mains,' Technical Guideline TG 105, September.

SA Water (2012). 'North South Connection - Frequently Asked Questions', http://www.sawater.com.au/SAWater/WhatsNew/MajorProjects/NSISP/nsisp_faq.htm, last updated 24/10/2012, accessed 4/12/2012.

SA Water and Government of South Australia (2012). 'Adelaide Airport Stormwater scheme', http://www.sawater.com.au/SAWater/WhatsNew/MajorProjects/AdelAirportStorm water Scheme.htm, last updated 7, 11/2012, accessed 12/11/2012.

South Australian Water Corporation (2011). 'Annual Report for the year ending 30 June 2011', South Australia Government.

South Australian Water Corporation (2012). 'Annual Report for the year ending 30 June 2012, SA Water and South Australia Government.

Sustainable Focus and Clark (2008). 'Report on sustainable water options for Adelaide.' Sustainable Focus Pty Ltd, September.

The Australian Pipeliner (2009). 'Glenelg to Adelaide: watering the Park Lands', http://pipeliner.com.au/news/glenelg_to_adelaide_watering_the_park_lands/008216/, October, accessed 16/11/2012.

Tam., V.W.Y., Tam., L. & Zeng, S.X. (2010). 'Cost effectiveness and tradeoff on the use of rainwater tank: An empirical study in Australian residential decision-making‟, Resources, Conservation and Recycling, vol. 54, pp. 178-186.

Thyer M.A., Duncan H., Coombes P., Kuczera G., Micevski T. (2009). 'Probabilistic Behavioural Approach for the Dynamic Modelling of Indoor Household Water Use', 32nd Hydrology and Water Resources Symposium. Newcastle, Australia

Treloar, G.J., Love, P.E.D., and Crawford, R.H. (2004). 'Hybrid life-cycle inventory for road construction and use.' Journal of Construction Engineering and Management, 130(1), 4-49.

Turner A., Retamal M., White S., Palfreeman L. and Panikkar A. (2010). 'Third Party Evaluation of Wide Bay Water Smart Metering and Sustainable Water Pricing Initiative Project', Report prepared by the Snowy

Mountains Engineering Corporation in association with the Institute for Sustainable Futures, UTS, for the Department of the Environment, Water, Heritage and the Arts, Canberra.

Turvey, R. (2001). ‘Annex A: Some comments on OFWAT’s long run marginal costs paper’, Found at: http://www.ofwat.gov.uk/regulating/reporting/pap_tec_lrmcannexa.pdf, accessed 11/7/2013.

Twort, A.C., Ratnayaka, D.D. and Brandt, M.J. (2000). ‘Water Supply.’ 5th Edition, Butterworth-Heinemann.

Wallbridge & Gilber (2009). ‘Urban Stormwater Harvesting Options Study C081266’, document prepared for Government of South Australia – Stormwater Management Authority.

Ward J. and Dillon P. (2011). ‘Robust policy design for managed aquifer recharge,’ Waterlines Report Series, No 38, January.

Water for Good (2010). ‘Water for Good. A plan to ensure our water future to 2050’, Government of South Australia.

Water for Good (2012). ‘South Australia is a nation leader in recycling wastewater’, Government of South Australia, http://www.waterforgood.sa.gov.au/stormwater-wastewater/wastewater/, last updated 15/11/2012, accessed 16/11/2012.

Water Services Association of Australia (2009). ‘Meeting Australia’s water challenges – Case studies in commercial and industrial water savings,’ Occasional Paper No. 23, July.

Weatherill J. (Premier), Snelling J. (Hon) and Caica P. (Hon) (2012). ‘New water prices for 2012-2013,’ News Release, Government of South Australia, 21 May.

Wilkinson, R.C. (2007). ‘Analysis of the energy intensity of water supply for West Basin municipal water district,’ West Basin Municipal Water District, March.

APPENDIX A: OTHER METHODS TO COMPUTE THE COST OF WATER SUPPLY

Net present value is one of the possible ways to compute the total costs of a water supply option: in this case operational and maintenance costs during the design life of the project are discounted back to present value using the discount rate (Figure 3). The total present value of cost is then computed by adding the present value of operational and maintenance cost to the present value of capital cost.

If the capital costs are spread uniformly throughout the design life of the project as shown in Figure 4b, it is possible to compute the levelised cost.

Levelised cost is a measure of the total cost of a system per unit of output. For a water source, the levelised cost may be determined by computing the total annual cost (defined as the amortised capital cost plus the annual operations, maintenance, replacement and repair costs) and dividing by the annual output of the system. i.e.

$$L = (C^{*}crf + O + M + R) / Q \qquad \text{(A1)}$$

where L = levelised cost ($/kL), C = present value of capital cost ($), O = annual operating cost ($), M = annual maintenance cost ($), R = annual cost of replacements and repairs ($)

Q = annual output (kL), crf = the capital recovery factor for a discount rate of i % p.a. and a project life of n years

$$crf = i / [1 - (1+i)^{-n}] \qquad \text{(A2)}$$

In addition to levelised costs, there are also other methods for assessing the economic cost of water supply. The marginal cost measures the cost increase (or decrease) associated with the production of an additional unit of water (or with the decrease in production by one unit) when all other services are constant. The use of the marginal cost for the water industry has the following drawbacks (Marsden Jacob Associates, 2004): i) the water industry has substantial fixed costs and economies of scale that are not reflected by the marginal cost; ii) marginal costs are not stable in the short term: they fall to a small value after the construction of a facility that increases the capacity and rise again when the capacity is exhausted; iii) several alternative ways exist to compute the marginal cost.

Long run and short run marginal costs can be computed. Long run marginal costs (LRMC) relate to the time horizon where all costs are variable (e.g. the planning horizon, the average life of assets, the time period until a new expansion is needed to meet demand). On the other hand, for short run marginal costs (SRMC) the system capacity is fixed. LRMC is explained by the following quotation from Turvey (2001).

'*The term LRMC is used to signify the cost effect of a change which involves some alteration in the amount or timing of future investment. SRMC, on the other hand, takes capacity as given, so relates only to changes in operating costs for example when the transport of additional water requires only additional pumping costs*.'

Marsen Jacob Associates (2006b) report that the levelised cost of water supply in Adelaide is 1.54$/kL (equal to $1.84/kL if inflated to 2013): this cost takes into account the concept of efficiency cost or by-pass price (therefore it includes the capital asset of the water utility) and has been estimated based on a uniform 6% p.a. rate of return. It has to be noted that the long run marginal cost, i.e. the cost of providing additional resources, is much larger than the full cost estimated by Marsen Jacob Associates (2006). Lane et al. (2012a) report that the long run marginal cost of providing potable water is $2.40/kL ($2.43 in $2013) as significant capital investment is necessary.

For comparison, the operating costs for Adelaide from 2006-07 to 2011-2012 are reported in Table 52 (data from the National Water Commission, 2013). The increasing cost per kL is caused by increased energy cost and by the increased amount of water pumped from the Murray River during the drought in 2003-2009.

The operating costs in 2011-2012 amounted to $1.14/kL. This value has been inflated using the consumer price indexes (CPIs) (Appendix D). The operating costs of supplying water in 2013 dollars are estimated to be $1.15/kL.

TABLE 52: OPERATING COSTS IN ADELAIDE (NATIONAL WATER COMMISSION, 2013) FOR ADELAIDE

Indicator	2006–07	2007–08	2008–09	2009–10	2010-11	2011-12
Operating cost—water ($/property)	233	228	295	265	249	293
Total connected properties—water supply (000s)	504	510	517	524	532	537
Total operating cost ($m)	117.025	116.430	152.341	138.758	132.598	157.270
Total urban water supplied* (ML)	159,477	140,923	139,129	125,800	124,777	138,411
Operating costs ($/kL)	0.73	0.83	1.09	1.10	1.06	1.14

* including residential, commercial, municipal, industrial and other uses.

APPENDIX B: GREENHOUSE GAS EMISSIONS

DEFINITION OF SCOPE 1, 2 AND 3 EMISSIONS

One aspect of the environmental impact of the different water supply options can be estimated by considering the greenhouse gas (GHG) emissions due to the construction and operation of water supply and distribution systems. The Department of Climate Change and Energy Efficiency of the Australian Government (2012a) publishes guidelines to estimate the greenhouse gas emissions of Australian facilities. The *Australian national greenhouse gas accounts* (Department of Climate Change and Energy Efficiency, 2012b) separates the GHG emissions into *direct* and *indirect* emissions. Direct emissions are a result of an organisation's activity and are produced from sources within the boundary of the organisation itself. Indirect emissions are produced by activities of other organisations: for example, the transport of a good to its final consumers is an indirect emission for the company that produced the good.

As emission factors depend on the specific activity, different *scopes* of emission factors exist. These include:

- *scope 1 emission factors* give the mass of carbon dioxide equivalent (kgCO_2-e) emitted per unit of activity at the point of emission release. For example, the GHG emission factor of fuel use and manufacturing process activities is computed using scope 1 emission factors.

- *scope 2 emission factors* give the mass of CO_2-e emitted from the generation of electricity purchased and consumed per unit of electricity consumed. 'Scope 2 emissions result from the combustion of fuel to generate the electricity, steam or heat and do not include emissions associated with the production of fuel. Scopes 1 and 2 are carefully defined to ensure that two or more organisations do not report the same emissions in the same scope' (Australian Greenhouse Office AGO, 2006).

- *scope 3 emission factors* give the mass of CO_2-e related to the extraction, production and transport of fossil fuel that will be burnt by an organisation, and to the consumption of purchased electricity. In this last case the scope 3 emission factors account for the losses in the electricity distribution network. More broadly, scope 3 emission factors include the disposal of waste generated, the use of products manufactured and sold, the disposal (end of life) of products sold and employee business travel (AGO, 2006).

With reference to the greenhouse gas emissions of electricity consumption, scope 1 emission factors account for the extraction and transport of source material; scope 2 emission factors account for the generation of electricity and scope 3 emission factors account for the transport of electricity and the losses that occur during this transport. The addition of scope 2 and scope 3 emission factors represents the emissions associated with the whole process, i.e. generation + transport.

In this report, the carbon footprint of each water supply option will be computed considering the average value for full cycle emissions for South Australia, i.e. 0.79 kgCO_2-e/kWh (scope 2 + scope 3). Emission factors related to the purchase of energy for South Australia are reported in Table 53 (data from the Department of Climate Change and Energy Efficiency (2012b)). It should be noted that, although the National Greenhouse and Energy Reporting System Measurement (NGER) (Department of Climate Change and Energy Efficiency, 2012a) requires to use the average emission factor for the State to convert renewable energy to GHGs, the purchase of GreenPower™ and the voluntary cancellation of Renewable Energy Certificates (RECs) generated by accredited GreenPower™ generators is considered to be equivalent to the direct use of renewable energy under the National Carbon Offset Standard Carbon Neutral Program (Australian Government, 2011). Therefore, although under the NGER system the gross emissions have to be reported, SA Water can deduct the portion of Scope 2 electricity emissions equivalent to the amount of green power purchased, so as to calculate a net carbon footprint (L. Perrin, SA Water, Pers. Comm., 22 May 2013). In general, in this report, gross emissions will be calculated.

TABLE 53: GHG EMISSION FACTORS FOR PURCHASED ELECTRICITY FOR SOUTH AUSTRALIA (DEPARTMENT OF CLIMATE CHANGE AND ENERGY EFFICIENCY, 2012B)

Financial year	EF for scope 2 (kgCO_2-e/kWh)	EF for scope 3 (kgCO_2-e/kWh)	Full fuel cycle EF (EF for scope 2 + EF for scope 3) (kgCO_2-e/kWh)
2007/08	0.77	0.12	0.89
2008/09	0.72	0.14	0.85
2009/10	0.67	0.14	0.81
Latest estimate*	0.65	0.14	0.79

*presumably for 2010/11

CAPITAL AND OPERATIONAL GHGS

In an analogous way to costs, greenhouse gas emissions can be divided into capital and operational GHGs. In this report, operational GHGs are mainly associated with the use of energy (mainly electricity) and chemicals. Note that, unless otherwise reported, GHGs caused by the use of chemicals will be neglected.

Capital GHGs are caused by the construction of civil works. For example, in the construction of a pipe system, GHGs are emitted during the constructions of the pipe (extraction of the raw material and pipe production) and by the transport and installation of the pipe. Also maintenance generates GHGs: for example, the replacement of a pipe will require a new pipe to be produced, transported and installed.

Analogously to the capital cost analysis, the capital GHG emissions caused by the construction of existing infrastructure will not be considered. GHG emissions caused by the construction of different water supply options will be presented as capital GHGs based on the capacity of the facility

The discount rate i_g used to compute the net present value of the GHGs has usually a lower value than the discount rate adopted for the cost. In this project, i_g will be assumed to equal zero, so as to take into account that GHG emissions that occur in the future do not have a lower impact than emissions at the current time. This value is recommended by the Intergovernmental Panel on Climate Change (IPCC) (Fearnside 2002). Therefore, to compute the present value of the operational GHGs, the operational GHGs will be simply multiplied by the number of years, $n_g = 25$ years.

Estimating capital, operating and maintenance greenhouse gas emissions is complicated, as it is difficult to estimate the embodied energy of some water systems' components (e.g. how much energy has been used to produce a pump) and because GHGs depend on the specific type of manufacturing process used (e.g some manufacturer could have more energy efficient processes so as to have lower embodied energy in their products). In addition, it is very difficult to estimate the emissions due to the transport of the material: for example, the pipe could be installed in the same city where it has been produced or in another country. Finally, there are uncertainties related with the estimation of the timing of maintenance. In this report, capital GHGs caused by pump installation and replacement will not be estimated.

SA Water is required to estimate its direct emissions and energy use under the Commonwealth Government's National Greenhouse and Energy Reporting System. However, only the total GHG emissions are publicly available[2]. Table 54 gives the greenhouse gas emissions for SA Water (data refer to the 15 of January 2013).

More information is contained in SA Water's Annual report (South Australian Water Corporation, 2012), where scope 1, 2 and 3 emissions are specified by facility (Table 56). It has to be noted that scope 1 emissions in Table 56 represent the direct emissions from fuel burning and fugitive emission sources, scope 2 emissions are caused by the consumption of electricity and scope 3 emissions are related to other indirect emissions caused by SA Water's activities, such as electricity transmission losses, some outsourced activities and emissions embodied in the products and services that SA Water purchases.

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[2] Data available from http://www.cleanenergyregulator.gov.au/National-Greenhouse-and-Energy-Reporting/ published-information/greenhouse-and-energy-information/Greenhouse-and-Energy-information-2010-2011/Pages/default.aspx#3, accessed on 30/1/2013

Table 56 also reports the decrease of emissions due to bio-sequestration, the production of energy using renewable resources and the purchase of renewable energy certificates (RECS). These interventions decrease CO_2 emissions, but, for comparison with the other options, an estimate of the GHGs without taking into account these GHG offsets will be presented.

TABLE 54: 2010-2011 GREENHOUSE AND ENERGY INFORMATION[3].

Registered Corporations	Total scope 1 greenhouse gas emissions(t CO_2-e)	Total scope 2 greenhouse gas emissions(t CO_2-e)	Total energy consumption (GJ)
South Australian Water Corporation	60,791	192,357	1,511,020

TABLE 55: GREENHOUSE GAS EMISSIONS (T CO2-E) IN 2011-2012 FOR SA WATER (SOUTH AUSTRALIAN WATER CORPORATION, 2012)

Facility	Scope 1 emissions	Scope 2 emissions	Scope 3 emissions	Total emissions 2011-12
SA Water corporate and aggregates	14,347	4,359	3,912	22,620
Non metropolitan water pumping and networks	110	124,363	26,869	151,343
Country WWTP	8,219	9,612	6,263	24,095
Metropolitan water treatment and networks	969	16,317	24,147	41,254
Bolivar WWTP	29,912	24,191	4,661	58,765
Glenelg WWTP	3,940	2,525	486	6,953
Christies Beach WWTP	3,377	5,600	6,102	15,080
Aldinga WWTP	585	1,443	328	2,357
Adelaide Desalination Project	3,563	14,180	78,377	96,121
Country outsourced facilities			5843	5843
Chemicals			13,165	13,165
Gross emissions	**65,025**	**202,415**	**174,670**	**442,243**
Catchment buffer zones and land holdings (Bio-sequestration)				-7,952
GreenPower and RECS				-31,795
Carbon offsets				n/a
Equivalent net emissions				**402,496**

[3] Data available from http://www.cleanenergyregulator.gov.au/National-Greenhouse-and-Energy-Reporting/ published-information/greenhouse-and-energy-information/Greenhouse-and-Energy-information-2010-2011/Pages/default.aspx#3, accessed on 30/1/2013

APPENDIX C: METHODOLOGY TO ESTIMATE COSTS, ENERGY AND GROSS GREENHOUSE GAS EMISSIONS

Several sets of data are necessary to estimate the costs, energy and gross GHG emissions of different options. Therefore, as shown in Figure 18, it is necessary to estimate five values: capital and operational costs, embodied and operational energy and the volume of water that the option is able to produce. Energy values can be converted in GHG emissions by simply multiply the energy by the emission factor of that energy source. Note also that, to compute the net present value, it is necessary to estimate the time horizon over which the option will be evaluated and the discount factor to be used. However, these values are usually assumed to be equal for all options.

CAPITAL COSTS

To estimate the capital costs of a water supply option it has to be decided if new facilities have to be built or existing facilities have to be upgraded. For example, if a new stormwater scheme is built, the capital costs include the cost associated with the harvesting of the stormwater and its storage, but it could also require the upgrade of water treatment facilities and the pipe infrastructure.

Therefore it is important to estimate the capital costs of the new facilities required and the cost associated with the upgrade of the existing system. In estimating these costs, it is also necessary to estimate the design life of each component: if the design life is shorter than the time horizon over which the project is evaluated, the replacement costs have to be estimated and accounted for.

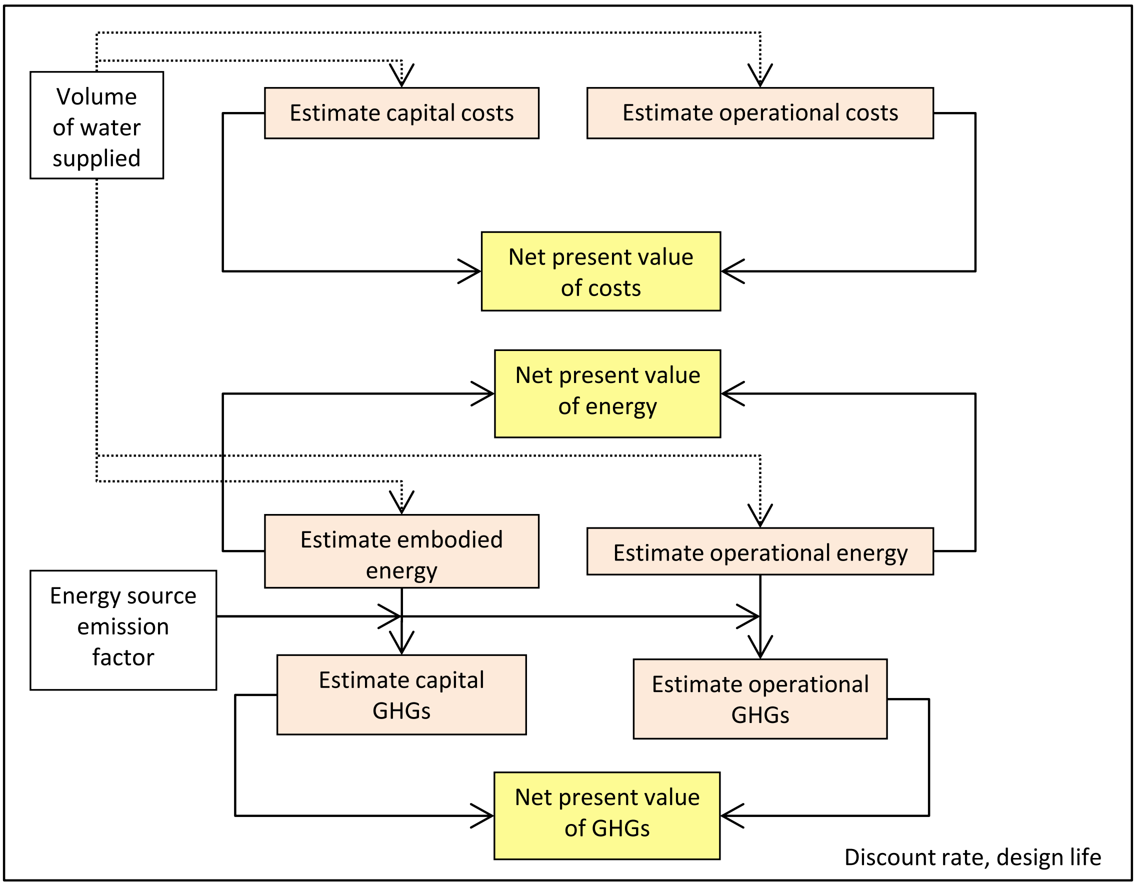


FIGURE 18: FLOWCHART DESCRIBING THE RELATIONSHIP BETWEEN CAPITAL AND OPERATIONAL COSTS, ENERGY AND GHG EMISSIONS.

As the capital costs in general vary with the capacity of the plant, it is also important to estimate the amount of water that can be provided by the new water supply and, in particular, it is important to estimate the limits of the water supply option. The estimate of the plant capacity will be treated in a later section. The flow chart in Figure 19 summarises the procedure for estimating capital costs.

OPERATIONAL AND MAINTENANCE COSTS

Operational costs are related to electricity, labour and chemicals usage. For example, in a water treatment plant, electricity is used to pump water through the facility to a clearwater tank and chemicals are used in the treatment. These costs depend on the volume of water treated and can be expressed as a cost per unit volume ($/kL).

Another component of the operational costs is the personnel cost: sometimes this cost can be neglected because it will be only a small part of the final total cost. However, there are cases, as for the desalination plant, where significant costs are incurred independent of the volume of water produced. For example, it is possible that the desalination plant requires personnel even when it is not operating (the likely reason for this is that, in case of need, it would be possible to bring the desalination plant online in a short period of time). It is also possible that contracts for electricity usage (or other utilities) impose a fixed cost independent of energy usage.

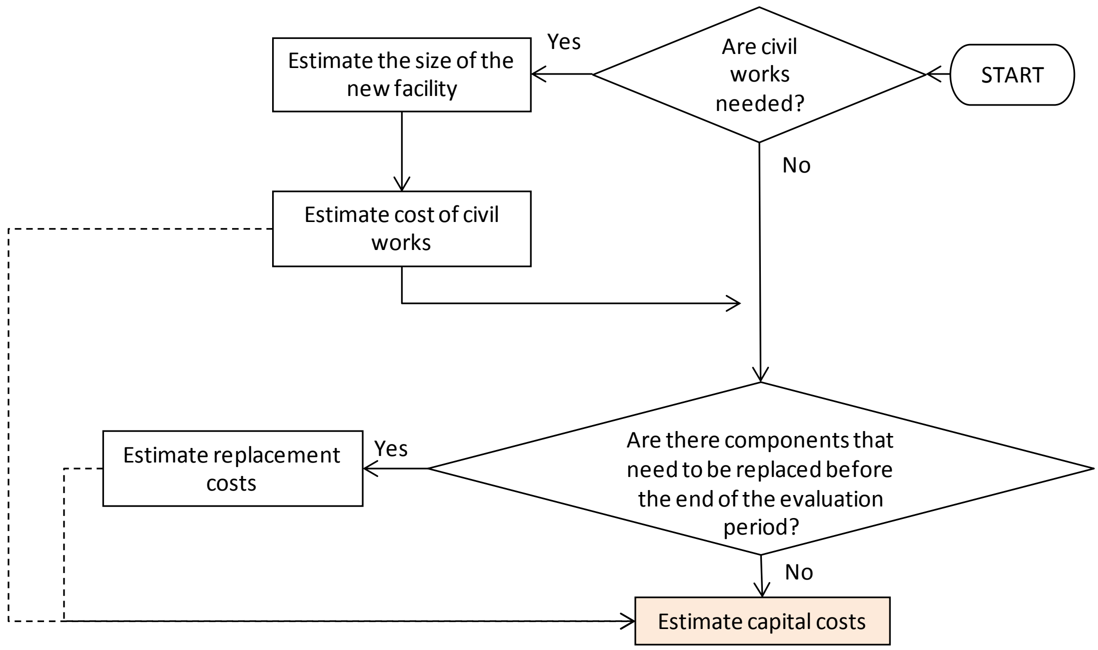


FIGURE 19: FLOWCHART FOR ESTIMATING CAPITAL COSTS.

A last expenditure that is spread throughout the design life of the facility is the maintenance cost. For this reason, in the following, maintenance costs are estimated together with the operational costs and treated in a similar way. Note that, as there could be components of the plant that are subject to frequent replacement, as is the case of the membranes for reverse osmosis in the desalination plant, their replacement costs can be considered as part of the operational costs. A summary of the important aspects to take into account in estimating the operational and maintenance costs is shown in Figure 20.

It should be noted that: estimation of the electricity costs requires an estimate of the energy consumption and the electric tariff (which is generally not publicly available); estimation of the cost of chemicals requires an estimate of the quantity of chemicals needed for a certain volume of water (which usually depends on the initial water quality) and the cost of the chemicals; estimation of replacement costs requires an estimate of how often a component will be replaced and how many components there are in the plant.

Sometimes, some of the operational and maintenance costs (or a reasonable value for similar plants) are already available in literature. Values obtained from the literature and direct cost estimates are both used in this report. However, it should be noted that both types of estimates include uncertainties and approximations.

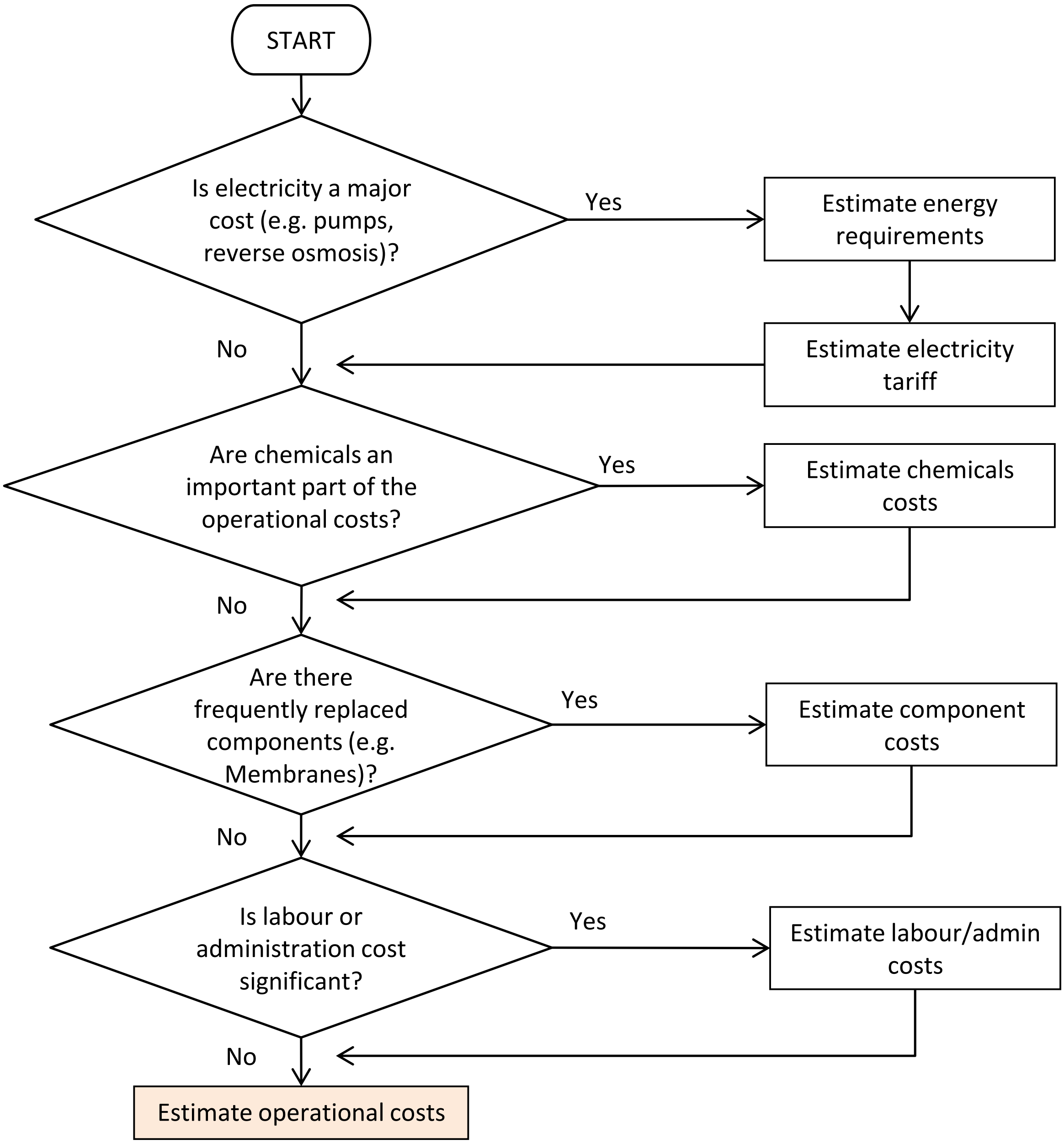


FIGURE 20: FLOWCHART FOR ESTIMATING THE OPERATIONAL COSTS.

ESTIMATING THE VOLUME OF WATER SUPPLIED

Estimating the volume of water that can be produced or saved by a water supply option is fundamental as it is important to relate the costs to the likely output. This task is also central because it interacts with many other disciplines. These disciplines usually help with estimating the physical, environmental or social constraints that a water supply option may face. In fact, often the volume of water that can be supplied may be less than the amount of water available at the source. A flowchart for estimating the volume of water that a source can supply is given in Figure 21.

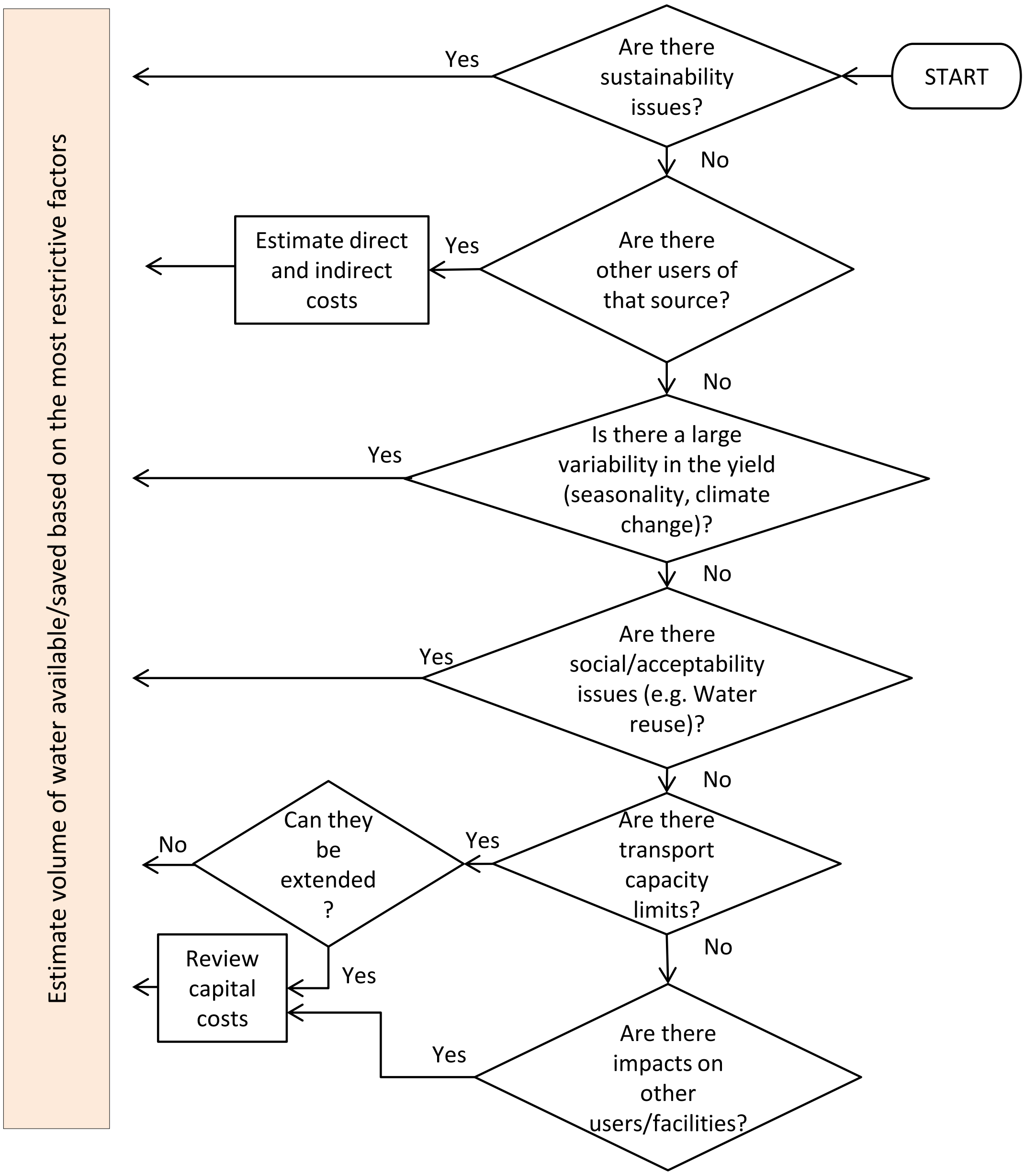


FIGURE 21: FLOWCHART FOR ESTIMATING THE VOLUME OF WATER THAT CAN BE SUPPLIED FROM A PARTICULAR SOURCE.

One of the first questions that has to be answered when a new water supply option is introduced or the capacity of an existing one is increased is 'what is the sustainable level of usage of that resource?'. Groundwater use is a typical example, as there are many cases around the world in which the overexploitation of this resource has caused serious problems: a low groundwater table can allow sea water intrusion, resulting in increased salinity; moreover, subsidence effects can cause damages to buildings and existing infrastructure. In general, even when these two problems are not present, it is important to limit the use of the resource to a sustainable level. Once the sustainable yield of a source has been established, it is important to check if there are other users of the source and if the additional or increased withdrawal will affect them. For example, water in the River Murray is used by various

States (Queensland, New South Wales, Victoria and South Australia) and satisfies potable, irrigation and environmental demands. In defining the sustainable limit for this resource, it is important to estimate the water requirements and rights of the other users: will the other users be entitled to continue to use the same amount of water? Can it be reduced? Can water be purchased from these users, and, if so, at which price?

As water is considered a primary source, its use is usually regulated by laws that can change, depending on the country. If a market for water exists, it is important to estimate the prices that water can reach: this will result in an addition to the operational costs. However, also when there is no price for water (e.g. a law establishes that potable use has priority over all other uses and it does not need to be sold), there can be costs associated with the economic loss of the other sectors, such as agriculture or hydroelectricity.

In estimating the costs and evaluating how much water demand can be satisfied by a source, it is also important to estimate the variability of the supply source. In fact, there could be seasonal or inter-annual variations in the supply source. A typical example is the use of rainwater tanks: even if the total volume of water that can be harvested in a year is equal to the demand, it could happen that, in a particular time period, the rainfall and demand patterns do not match and the water is not available when it is needed. Another example is the use of water from the Mount Lofty Ranges: in dry years this source is significantly reduced and the withdrawal from other sources will need to be increased. Note that these other sources can also be subject to variability.

Variations in the amount of water supplied affects not only the estimate of the amount of demand that can be satisfied, but also the capital costs of the water supply option. For example, seasonal variations can impact the required size of the water storage, of the pumping station and of the associated pipe system.

For some of the less conventional water supply options, the social acceptability of the water supply has to be evaluated. Wastewater reuse is a typical example: despite the technical possibility of reaching potable standards, the use of this source is usually limited to non-potable uses. For most countries, this is also a legal requirement; however, even if wastewater reuse for potable use was allowed, social aspects such as public acceptability have to be accounted for.

Once water availability and usability have been assessed, two other factors have to be considered: the impact on existing infrastructure of delivering water from the source to the users and the impact on the existing wastewater collection system. For example, a desalination plant (as well as many other water sources) produces water at a specific location. This water has to then be transported to the users: existing pumps and pipes might be able to deliver the additional flow, but, if this is not the case, the required upgrades have to be costed. It is also possible that these costs could be so large that it is more cost effective to reduce the capacity of the plant (if a more cost effective supply source exists).

After being used, water is usually treated before being discharged and some of the interventions could impact on the wastewater infrastructure. For example, the use of grey water reduces the amount of water that flows in the sewer system and this can cause deposition problems. In this case, it is necessary to evaluate how this impact can be reduced, as well as the associated costs.

EMBODIED ENERGY AND CAPITAL GREENHOUSE GAS EMISSIONS

In a similar way to the capital costs, in order to estimate the embodied energy and the capital GHG emissions it is necessary to estimate what capital works are needed, the size of the facilities and if and which components will need to be replaced (Figure 19). At this point, it is necessary to estimate the embodied energy of the components and the energy that is used during the construction of the plant. The embodied energy measures the energy that has been used to build a facility. For example, the housing of a pumping station will take into account the energy used to produce the concrete and the quantity of concrete needed and, ideally, the energy used in moving the material from its production place to its final destination. Moreover, energy used during the construction of the pumping station has to be accounted for (e.g. the mechanical energy used in excavating the ground for the basement of the pumping station).

As explained in the previous section dedicated to GHG emissions, the *Australian national greenhouse gas accounts* (Department of Climate Change and Energy Efficiency, 2012b) provides embodied energy and emission factors for some of the materials and for energy usage. However, it is still very difficult to estimate the embodied energy of many components, e.g. pumps, and a great level of detail is necessary to estimate the GHGs of civil works, e.g. the amount of concrete needed. For this reasons, often approximate values are used.

OPERATIONAL ENERGY AND GREENHOUSE GAS EMISSIONS

Operational energy use is usually associated with pumping and water treatment. Operational GHGs are caused by the use of chemicals and energy. Analogously to the operational cost associated with the use of chemicals, the quantity of chemicals used has to be estimated and then multiplied by the embodied energy of the chemicals. Calculation of the GHG emissions caused by the use of energy requires the estimation of the energy consumption and of the energy source used. This energy source is often grid electricity, but if the new facility will be powered with other sources, e.g. solar energy, this needs to be taken into account.

APPENDIX D: ADJUSTING PREVIOUS COST DATA

Cost data collected in this report often refer to different periods of time. As prices change over time due to inflation, it is necessary to relate them to the same time period to be able to compare them.

The Consumer Price Index (CPI) has been used in this report. The values used are shown in Table 56. Values are taken from the ATO government website[4], and are computed and reported each year by the Australian Bureau of Statistics (ABS). ABS (2013) report that the present value (C_{2013}) of any past cost (C_{past}) are related to the present CPI (CPI_{2013}) and the past CPI (CPI_{past}) by the following formula:

$$C_{2013} = \frac{C_{past}}{CPI_{past}} \cdot CPI_{2013}$$

In the report, the latest CPI available (March 2013) has been used. Note also that CPI_{past} has been computed as the average of the CPIs in the year of publication of the reference.

TABLE 56: CPI VALUES FOR EACH YEAR.

Year	Mar	June	Sept.	Dec.	Year	Mar	June	Sept.	Dec.
2013	102.4				*2008*	90.3	91.6	92.7	92.4
2012	99.9	100.4	101.8	102.0	*2007*	86.6	87.7	88.3	89.1
2011	98.3	99.2	99.8	99.8	*2006*	84.5	85.9	86.7	86.6
2010	95.2	95.8	96.5	96.9	*2005*	82.1	82.6	83.4	83.8
2009	92.5	92.9	93.8	94.3	*2004*	80.2	80.6	80.9	81.5

[4] Australian Taxation Office, Consumer price index (CPI rates), http://www.ato.gov.au/taxprofessionals/content.aspx?doc=/content/1566.htm, last accessed 31/5/2013

APPENDIX E: OPERATIONAL COSTS OF THE DESALINATION PLANT

Considering the cost percentages reported by Hoang et al. (2009) (Figure 9) and the operational and management costs reported by ABC News (2010) ($130 million/year at full capacity) the costs of labour, chemicals and membranes and the operational costs can be estimated: $28.26 million for labour costs (which will be considered independent of the volume of water produced by desalination), $37 million for chemical and membranes and $65 million for energy costs. Labour costs will be considered fixed, regardless of the actual production of the desalination plant, and will be rounded to $30 million/year.

The estimate of ABC News is based on a tariff equal to $0.13/kWh. As in this report a tariff equal to $0.15/kWh is assumed to account for the increase in electricity costs, the resultant levelised operational and management costs of the desalination plant at full capacity are $1.42/kL (the energy costs have increased from $65m to $75m, with other costs being the same).

The energy consumption of the desalination plant is considered to be 5 kWh/kL and it is inclusive of pumping to Happy Valley Water Treatment Plant. ATSE (2012) reports that the '*Proposed Adelaide desalination plant environmental impact statement*' by SA Water (2009) (Response Document, January) states an energy consumption of 4.5 kWh/kL for the desalination only. The energy consumption of pumping to Happy Valley Water Treatment Plant (WTP) can be estimated according to the power of the pumping necessary to lift the water.

The Gilberton pump station will be able to transport 375 ML/day (equal to 137 GL/year) from the Desalination plant at Port Stanvac to Happy Valley WTP (Arup, 2012). As previously reported in the desalination section, power equal to 9846 kW has been estimated in this report when the pumping station is run at full capacity (the maximum operational time of the plant is equal to 22.7 hours). The pumping station will be also able to deliver a minimum flow equal to 30 ML/day. In this case, the power required is estimated to be 600 kW.

The power used by the pumping station as a function of the flow delivered by the pumping station can be expressed as:

$$P = 0.0346 \cdot Q^2 + 18.206 \cdot \mathrm{Q} + 194.55$$

where Q is the flow delivered in ML/day and P is the power in kW. The energy used for lifting the water can be calculated by multiplying the power by the number of operating hours. It has been assumed that the pumps are operating 20 hours per day, considering that the maximum operational time of 22.7 hours will not occur frequently. A linear regression has been used to interpolate the value (R^2=0.954).

$$E\left(\frac{kWh}{kL}\right) = 0.0004 \cdot \mathrm{Q} + 0.4517$$

The energy used ranges from about 0.48 kWh/kL for delivering 30 ML/day to about 0.64 kWh/kL to deliver 375 ML. It is therefore considered plausible that only 0.5 kWh/kL are needed for the pumping and that the figure of 5 KWh/kL can be used to represent the cost of desalination and pumping the water to Happy Valley for blending.

Appendix F: Methodology to Estimate the Water savings of Rainwater Tanks

To estimate the volume of water that can be saved by introducing rainwater tanks, it is necessary to evaluate a number of parameters (Figure 22). First, it is necessary to identify for which use the water in the tank will be used (e.g. indoor, outdoor, hot water). Then it is necessary to estimate the water demand for that particular use. This also involves estimating when that volume of water is needed. This is particularly true for outdoor water use, which is typically larger in summer when rainfall is low. Therefore, it is also necessary to estimate the rainfall pattern and the emptying or filling of the tank. Basically, the water consumption and the rainfall pattern have to be simulated for one year (assuming that one year will give a representative result) so as to estimate tank yield. If the rainwater tank provides water for indoor uses it is also necessary to estimate the occupancy of the house, as this is an input to estimate the water demand.

At this point, it is important to estimate how many houses can still be equipped with a rainwater tank (and for which water use). In this process, as tank yield depends also on tank size, it will be also necessary to estimate which tank size (or tank size distribution) will be adopted. For example, for outdoor water use, houses that do not have a garden or do not water the garden will not install a rainwater tank.

Finally, it is important to check if there are constraints (they could be physical, economica or social aspects) that limit the spread of rainwater tanks, e.g. short term renters do not usually invest in the property. This procedure has been applied in the following to estimate the volume of mains water that could be saved by rainwater tanks.

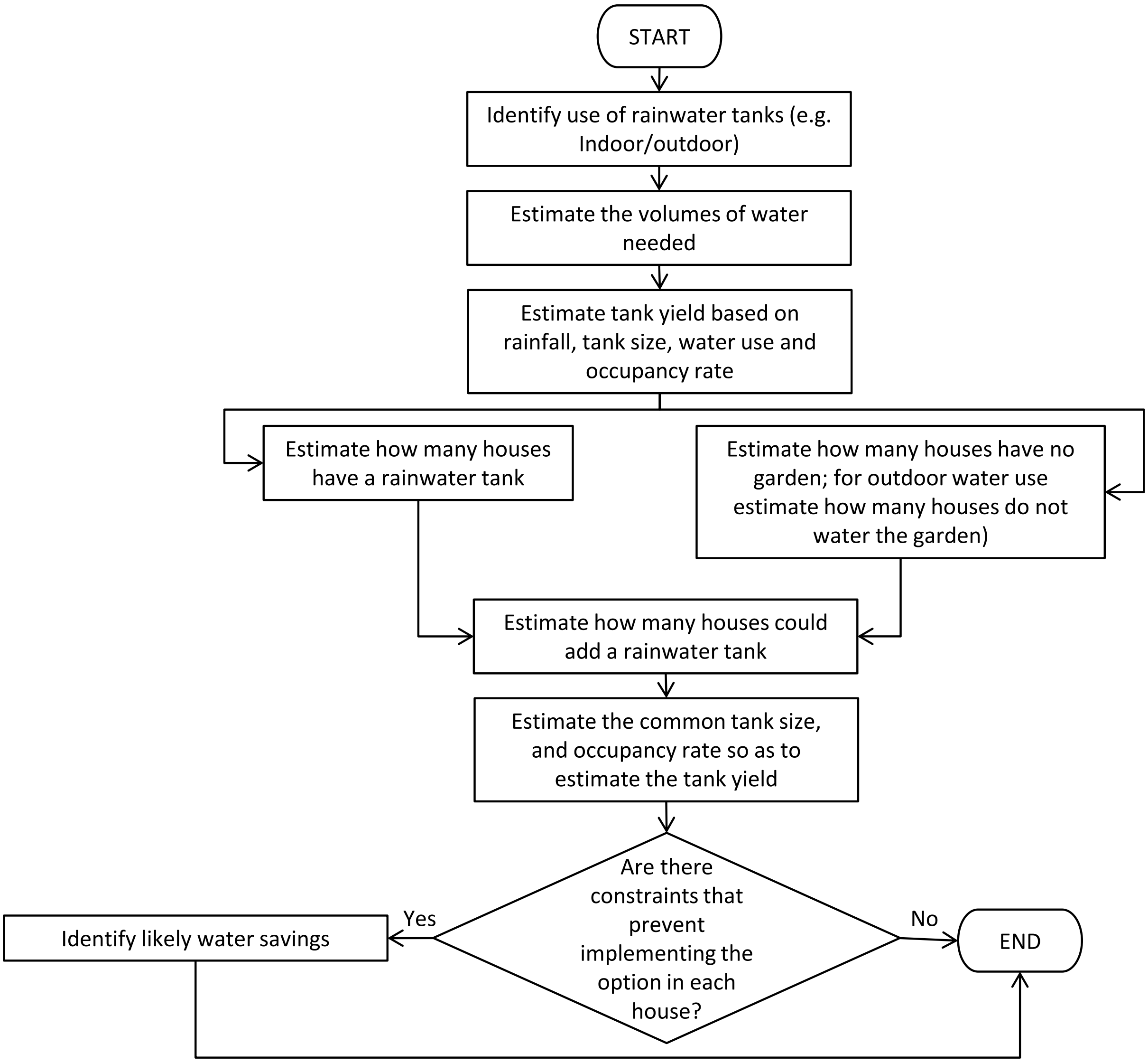


FIGURE 22: FLOW CHART TO ESTIMATE THE VOLUME OF WATER THAT CAN BE SAVED BY THE INTRODUCTION OF RAINWATER TANKS.

According to ABS (2011a) data, rainwater provided the main source of water for bathing and showering in 12% of households (compared with 6% nationally) and for the washing of clothes (12% compared with 7% nationally). However, the use of rainwater tanks was limited in Adelaide. For example, only 2% of the households washed clothes using water from rainwater tanks, while in the rest of the region this percentage reached 41%.

In order to estimate outdoor water use, it is important to note that 15% of households already used this source (ABS, 2011a). This percentage has nearly doubled from 2007 (8%) and also the number of households that opted for not watering the garden has increased (from 9% to 12%). This change is recent and probably due to different types of dwelling construction. Figure 23 shows the different sources of water used for garden watering in South Australia.

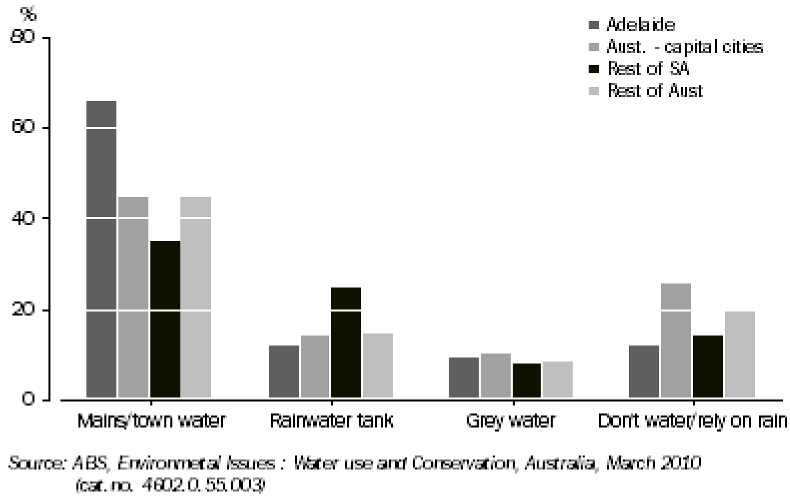


FIGURE 23: MAIN SOURCE OF WATER FOR HOUSEHOLD GARDENS (FROM ABS, 2011A)

The amount of water saved by using new rainwater tanks will be reduced to less than the 25 GL/year estimated by the Government of South Australia (2004), because of the large uptake of rainwater tanks in the recent years. In particular, the 2004 report estimated that only 37% of the houses did have a rainwater tank, while ABS (2011a) reports an average of 49%. If the water savings are decreased proportionally, only 19.78 GL/year can be saved. However, this volume is much smaller if the tank yield is considered. Assuming that 22 kL/year/property could be saved for internal and external use and that only 28% of the existing properties could install a rainwater tank (properties that do not have space for a rainwater tank and properties that do not water the garden are excluded), the maximum possible saving is 2.9 GL/year. If only the external use is considered (10 kL/year/property), 1.3 GL/year of water could be saved. Note that, if the largest yield estimated using Rain Tank Analyser (2009) is used (14 kL/property/year and 32 kL/property/year for outdoor and for outdoor and indoor, respectively), the previous volumes increase to 1.9 GL/year and 4.3 GL/year.

These numbers are significantly lower than the estimate by the Government of South Australia. The difference can be due to the fact that only 2 kL rainwater tanks are considered, but, depending on the size of the connected roof area and the size of the tank, larger yield can be obtained. Also, this estimate does not consider the fact that the tank can be plumbed into the hot-water system. Finally it is considered that all existing tanks are plumbed for indoor use, while in reality, some of them could be used only for outdoor water use. However, these results are not unreasonable if it is considered that: (i) the water provided by the rainwater tank (22 kL/year) corresponds to 17% of the demand for outdoor, toilet and laundry (about 61 GL/year) on average, and (ii) that about 72% of the houses have already a rainwater tank or they will not install it in any case. Note also that the water savings are estimated based on water consumption equal to 191 kL/year/property (data 2009-10 from the National Water Commission, 2010): consumption data on mains water for 2004-05 were 23% higher and could lead to larger estimates of savings.

APPENDIX G: PRICE ELASTICITY OF DEMAND FOR WATER

The demand for water, as other goods, is affected by price: in general, if the price increases, the demand decreases. Curve *b* in Figure 24 represents a demand function for a hypothetical household: if the price of the water is p_0, the corresponding demand is d_0. If the water price increases, for example, to p_r, the demand would reduce to the value d_{rb}.

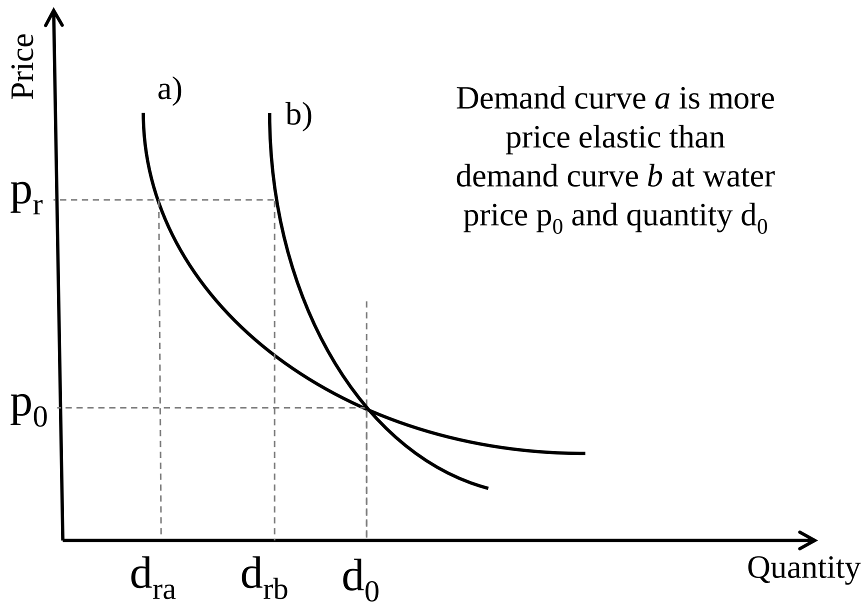


FIGURE 24: DEMAND-PRICE RELATIONSHIP FOR A HYPOTHETICAL HOUSEHOLD.

Price elasticity is used to describe the relation between the change in demand in response to a change in price, as shown by the equation below where *dQ* is the change in demand and *dP* is the change in price. Price elasticity usually has a negative sign and can have different values depending on the position on the demand curve on which it is measured.

$$elasticity = \frac{dQ/Q}{dP/P} = \frac{dQ}{dP} \cdot \left(\frac{Q}{P}\right)$$

If demand has a low elasticity, the demand does not vary much when the price is changed. Indoor water demand usually has a low elasticity because it is associated with basic needs. On the contrary, if the elasticity is high, there are large variations in demand for small variations in price. In Figure 24, curve *b* has a lower price elasticity than curve *a*: for the same increase in price (from p_0 to p_r), the decrease in demand is smaller for curve *b* (from d_0 to d_{rb}) than for curve *a* (d_0 to d_{ra}).

As mentioned before, the elasticity of water demand depends on several factors and may change in time and location and on the current level of demand. Furthermore, each consumer may have a different water demand curve.

Kuczera and Ng (1994) researched the elasticity of the water demand curve in Newcastle. Data were collected from a limited number of houses in Newcastle in 1976 and 1987 to calibrate the demand curves. The two different years allowed verification of some assumptions about the shape of the demand curve for indoor water use, which was assumed to be of the form:

$$Q_{in} = D_{in}[d_{in} + (1 - d_{in})e^{-\gamma_{in}p}]$$

where Q_{in} is the per capita indoor water consumption (L/person/connection/day), p is the price of water, D_{in} is the maximum level of consumption, d_{in} is the fraction of D_{in} related to basic needs and γ_{in} is the price parameter. A similar relation has been estimated for outdoor consumption, but, to account for the fact that when it rains there is no need to water the garden, an additional factor was added. The calibration of the parameters for two different values of the subsistence demand d_{in} and d_{out} is presented in Table 57 and the resulting curves are shown in Figure 25.

Dandy et al. (1997) developed linear regression equations for the annual and seasonal water consumption of 320 households in Adelaide for the period 1978/79 to 1991/92 using both static and dynamic models. The dynamic models included the household's water consumption in the previous year as an explanatory variable, the static models did not. This enables both short run and long run elasticities of demand to be estimated.

TABLE 57: PRICE DEMAND CURVE PARAMETERS ESTIMATED FOR NEWCASTLE (KUCZERA AND NG, 1994).

Prior values of d_{in}	Parameter	Mean	Standard deviation
Indoor			
0.25	D_{in}	221	2
	γ_{in}	0.615	0.031
0.45	D_{in}	222	2
	γ_{in}	0.904	0.051
Outdoor			
0	D_{out}	3.43	0.22
	γ_{out}	1.32	0.19
0.25	D_{out}	3.44	0.22
	γ_{out}	2.18	0.41

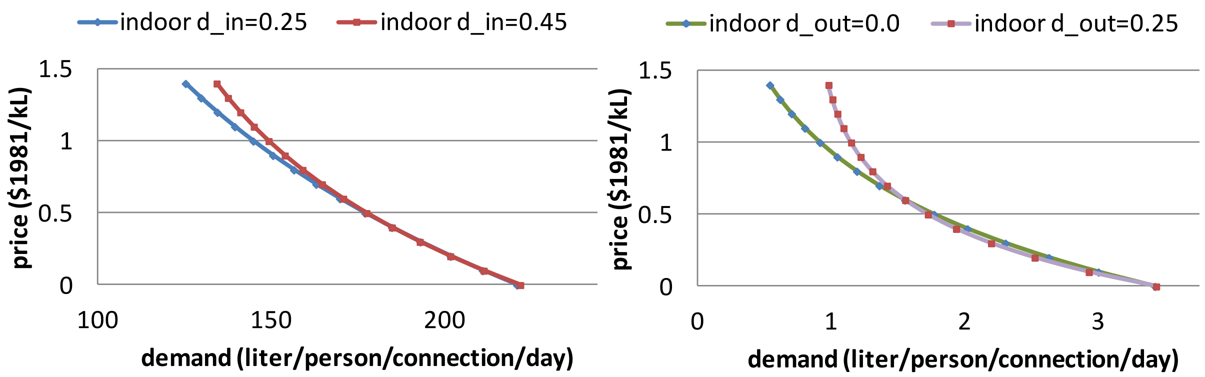


FIGURE 25: WATER PRICE DEMAND CURVE ESTIMATED BY KUCZERA AND NG (1994) FOR NEWCASTLE.

The elasticities of demand estimated from the models are given in Table 58. The price elasticity of demand for annual consumption was found to be in the range -0.63 to -0.77. The fact that these values are larger than the ones usually reported in literature (-0.20 to -0.50) is explained by the large outdoor consumption in Adelaide (about 40% of the total consumption according to ABS, 2011a). It is important to note that the elasticity varies between the short run and the long run, with the latter value being generally larger than the former. The short run elasticity is basd on the change in demand in the year following the price change. Long term elasticity is based on the long term adjustment to a change in price. Also, Dandy et al. (1997) analysed other factors that influence water demand and its elasticity: the seasonal variations of water demand (as the consumption in winter is mostly related to indoor use), the property value (associated with income) and the number of residents (Table 58).

TABLE 58: WATER DEMAND PRICE ELASTICITIES ESTIMATED BY DANDY ET AL. (1997) FOR ADELAIDE.

Model	Type of model	Price		Property value		Number of residents	
		Short run	***Long run***	***Short run***	***Long run***	***Short run***	***Long run***
Annual	*Static*		-0.63		0.32		0.19
	Dynamic	*-0.28*	-0.77	0.14	0.38	0.04	0.11
Winter	*Static*		-0.45		0.28		0.32
	Dynamic	*-0.12*	-0.29	0.16	0.33	0.19	0.42
Summer	*Static*		-0.69		0.41		0.10
	Dynamic	*-0.36*	-0.86	0.15	0.49		NS

Chong et al. (2009) used price-demand elasticities between -0.3 and -1.7 to estimate the cost of water restrictions to householders, industry, government and water utility. The largest elasticity (in absolute value) is larger than the typical values adopted in literature to account for the fact that the outdoor demand could be much more elastic than the total demand, especially in drought periods.

Olmstead and Stavins (2008) report that price elasticity may increase by 30 percent or more when price information is posted on water bills (Gaudin, 2006) and that price elasticity may be higher under increasing-block prices (in which the marginal volumetric water price increases with consumption) than under uniform volumetric prices (Olmstead et al. 2007). In addition, water users are more sensitive to water prices in the long run, as they can adopt water efficient appliances.

APPENDIX H: CHANGES IN ADELAIDE WATER CONSUMPTION DUE TO WATER RESTRICTIONS

As shown in Figure 26, in order to estimate the effectiveness of water restrictions, it is important to collect past data and to analyse past and present demand. As demand is also a function of the meteorological conditions, it is also important to analyse if significant climate variations have occurred or if the available data are not representative because they are affected by an exceptional dry/wet year. In the following, the effectiveness of water restrictions and the changes in water demand will be analysed for Adelaide.

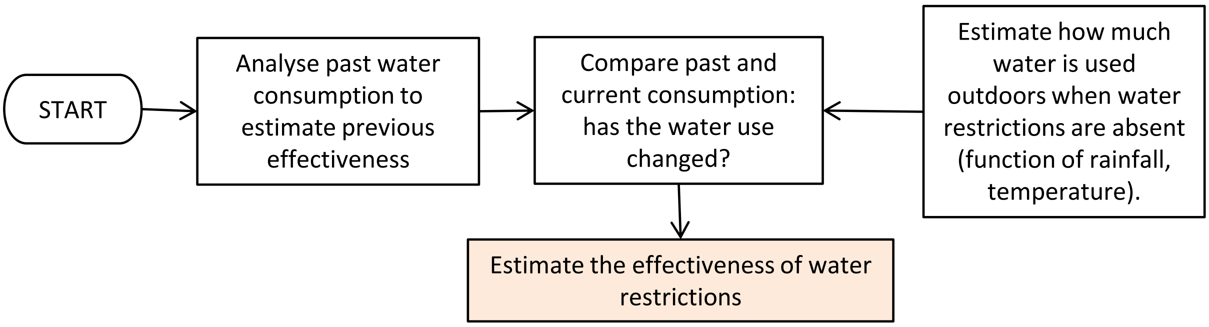


FIGURE 26: FLOWCHART FOR ESTIMATING THE EFFECTIVENESS OF WATER RESTRICTIONS.

The effects of water savings strategies in Adelaide and in South Australia are reported by the Australian Bureau of Statistics (ABS) (2011a). Before the introduction of Permanent Water Conservation Measures (26 October 2003), the average water consumption of South Australian households was 756 L/day (data 2000-2001). In 2003-04 the average water consumption reduced to 644 L/day per household (~15% reduction). ABS (2011a) reports that this value was maintained for the following years, with only a slight increase (to 660 L/day/household) in 2006-07.

Level 3 Water Restrictions were introduced on the 1st of January 2007 and consumption was further reduced to 523 L/day/household (corresponding to a further 19% compared to 2003-04 consumption). This quantity was maintained around this level until the 1st of December 2010, when the Water Restrictions were eased. After this date, Water Wise Measures were introduced (except for the Eyre Peninsula, where Water Restrictions were eased in April 2011). The Annual Report from the South Australia Water Corporation (2011) states that the water consumption is still low (200 GL in 2011) and lower than the Water Wise measures target (248 GL/year).

It is important to note that the maintenance of a low level of consumption is likely due to a combination of effects: the use of more efficient appliances, the effect of the increase of the water price in the last few years and the information campaigns about the importance of water and how to save it. It is expected that the next time water restrictions are applied they will not reduce the demand by the same percentage.

Comparing demand during and after the water restrictions is complicated by the difficulty of separating the residential consumption from the other uses and by the influences that warmer years can have on demand. Data contained in the annual report from the South Australian Water Corporation (2012) show that 135,276 ML were delivered in 2011-2012 to an estimated population of 1,149,000 in Adelaide. Assuming an average occupancy of 2.4 persons per dwelling (ABS Census, 2011), the average consumption per property is 774 L/day/property. This consumption seems relatively large compared to the estimates during the Water Restrictions (and compared to the demand before the Permanent Water Conservation Measures), because it also takes into account commercial and industrial uses. The proportion of residential/commercial-industrial uses can be estimate from the data contained in the annual report 2011 (South Australian Water Corporation, 2011), where it is reported that the average residential consumption in Adelaide was 170.6 kL/year/property. This results in an average daily consumption of 195 L/day/person (the same rate of occupancy has been used). As the 2012 annual report shows that 310 L/day/person are used (including commercial and industrial use), it is estimated that the residential consumption is 62.8% of the total consumption, resulting in a residential consumption in 2011-2012 equal to 486 L/day/property.

The fact that this consumption is lower than the consumption during the period of water restrictions is likely caused by the difference in the weather conditions and the assumptions made. It is believed that water restrictions would still reduce the demand if they were applied. However, due to the lack of data on the effect of water restrictions on current consumption, it is proposed to assume an effectiveness of the water restrictions in the range 10%-20% compared to the unrestricted demand. Note that this percentage is based on the data reported in Chong et al. (2009) that estimated water savings in the order 6%-24% and does not take into account that, since 2006, the water use has been reduced (thus, overestimating the possible savings).

APPENDIX I: METHODOLOGY TO ESTIMATE THE COSTS AND WATER SAVINGS OF WATER EFFICIENT APPLIANCES

In order to estimate the cost of water efficient appliances it is important to estimate the cost of the appliances themselves (inclusive of installation, maintenance and operational costs), as well as the volume of water saved. This has to take into account many factors, as shown in Figure 27.

For each water efficient appliance (WEA) under analysis, it is necessary to estimate the volume of water that this appliance is able to save. First, it is necessary to estimate how many times the WEA will be used in a given time (e.g. day or year). Then, for many appliances, it is necessary to estimate the number of people in the house. This is because most WEAs are at the household level and switching to a WEA, for example using low-flow shower heads, reduces the demand of all house residents.

To quantity the volume of water that can be saved, the current water consumption and the consumption after every house has a water efficient appliance installed has to be computed. The first estimate requires a determination of which is (or are) the most common non water efficient appliance and its actual consumption of water. It is also important to estimate how many houses are already equipped with water efficient appliances. Once these inputs are known, it is possible to calculate the maximum volume of water saved. Note that there can be economic or social factors that prevent the complete replacement of all existing water appliances. Therefore the maximum water savings have to be reduced to a likely estimate.

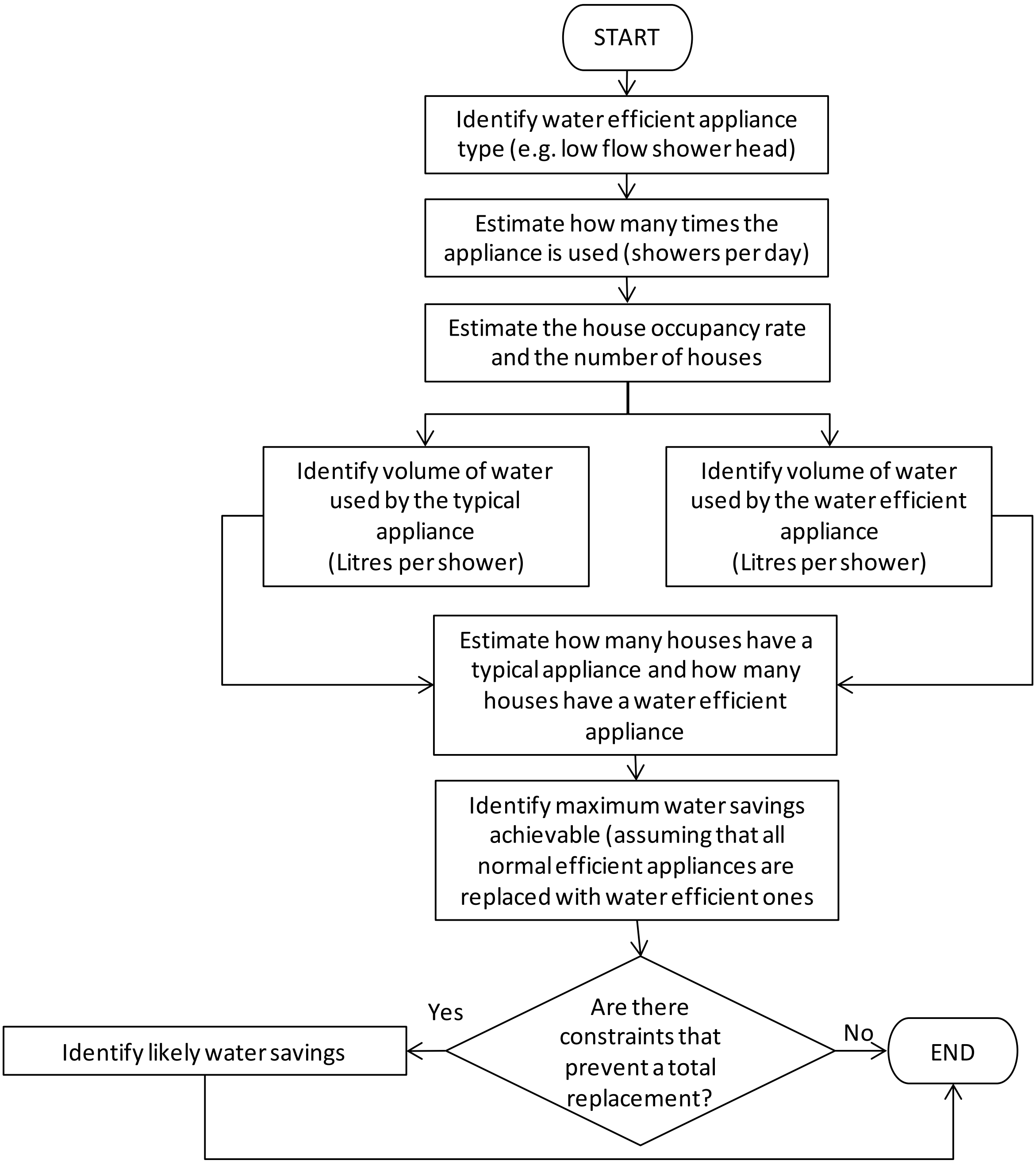
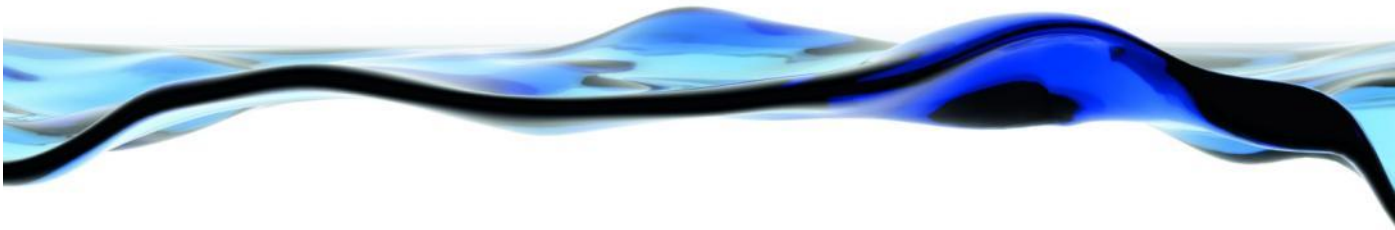


FIGURE 27: FLOWCHART FOR ESTIMATING THE WATER SAVINGS DUE TO THE INTRODUCTION OF WATER EFFICIENT APPLIANCES



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