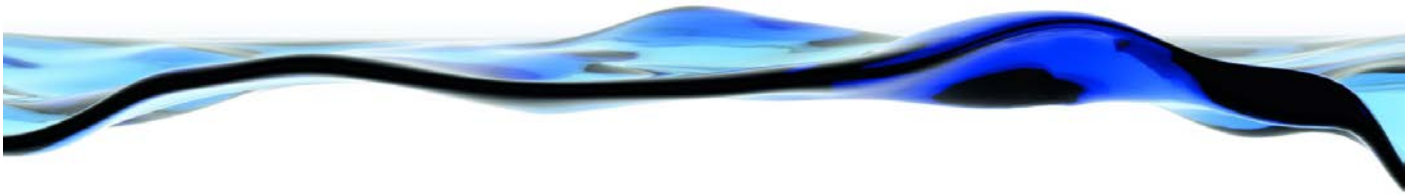
Managed Aquifer Recharge and Stormwater Use Options: Net Benefits Report



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Executive Summary

This report presents a general framework to assess the net benefits of stormwater use in Australia. This framework is demonstrated through a case study involving managed aquifer recharge in the Parafield catchment in the City of Salisbury. The framework and tools consider a broad scope of economic, environmental and social criteria for a number of stormwater harvesting options in the study area.

The general framework will assist authorities to define the scope for evaluation of their projects. Techniques for analysing a wide array of economic benefits and costs, water supply and water quality issues, environmental and social impacts are outlined and demonstrated in the Parafield case study. The proposed framework should assist authorities to assess the following aspects of proposed stormwater reuse schemes:

- The net present value of direct economic benefits and costs via a traditional cost-benefit analysis
- Environmental benefits and costs (assessment of externalities such as energy, greenhouse gas emissions, improved water quality, impact on the quality of receiving waters and urban amenity through increased land values)
- Social values of the key stakeholders and the community
- A broader multi-criteria analysis (MCA) of factors not easily incorporated in a standard cost-benefit analysis

A MCA allows for relative weights to be placed on each of the economic, environmental and social criteria. The choice of these weights is a transparent process that explicitly enables differences in values between key decision makers to be identified.

When all the components are brought together in a multi-criteria decision framework, authorities will be in a position to choose between the various options for treatment and end use of the harvested stormwater.

The options considered in the Parafield case study are summarised in Table S.1. They are grouped in terms of water end uses i.e., irrigation of open space (Options 1-4), third pipe supplies to households for toilet flushing, washing machine and garden uses (Options 5-8) and potable uses (options 9-12).

The results obtained for the case study depend on the assumptions and data used and are presented here as indicative outcomes only. In particular, the results are sensitive to the assumed cost savings from traditional potable water sources. In the case where a value of $2.75 per kL is assumed (based on the 2011 estimate of long run marginal cost of potable supply), the following stormwater harvesting options have positive economic benefits for the Parafield scheme:

(1) Three of the options that involve watering of public open space (in the following order of preference: Option 4, 2, and 1);
(2) All of the potable use options (in the following order of preference: Option 10, 11, 12 and 9); and

None of the third pipe options have positive economic benefits because of the cost of constructing an additional distribution network.

The overall order of ranking of preferred options in terms of net present value for the given assumptions is: 4, 10, 2, 3, 11, 12 and 9.

When a full multi-criteria analysis is carried out including environmental and social criteria, the same seven options are favoured with some change in rank order. In addition, Option 1 is added to the list and ranks higher than Option 12. Also, Option 9 ranks higher than Option 12 when environmental and social factors are considered. Overall the use of harvested stormwater for watering public open space receives a higher ranking than its use for direct or indirect potable purposes due to the higher social acceptability of watering public open space.

Options 5 and 6 for greenfield sites are the most favoured of the third pipe systems when a full multi-criteria analysis is carried out. However, it ranks below all of the options involving watering of public open space or potable uses.

It is clear that the economic viability of the various stormwater options is sensitive to the assumed yields and benefits per kilolitre of harvested stormwater supplied to the consumer. Careful consideration of the variability and certainty of all assumptions should be undertaken before committing to an investment strategy.

Table S.1 Descriptions of available options for storage, treatment and blending of stormwater for three classes of uses; open space irrigation, third pipe non-potable supplies and drinking water supplies

Options	Description
	Open space irrigation – external use only
1	Without aquifer storage (former practice)
2	With aquifer storage and recovery (current practice)
3	Option 2 followed by disinfection.
4	Option 2 followed by blending with tertiary treated wastewater and disinfection.
	Third pipe system – external and internal household uses for toilet flushing, washing machine and for garden watering
5	Without aquifer storage and then disinfection.
6	With aquifer storage and recovery then disinfection.
7	Option 5 (no aquifer) and blending with treated wastewater and disinfection (former practice).
8	Option 6 followed by aquifer, and blending with treated wastewater and disinfection (current practice).
	Drinking water uses
9	With aquifer storage and recovery followed by treatment and disinfection then injected directly into mains water distribution system.
10	Without aquifer storage. Transfer to the Little Para Reservoir, then treatment and disinfection.
11	With aquifer storage and recovery then transfer to the Little Para Reservoir followed by treatment and disinfection.
12	Same as Option 11with intermediate treatment between aquifer and reservoir.

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Glossary

Water Types Definitions

*Desalination water***	*Desalination water* is the volume of water sourced from desalination processes and is not confined to marine desalination.
*Non-potable water***	*Non-potable water* is water that is not intended for use as a drinking water supply.
*Potable water***	*Potable water* is water that is intended for use as a drinking water supply. Potable water should materially meet the Australian Drinking Water Guidelines 2011 (ADWG) or equivalent.
*Raw water***	*Raw water* is water that is untreated water.
*Recycled water****	*Recycled water* is water generated from sewage, grey water or stormwater systems and treated to a standard that is appropriate for its intended use.
*Urban stormwater***	*Urban stormwater* is water within the urban stormwater drainage system. Urban stormwater may be received from or supplied to other infrastructure operators. It may also be supplied for managed aquifer recharge.
*Urban stormwater used***	*Urban stormwater used* is treated urban stormwater used by the utility for urban water supply and it may be potable or non-potable.
Wastewater	Material collected from internal household and other building drains; includes faecal waste and urine from toilets, shower and bath water, laundry water and kitchen water.

Other Definitions

Anaerobic	Conditions where oxygen is lacking; organisms not requiring oxygen for respiration.
Aquifer	A geological formation or group of formations capable of receiving, storing and transmitting significant quantities of water. Aquifer types include confined, unconfined and artesian.
Aquifer storage and recovery (ASR)	The recharge of an aquifer via a well for subsequent recovery from the same well.
Aquifer storage transfer and recovery (ASTR)	The recharge of an aquifer via a well for subsequent recovery from another well, to allow a minimum residence time in the aquifer before recovery.
Aquitard	A geological layer that has low permeability and confines or separates aquifers.
Assessment	The overall process of using available information to predict how often (likelihood) hazards or specified events may occur and the magnitude of their consequences (adapted from AS/NZS 4360:1999).
Beneficial use	The value of water in sustaining ecological systems, as well as the economic uses of water (eg drinking water, irrigation, industrial and mining water supplies). Water-quality requirements are determined by the class of beneficial use.
Biodiversity	The variety of life forms, including plants, animals and microorganisms; the genes they contain; and the ecosystems and ecological processes of which they are a part.
Catchment*	An area of land surrounding a water storage. The runoff water from rain falling over the catchment drains into the storage and collects nutrients, minerals and other contaminants (including microorganisms) from the surface of the land. Area of land that collects rainfall and contributes to surface water (eg streams, rivers, wetlands) or to groundwater.
Critical limit	A prescribed tolerance that must be met to ensure that a critical control point effectively controls a potential health hazard; a criterion that separates acceptability from unacceptability.
Cryptosporidium	Microorganism that is highly resistant to disinfection; commonly found in lakes and rivers. Cryptosporidium has caused several large outbreaks of gastrointestinal illness

	with symptoms such as diarrhoea, nausea and stomach cramps. People with severely weakened immune systems are likely to have more severe and more persistent symptoms than healthy individuals (adapted from United States Environmental Protection Agency).
Desalination*	A water treatment process used to convert highly saline water into water suitable for human consumption. Treatment involves passing saline water through membranes at a high pressure.
Digital Elevation Model (DEM)	A digital elevation model is a digital model or 3-D representation of a terrain's surface created from terrain elevation data.
Dissolved Air Floatation Filtration (DAFF)	Dissolved air flotation filtration (DAFF) is a water treatment process that clarifies wastewaters by the removal of suspended matter. The removal is achieved by dissolving air in the wastewater under pressure and then releasing the air at atmospheric pressure in a flotation tank or basin. The released air forms tiny bubbles which adhere to the suspended matter causing the suspended matter to float to the surface of the water where it may then be removed by a skimming device.
Disinfection	The process designed to kill most microorganisms, including essentially all pathogenic bacteria. There are several ways to disinfect; chlorine is most frequently used in water treatment.
Distribution system	A network of pipes leading from a treatment plant to customers' plumbing systems.
Drinking water	Water that is suitable for human consumption.
E. coli	*Escherichia coli*; bacterium found in the gut. Used as an indicator of faecal contamination of water.
Effluent	The outflow water or wastewater from any water processing system or device.
Environmental flows	Environmental allocation for surface water rivers, streams or creeks.
Geographical information system (GIS)	A geographic information system is a system designed to capture, store, manipulate, analyze, manage, and present all types of geographical data.
Groundwater*	Water beneath the earth's surface (often between saturated soil and rock) that supplies bores, wells or springs.
Guideline value	The concentration or measure of a water quality characteristic that, based on present knowledge, either does not result in any significant risk to the health of the consumer (health-related guideline value), or is associated with good-quality water (aesthetic-guideline value).
Hazard	A biological, chemical, physical or radiological agent that has the potential to cause harm.
Hazard control	The application or implementation of preventive measures that can be used to control identified hazards.
Hazard identification	The process of recognising that a hazard exists and defining its characteristics.
Hazardous event	An incident or situation that can lead to the presence of a hazard (what can happen, and how it can happen).
Impact	Having an effect on endpoints such as people, plants, soil, biota, water or a part of the environment.
Indicator	Measurement parameter or combination of parameters that can be used to assess the quality of water; a specific contaminant, group of contaminants or constituent that signals the presence of something else.
Inflows*	Water flowing from catchments into reservoirs through streams, rivers and creeks.
Irrigation	Provision of sufficient water for the growth of crops, lawns, parks and gardens; can be by flood, furrow, drip, sprinkler or subsurface water application to soil.
Log reduction or removal	Logarithmic (base 10) concentration reductions, effectively reduction by a factor of 10. Used in reference to the physical–chemical treatment of water to remove, kill, or inactivate microorganisms such as bacteria, protozoa and viruses.

Mains water	Potable water from a reticulated water supply, e.g. town water supply.
Managed aquifer recharge (MAR)***	The intentional recharge of water to aquifers for subsequent recovery or environmental benefit.
Management	The systematic evaluation of the water supply system, the identification of hazards and hazardous events, the assessment of risks and the development and implementation of preventive strategies to manage the risks.
Inherent risk	The level of risk in the absence of preventive measures; also referred to as inherent or unmitigated risk.
Monitoring	Systematically keeping track of something, including sampling or collecting and documenting information.
Native groundwater	Groundwater that was present before recharge operations.
Nitrogen	An important nutrient originating from human and domestic wastes; found in high concentrations in recycled waters. A useful plant nutrient that can also cause off-site eutrophication problems in lakes, rivers and estuaries; it can also contaminate groundwater.
Non-drinking water*	Water that is not suitable for human consumption.
Nutrient	A substance that provides nourishment for an organism. The key nutrients in stormwater runoff are nitrogen and phosphorus.
Observation well	A narrow bore, well or piezometer; its sole function is to permit measurement of water level and water quality.
Pathogen	A disease-causing organism (eg bacteria, viruses, protozoa).
Pollutant	Substance that damages the quality of the environment.
Pretreatment	Any treatment (eg detention, filtration) that improves the quality of water before injection.
Quality	The totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs; the term ‘quality’ should not be used to express a degree of excellence.
Quality assurance	All the planned and systematic activities implemented within the quality system, and demonstrated as needed, to provide adequate confidence that an entity will fulfil requirements for quality.
Quality control	Operational techniques and activities that are used to fulfil requirements for quality.
Recycled water	Water generated from sewage, grey water or stormwater systems and treated to a standard that is appropriate for its intended use.
Reservoir*	A natural or artificial body of water used as a storage for water supply.
Residual risk	The risk remaining after consideration of existing preventive measures.
Reuse	Using water that would otherwise be discharged to wastewater or stormwater systems, for domestic, commercial, agricultural or industrial purposes.
Risk	The likelihood of a hazard causing harm to exposed populations in a specified timeframe; includes the magnitude of that harm.
Risk assessment	The overall process of using available information to predict how often (likelihood) hazards or specified events may occur and the magnitude of their consequences.
Risk management	The systematic evaluation of the water supply system, the identification of hazards and hazardous events, the assessment of risks, and the development and implementation of preventive strategies to manage the risks.
Runoff	Surface overland flow of water resulting from rainfall or irrigation that exceeds the soil’s infiltration capacity.
Salinity	The presence of soluble salts in soil or water. Electrical conductivity and total dissolved salts are measures of salinity.
Screen	Slotted tube or wire-wound tubular frame in a well; permits the flow of groundwater to the well while maintaining the well’s integrity.

Sediment	Unconsolidated mineral and organic particulate material that has settled to the bottom of aquatic environments.
Sewage or wastewater	Material collected from internal household and other building drains; includes faecal waste and urine from toilets, shower and bath water, laundry water and kitchen water.
Source control	Control of times of watering or of public access to irrigated public open space.
Source water*	Water prior to any treatment or disinfection or recharge.
Species	Biological: a group of organisms that resemble each other to a greater degree than members of other groups, and that form a reproductively isolated group that will not normally breed with members of another group.
Stakeholder	A person or group (eg an industry, a government jurisdiction, a community group, the public) that has an interest or concern in something.
Standard (eg water quality standard)	An objective that is recognised in environmental control laws enforceable by a level of government.
Storage	A natural or artificial impoundment used to hold water before its treatment or distribution (eg reservoir, aquifer).
Stormwater***	Rainwater that runs off all urban surfaces such as roofs, pavements, car parks, roads, gardens and vegetated open space.
Surface water	All water naturally open to the atmosphere (eg rivers, streams, lakes, reservoirs).
Surrogate	Surrogate analytes are used to improve monitoring cost efficiency or reliability for classes of hazards for which representative surrogates are easier to measure or have lower detection levels.
Suspended solids	Solids in suspension in water; removable by laboratory filtering, usually by a filter with a nominal pore size of about 1.2 µm.
Target criteria	Quantitative or qualitative parameters established for preventive measures to indicate performance; performance goals.
Total dissolved solids (TDS)	Total Dissolved Solids (TDS) is a measure of the combined content of all inorganic and organic substances contained in a liquid in: molecular, ionized or micro-granular (colloidal sol) suspended form.
Treatment (water)*	The filtration and disinfection processes employed to produce drinking water.
Turbidity	The cloudiness of water caused by the presence of fine suspended matter.
Virus	Protein-coated molecules of nucleic acid (genetic material) unable to grow or reproduce outside a host cell.
Water recycling	A generic term for water reclamation and reuse. Can also describe a specific type of reuse where water is recycled and used again for the same purpose (eg recirculating systems for washing and cooling), with or without treatment in between.
Water supply system*	The complete system that provides a water supply to customers. It includes all infrastructure from catchment to tap, including the source water, water storage reservoirs, treatment plants and distribution networks.

* SA Water 2010-11 Drinking Water Quality Report
http://www.sawater.com.au/NR/rdonlyres/6CE0CA74-57E4-4500-A113-7AFAC9A18033/0/DWQReport201011.pdf

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*** NRMMC, EPHC, NHMRC (2009). Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Managed Aquifer Recharge. National Water Quality Management Strategy Document No 24, July 2009.

1. Introduction

Unmanaged stormwater runoff increases the potential for flooding, diminishes receiving water quality, and contributes to loss of vegetation through erosion, and decline in the health of aquatic habitats in watercourses and receiving waters (Department for Water, 2009). Stormwater harvesting that may include aquifer storage and recovery (ASR) has the potential to yield benefits through the provision of additional water (thereby reducing reliance on traditional water sources); through flood protection, and by reducing the discharge of stormwater pollutants into receiving waters where they can harm riverine, estuarine and marine environments.

The aim of this study is to outline a transferable methodology for assessing, and where possible, quantifying the economic, environmental and social impacts of stormwater harvesting including aquifer storage and recovery (ASR). The methodology begins with the assembly of the information needed to evaluate the alternatives under consideration and then introduces the use of multi-criteria analysis (MCA) to enable a final recommendation to be made. Multi-criteria analysis enables inclusion of all relevant criteria including those that are difficult if not impossible to assign an economic value to (UK Department of Transport, 2000; Mendoza and Martins, 2006). These criteria, together with economic criteria can then be weighted by key stakeholders to identify preferred option(s). A more detailed comparison of MCA and cost-benefit analysis is given in Appendix A.

The methodology presented in this report is step wise. It begins with an economic assessment of benefits and costs and then extends it to include consideration of broad environmental and social criteria.

The methodology is demonstrated using a case study at Parafield, north of the city of Adelaide, SA.

2. Methodology

In this section, the generic methodology for assessing the performance of various stormwater harvesting alternatives is presented (Figure 2.1). The proposed methodology utilises multi-criteria analysis and builds on existing frameworks (Goonrey et al., 2007; Maheepala et al., 2006a; Maheepala et al., 2006b; Maheepala et al., 2009) to assess stormwater harvesting schemes. In subsequent sections the proposed methodology is applied to a stormwater harvesting scheme in Adelaide.

As can be seen in Figure 2.1, the proposed generic framework consists of four steps (A, B, C, and D). In the first step (Step A), the problem is defined and relevant background data are collected. The problem definition includes the identification of the various stormwater harvesting alternatives to be assessed, which requires the definition of appropriate system boundaries and assessment criteria (i.e. various economic, environmental and social criteria).

The second step (Step B) involves selecting feasible infrastructure configurations that are part of the different stormwater harvesting alternatives (e.g. detention basins, wetlands, wells, distribution systems) as the size of each of these components affects the performance criteria in terms of cost, energy usage, greenhouse gas emissions, water quality, system yield / reliability and other measures. This generally requires the development and use of one or more hydrologic and hydraulic simulation models. In practice only a limited number of configurations are feasible and some of these can be excluded because they are technically inferior.

After the list of feasible alternatives has been drawn up, the performance of the different stormwater harvesting alternatives can be assessed (Step C) and a subset chosen for formal analysis. This step includes a formal cost-benefit analysis which can include a preliminary ranking (and possibly short-listing) of alternatives.

The final step is to rank the alternatives using Multi-Criteria Decision Analysis (Step D) in order to identify the alternative that represents the best overall option in accordance with user-defined preferences.

Figure 2.2gives a more detailed picture of the steps in the methodology. These steps are described in the following subsections.

Figure 2.1: Overall framework for the assessment of the performance of different stormwater harvesting alternatives

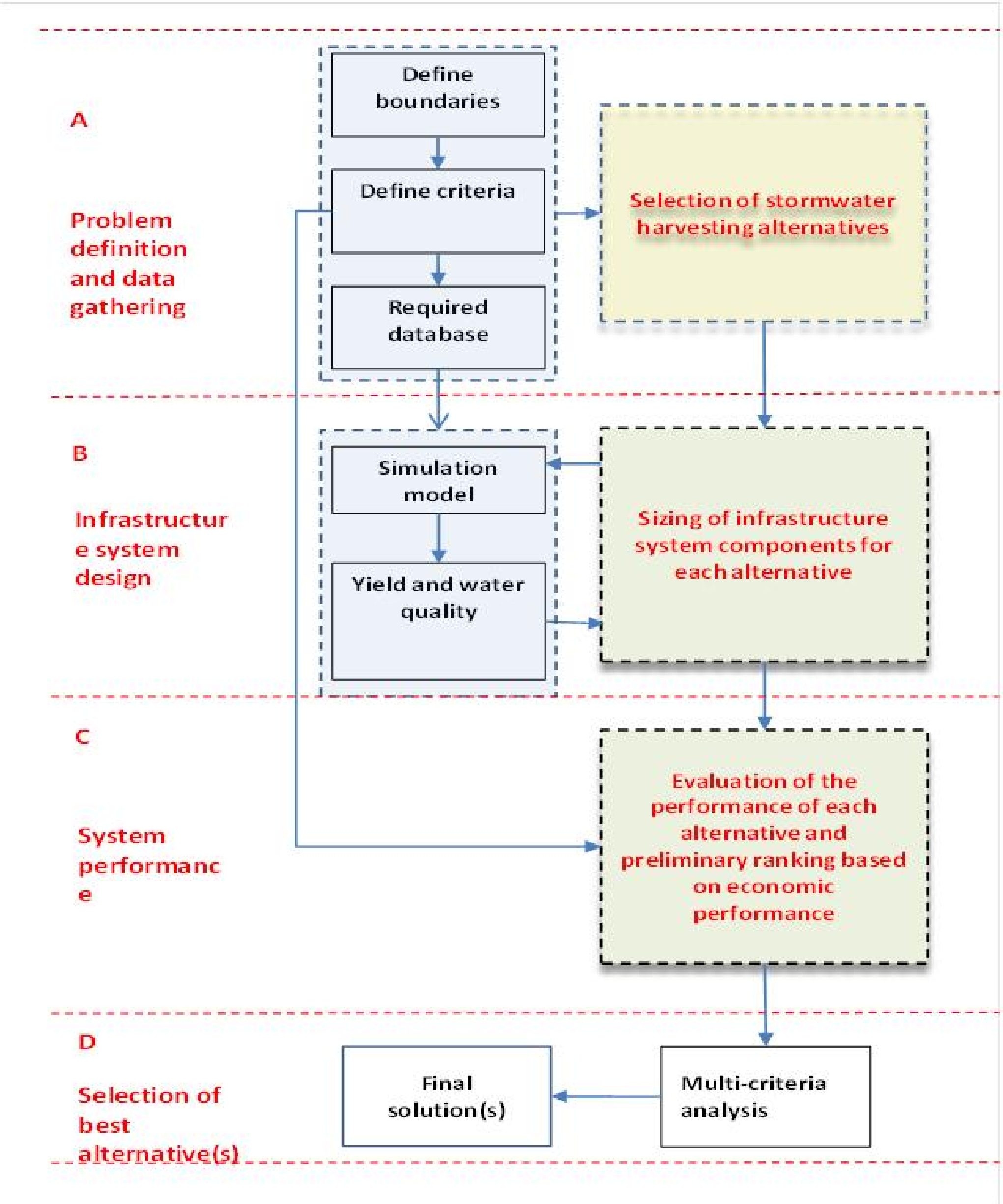
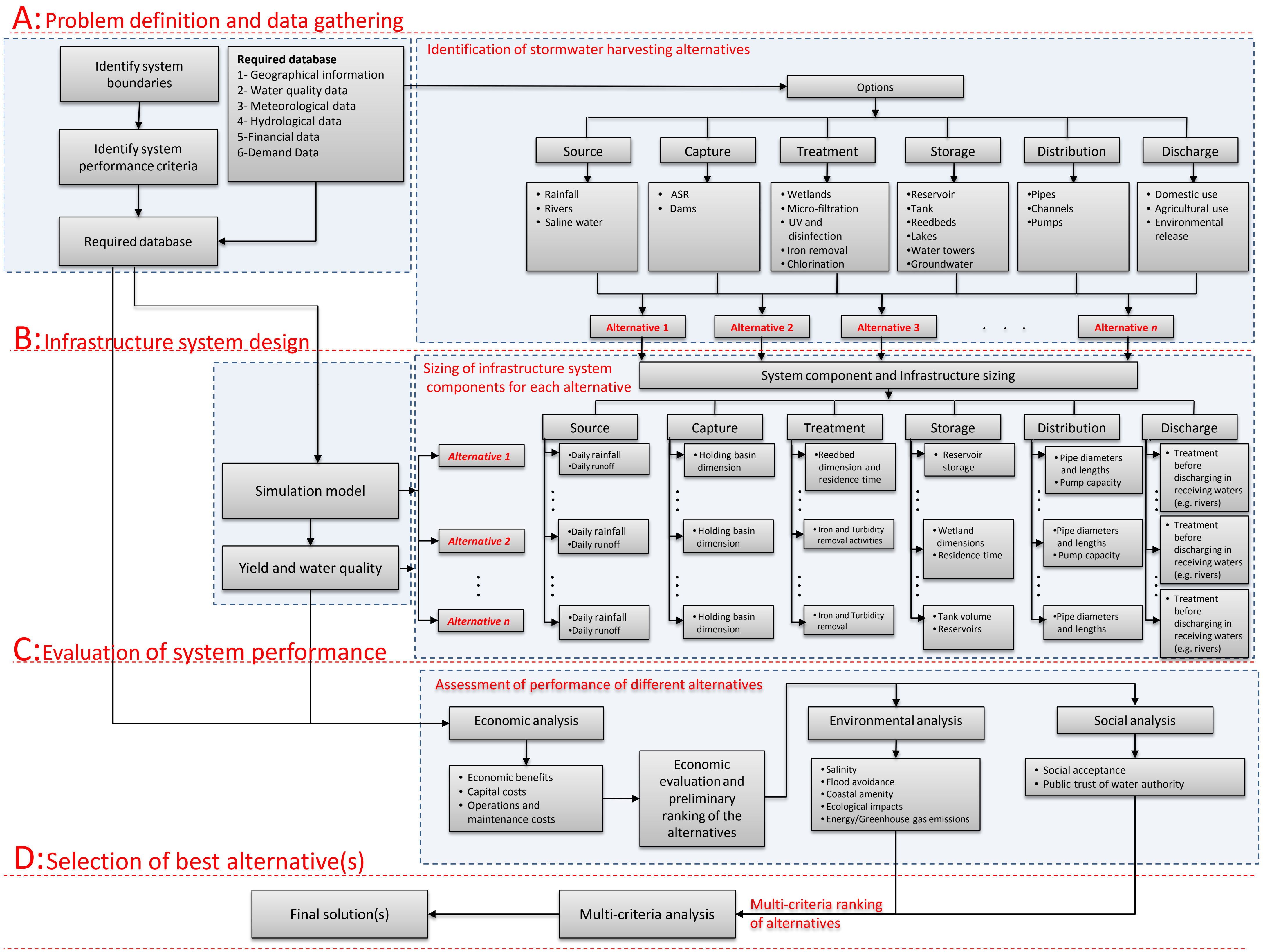


Figure 2.2: Details of generic methodology for assessing the performance of alternative stormwater harvesting systems.



2.1 Problem definition and data gathering (Step A)

The first step in the proposed generic methodology (Step A) involves the identification of the system boundaries including both the geographic and administrative boundaries of the scheme. This will assist in identifying the key stakeholders and in quantifying the performance criteria for the scheme.

An important component of Step A is the identification of criteria against which the performances of the various alternatives are assessed. These criteria should include all relevant performance metrics and will normally include economic, environmental and social components. Key stakeholders should be consulted to ensure that all relevant criteria have been included. The definition and assessment of these criteria requires the definition of the physical boundaries of the system being considered, as well as assessment of the impacts associated with the various stormwater harvesting alternatives.

The economic criterion commonly used is the present value of all market benefits minus the present value of all market costs (called the “net present value”). The determination of net present value requires an appropriate discount rate and project life to be identified.

The environmental impacts of stormwater harvesting will be assessed using an ecosystem services approach. In general there may be many environmental impacts that need to be considered. These impacts can be represented as a chain of consequences leading to a change in the quantity or quality of existing ecosystem services.

The underlying principle behind ecosystem services thinking is that ecological systems and natural capital stocks (environmental resources) contribute to social welfare. The value of ecosystem services can be assessed in terms of the changes in social welfare that they generate. The ecosystem services typology considers a broad range of social welfare-generating provisioning (e.g. food, fresh water), regulating (e.g. flood-, climate-, erosion-, and water quality- regulation), cultural (e.g. recreation, cultural heritage), and supporting (e.g. water, and nutrient cycling) services provided by functional natural environments (MEA, 2003; TEEB, 2010).The terminology and typology of ecosystem services is not consistent in the literature and is constantly evolving. This assessment adopts the typology and terminology after Boyd and Banzhaf (2007).

A list of potential environmental impacts associated with stormwater harvesting is given in Table 2.1.

The social criteria need to be decided in consultation with the key stakeholders and may include the distribution of benefits and costs to specific groups in the community, social acceptability of the various options and degree of trust of the water authority to deliver water of the desired quality and reliability. The last two of these can be assessed using focus groups or surveys.

The final component of Step A is to define the various stormwater harvesting options to be assessed. As shown in Figure 2.2, this requires the selection of options at the various stages of the water cycle, including source, capture, treatment, storage, distribution to end users and discharge to receiving waters, for each stormwater harvesting alternative to be assessed.

Table 2.1: – List of potential environmental impacts of stormwater harvesting using ecosystem services typology

Ecosystem service impact	**Description**
Cultural services	
Conservation ethic	citizens in surrounding residential areas feel good that water is conserved
Provisioning services	
Fish production values	improved stream or coastal water quality results in increasing commercial fish catches or improved food quality
Recreation	improved stream or coastal water quality results in increasing recreational activity (swimming, boating, recreational fishing, etc)
Amenity Space	increase water available for improvements in the recreational greenness of open space thereby increasing recreational activity in parks and yielding health benefits for citizens in surrounding residential areas and increased land values
Coastal/Estuarine Amenity	improved water colour and clarity in water ways downstream of the catchment which may be valued in and of itself
Freshwater provision	provides an alternative freshwater source for urban use and enhances reliability of water supply
Regulation services	
Water quality	Reduction in pollution levels to receiving waters of, for example, nutrients and pathogens
Flood mitigation	Mitigation of the risk of property and infrastructure damage due to flooding
Erosion control	Mitigation of the risk of erosion (sediment transport), and channel scaring in a catchment
Climate/air quality regulation	Reduction in energy consumption and GHG emissions associated with urban water supply and demand management
Supporting services	
Habitat maintenance	Increased (or reduced) environmental flows servicing ecological assets and supporting species biodiversity
Nutrient and soil cycling	Maintenance of soil and nutrient cycles

Potential water sources include stormwater from different catchments, or if stormwater is to be blended, recycled water derived from treated sewage effluent, reservoir water or desalinated water. Once water sources have been defined for each option, water capture methods need to be identified (e.g. holding basin, wetland, etc.), and treatment alternatives (e.g. wetlands, disinfection etc.) defined for each option. Water treatment options will depend on the source water quality, as well as the use to which the treated water is to be put (e.g. potable, non-potable). After treatment, the water has to be stored in surface storages, aquifers, or tanks, etc. Next, the water has to be distributed; this is generally done via a system of pipes and pumps. In conjunction with this step, a decision must be made as to what the end uses of the harvested water will be. Finally, some or all of the water may be discharged into receiving waters (e.g. rivers, lakes, coastal waters, etc.). Each stormwater harvesting alternative consists of a different combination of source, capture, treatment, storage, distribution, end uses and discharge options.

The final component of Step A is the establishment of a database that provides the information necessary for the assessment of the selected stormwater harvesting alternatives in accordance with the selected assessment criteria and system boundaries. This would typically include ecological and financial data (e.g., cost of supply), geographic information (e.g., catchment boundaries, topography, land use), water quality data (e.g., salinity and pollution levels), and meteorological and hydrological data (e.g., daily rainfall and runoff coefficients) for the system under study.

2.2 Infrastructure system design (Step B)

The various infrastructure components associated with the different stormwater harvesting alternatives need to be designed (sized) in order to be able to assess their performance in accordance with the selected criteria (see Table 2.2). Such components include those associated with the capture (e.g. dimensions of detention basin), treatment (e.g. dimensions of wetlands), storage (e.g. number and size of wells associated with aquifer storage and recovery), distribution (e.g. sizing of pipes and pumps) and discharge (e.g. sizing of pipes / channels) of each of the stormwater harvesting alternatives. Assessment criteria affected by the design of these components include cost, energy usage, greenhouse gas emissions, water quality, public health impacts and reliability of the supply. Reliability of the supply is an important consideration, particularly when assumptions are made regarding the provision of public water supply as a backup. Consequently, this step is critical. The ultimate aim of Step B is to develop a short list of preferred options that are technically superior and hence worthy of formal analysis in Step C.

Infrastructure component design generally requires the development of hydrological and hydraulic simulation models. As the potential yield from stormwater harvesting schemes is affected by the amount of rainfall and subsequent runoff from source catchments, which can be highly variable, rainfall-runoff models of the source catchments may need to be developed. These need to be linked with hydraulic simulation models of the various infrastructure components, including detention basins, wetlands and distribution systems to enable these components to be sized. In addition, as water quality is generally a concern in relation to the impact of stormwater harvesting schemes, water quality simulation models may also need to be developed; such models generally make use of the outputs from the hydrologic / hydraulic simulation models. As shown in Figure 2.2, the development of these data requires input from the database of geographic information (e.g. topography, distances) and hydrologic data (e.g. rainfall, runoff and water quality data for the calibration and validation of the hydrologic, hydraulic and water quality models).

Table 2.2: List of the elements/facilities that may need to be included in a stormwater harvesting system

Items	Effective parameters	Description and types
Storage Basins **Wetlands and reed beds**	Number and dimensions Dimensions and layout, vegetation types	
Managed aquifer recharge facilities **Treatment plants**	Number of wells, /basins, recharge rate, recovery rate, storage capacity, recharge credit, depreciation rate Type of treatment plant, processes, capacities	ASR wells, ASTR wells, infiltration basins, check dams, infiltration galleries Iron removal, turbidity removal, UV and disinfection, lime and soda ash filtration, manganese removal,
Storages	Capacity, intake rate, recovery rate, depth, evaporation rate	Basins, wetlands, tanks
Pump stations	Number of pumps	Depends on the total head (static head and head loss)
	Type of pumps	Depends on the total head, discharge, permitted velocity, slope, type of pipe
	Pump power	Depends on the total head (static head and head loss), type of pipe, discharge
	Pumping time and schedule	Depends on the local constraints and limitation, volume of water, GHG emissions
Pipeline	Pipe materials	PVC, DICL, other
	Pipe diameters	Depends on available sizes for selected materials

2.3 Evaluation of system performance (Step C):

Evaluation of system performance involves the calculation of each of the economic, environmental and social criteria for each of the stormwater harvesting options considered in order to determine their relative merits (Figure 2.2). In addition, a preliminary ranking and possibly screening of alternatives can be carried out after the economic assessment. These steps are described in more detail below.

2.3.1 Economic analysis (Adapted from RMCG, 2013 and Marsden Jacobs Associates, 2013)

An economic analysis of a project compares the economic benefits of a project with its economic costs, from society's perspective. That is, the total economic benefits attributable to a project are compared with the total economic costs, regardless of to whom those benefits accrue. Where the total economic benefits exceed the total economic costs, the project produces net benefits to society and is economically justified. Commonwealth of Australia (2006) provides a guide for the conduct of cost-benefit analysis including the conceptual basis for cost-benefit analysis, the principles for estimation of costs and benefits, discounting future benefits and costs and the handling of risk and uncertainty.

Benefits and costs accrue in different ways and over different time periods. Capital costs are often incurred at the start of a project, while benefits occur over the project lifetime. In the case of stormwater harvesting projects, benefits can increase over time as stormwater yield increases. As such, both benefit and cost streams over the project lifetime are discounted by an appropriate discount rate to present day terms, producing 'present value' (PV) benefits and costs.

PV benefits less PV costs gives the 'net present value' (NPV) of a project; if greater than zero, the project is economically justified. PV benefits divided by PV costs gives the 'benefit-cost ratio' (BCR) for the project; this informs us of the scale of benefit for every dollar spent.

The economics of water and stormwater projects

A key challenge for assessing the economic viability of stormwater projects is that, while costs are relatively straight-forward to estimate, the direct benefit stream is far more complicated to delineate and measure.

Some benefits accrue to the users (such as the potential to avoid water restrictions during drought), and others more broadly to society (for example, local amenity).

Additionally, some benefits are essentially avoided costs that would have been incurred in the absence of the stormwater project. These need to be carefully considered for their relevance and scale, given that stormwater projects are usually small relative to total water supply in a city.

Also, different methods exist for estimating the range of benefits that accrue to stormwater projects. The double counting of benefits and costs must be avoided.

In the framework presented in this report the economic criterion will be based on the market benefits and costs. Non-market values related to environmental and social impacts can be assessed in the environmental and social criteria (respectively).

Project Costs

As noted previously, assessment of economic costs associated with stormwater projects is relatively uncomplicated. Two general factors require consideration in assessing relevant costs:

1. Marginal costs: Costs must include only those that would not have been incurred in the absence of the project (for example, if a wetland is built on existing public open space, included maintenance costs should be those additional to the maintenance costs already incurred in the absence of the project).
2. No sunk costs: As an extension to the above, costs that have already been incurred are sunk and are not relevant to project costs. However, the ongoing operating and maintenance costs of these facilities may be relevant.

Stormwater project costs

The most obvious cost elements of a stormwater project are the capital and operating costs of the project itself. These are marginal costs in the sense that if the project did not go ahead they would not have been incurred. In addition to capital costs (land purchase if required, infrastructure expenditure) operating expenditure may include energy use, monitoring and maintenance, and administrative costs.

These will differ in size and scope for each project, but critically include cost items that would not have been incurred in the absence of the project ('marginal' expenditure).

Related project costs

A range of costs exist that may be additional to core project costs may need to be included in the analysis. For example, it may be necessary to include the cost of any new infrastructure that needs to be built or reconfigured to enable storm water to be delivered to the user. If no distribution network exists prior to the project, then relevant costs include the capital costs of distribution, as well as ongoing operating costs of delivery. If the distribution network already exists, then only marginal operating costs are relevant to the project.

Any other costs to the water system that are incurred due to the project must be assessed and included. For example, additional monitoring and regulatory compliance costs for an indirect potable reuse project would need to be included.

Project Benefits

Identification and quantification of project benefits is significantly more difficult than for project costs. Careful delineation and rigorous assessment is critical for development of a defendable economic assessment.

As with costs, all quantified benefit streams must be marginal (only reflecting new and additional benefits) and ignore that quantum of benefits arising from sunk investments.

Value to stormwater customer or user

The use of stormwater provides the user with a bundle of product attributes that may be different from alternative water sources (such as potable supply) or may allow the user access to a resource where no other water supply exists.

For example, the use of stormwater may provide personal value to users due to sustainability considerations and perceived environmental performance. In the multi-criteria framework presented in this report these benefits will be included in the environmental criteria.

Reduced stormwater management costs

An 'avoided cost' attributable to a stormwater reuse project may be a reduction in the costs of stormwater management downstream of the facility. According to National Water Commission (2010) and Department of Sustainability, Environment, Water, Population and Communities (2011), these benefits may be found in:

- A reduction in stormwater management capital expenditure due to lower peak flows achieved by the project;
- A reduction in flood mitigation actions that would have been undertaken in the absence of the project; or
- A reduction in the costs of actions to meet best practice stormwater quality requirements or regulations in the relation to the unharvested stormwater.

Once demonstrated, these avoided costs (including deferral of capital costs) are legitimate benefits to a project that should be included in an economic assessment.

Avoided potable system costs

An important benefit of stormwater reuse as an alternative supply source is that it often replaces water from the potable system, thus avoiding the variable operating costs of potable supply and, where appropriate, deferring next stage augmentations to the potable system.

Assessing the value of this reduction in potable use is challenging, and should preferably reflect the Long Run Marginal Cost (LRMC) of water supply (Marsden Jacobs Associates, 2013 and RMCG, 2013). LRMC is explained in 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."*

LRMC will differ by location and will reflect not just the short term delivery costs of the water supply system, but also the unit impact on the amount or timing of future investments.

It is recognised that alternative frameworks related to cash flow issues might be used by state or local governments.

Using only the short run variable cost of potable water delivery (treatment and pumping) as the avoided potable system costs will ignore the impact of the stormwater project on deferral of the next system augmentation. Where that augmentation will not occur for a long time period, the LRMC will be significantly lower than when an augmentation is pending.

Ideally, the variable water charge levied by the relevant water authority will reflect LRMC, but this may not be true in all cases. When water charges do not equate with LRMC then an estimate of LRMC needs to be developed.

The determination of long run marginal costs (LRMC) for a water utility is a non-trivial exercise that requires regular review and updating. It is regularly undertaken by the water utilities in the UK as a requirement of the regulatory authority OFWAT (OFWAT, 2001). The definition of LRMC used by OFWAT (OFWAT, 2001) is given below:

"(PV of Annuitised capital costs of investments required to meet peak demands + operating costs of meeting peak demands) / (PV of discounted volumes of peak demand)"

Improved (or degraded) water quality

Depending on the level of treatment, harvested stormwater may be of a higher or lower quality than the mains supply. In general, it would be expected that the mains water is of a higher quality than treated stormwater, but this is not necessarily the case for all water quality parameters. For example, the salinity of stormwater could be lower than that of the mains supply.

Regardless of this, the management of water quality needs to ensure that public health and the environment are not adversely compromised. Consideration also needs to be given to the mixing of water of various qualities from different sources, if applicable, to a particular option.

2.3.2 Cost-Benefit analysis

Once the cost and benefits of each option have been quantified, a formal cost-benefit analysis can be carried out. In this, options can be compared in terms of net present values (PV benefits minus PV of costs). A preliminary screening of options can be carried out by eliminating those options that have high negative values of NPV. However, it should be noted that some options that have a negative NPV (and hence are not viable from a purely economic point view) may be desirable in terms of the environmental and/or social criteria and should not eliminated at this stage. A preliminary ranking of options can be carried out based in their NPV (or other appropriate economic criteria). It should be noted that an uncertainty analysis has not been undertaken and changes in assumptions or yields may alter the outcomes.

2.3.3 Environmental analysis

As the environmental impacts of stormwater harvesting schemes are case study specific, a generic process for selecting and quantifying environmental costs and benefits of investments in stormwater management is presented here, and is based on the screening method of Bryan and Kandulu (2009).The proposed process involves:

I) identifying and organising environmental impacts using the typology of ecosystem services, and

II) quantifying environmental impacts in dollar terms where possible or in other physical measures where an economic evaluation is not possible.

I) identifying and organising assessment of environmental impacts using the ecosystem service typology

The concept of ecosystem services provides a framework for assessing systematically a comprehensive range of environmental costs and benefits. Ecosystem services typology considers a broad range of public welfare-generating *provisioning* (e.g. food, fresh water), *regulating* (e.g. flood-, climate-, erosion-, and water quality- regulation), *cultural* (e.g. recreation, cultural heritage), and *supporting* (e.g. water, and nutrient cycling) services that sustain and fulfil human life provided by natural, functioning environmental resources. Thus, in this framework, environmental impacts can be assessed in terms of changes in the welfare value society derives from the ecosystem services provided by the environment that have been impacted by stormwater harvesting.

The ecosystem service framework can also be used as a structured means of systematically identifying and cataloguing all the environmental impacts associated with stormwater management options prior to the assessment of environmental costs and benefits. For example stormwater harvesting may result in increased urban recreational opportunities in a catchment. In the ecosystem services framework, this would be evaluated as an increase in the stock and quality of cultural ecosystem services under ‘recreation’. Stormwater harvesting in a catchment may also lead to reduction in pollution from storm-water run-off to receiving waters. In the ecosystem services framework, this would be categorised as a ‘water quality regulation’ benefit.

Quantifying every possible impact of a water management investment decision is rarely feasible for a number of reasons, including limited availability of data, time constraints, and limited availability of technical expertise and financial resources. Consequently, a screening process is needed. In this study Figure 2.3 was used to determine the most important impacts so as to get the highest return on quantification effort under resource constraints.

Significant environmental impacts to be considered for quantification are the impacts that are likely to occur frequently and/or have direct consequences based on best available contextual knowledge: the evaluation of the impacts has to take into account ecological aspects; geographic information (e.g. topography, land use), water quality modelling (e.g. salinity and pollution levels) and meteorological and hydrological characteristics of a catchment.

The estimation of the energy and greenhouse gas emissions associated with each option is one of the impacts that maybe included in this analysis. The process for undertaking the analysis of energy and greenhouse gas emissions is described in more detail in Appendix B.

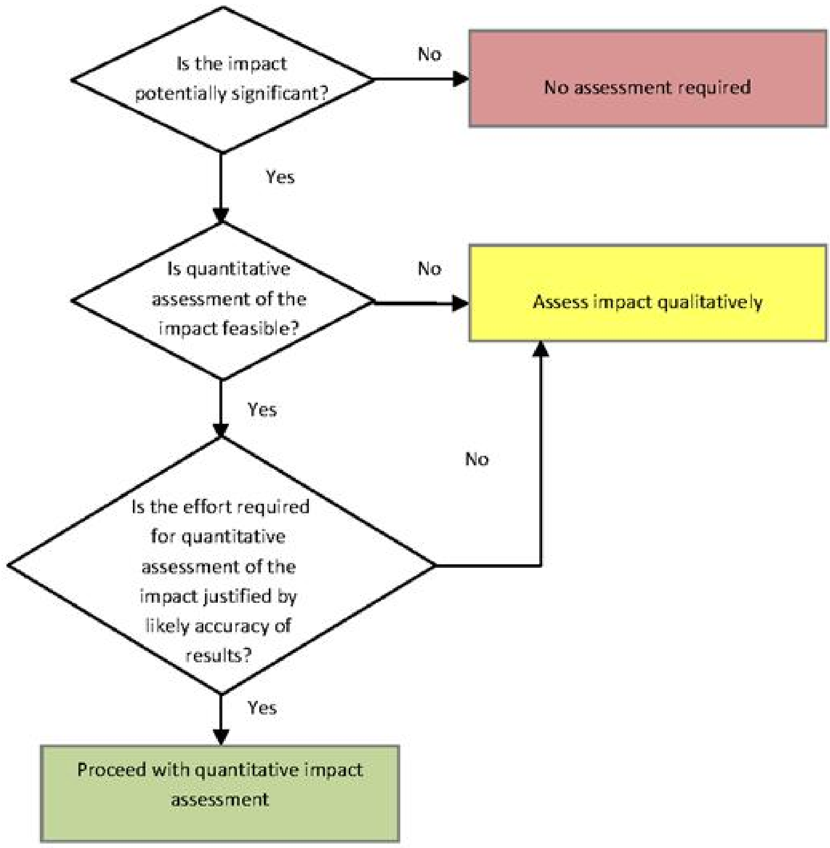


Figure 2.3: Flowchart illustrating how to choose which costs and benefits to quantify

II) Quantifying each of the costs and benefits of ecosystem service impacts

There is a wide range of established market and non-market evaluation techniques for quantifying changes in social welfare associated with changes in the quality and quantity of ecosystem services from investments in water management (Alam et al., 2006). Market evaluation techniques use information from existing markets to derive the value of ecosystem services to society. For example, changes in revenues from fish production can be used to estimate the value of loss of production from a fishery affected by water pollution. Non-market valuation techniques use survey methods to directly elicit society's willingness to pay or to accept compensation for different quantities and/or qualities of an environmental good or service.

Where markets for ecosystem services do not exist and non-market valuation is not feasible, damage replacement or avoidance cost can be used to estimate the social welfare value of ecosystem services instead of stated and revealed preference methods (Liu et al., 2010; WERF, 2010). For example, augmenting treated stormwater in the mains water supply system for a city can result in less saline water delivered to households and industries. The value of reduced salinity, a water quality regulation ecosystem service generated by stormwater harvesting, can be quantified by estimating the cost avoided by households and industry due to reduced expenditure on replacing equipment damaged by mains water.

The key in quantifying costs and benefits of environmental impacts of water management investments is to be able to isolate the contribution of ecosystem services to the value of welfare-bearing goods. One caveat worth noting is that when the value of ecosystem services is assessed by looking at the welfare generated by the goods produced using the ecosystem services, there is the risk of overestimating the value of the ecosystem services by attributing all of the value of the goods produced to those ecosystem services (Bateman et al., 2011). This is because the goods may be produced by combining the ecosystem services under assessment with other resources or factors of production, such as manufactured or human capital. Whilst improvements in the quality and quantity of ecosystem services would lead to some net gain in value, it may not be easy to isolate the contribution of changes in the quality and/or quantity of ecosystem services where there has been some reallocation of other resources and production factors.

Supporting and regulating services are often of indirect use as they support the services that directly affect human well-being. Supporting and regulation services cannot be valued independently due to the potential for double-counting. For example consider stormwater harvesting in a catchment resulting in a number of environmental impacts including reduced pollution in waterways, reduced erosion from river banks, and increased fish population in coastal waters. The value of fish production, a provisioning service to commercial fishermen, can be defined as the profit derived from the sale of the additional fish from improvements in coastal water quality. This profit is dependent on and additional to the benefits of reduced erosion in the catchment. A more detailed catchment level analysis of impacts is given in Appendix C.

2.3.4 Social analysis

A comprehensive social analysis targeting public acceptability of and/or the preference for various water supply options is typically conducted using a multi-method approach, to explore and measure drivers of public acceptability and behaviour in an unbiased manner. The first step in a well planned social assessment is to conduct a qualitative analysis with key informants (e.g. residents, stakeholders, industry), involving one-on-one interviews and/or small focus groups, to determine, in situ. This allows factors to emerge as dominant themes in discussions about the topic of interest (i.e. stormwater). This qualitative method ensures that researcher biases do not directly influence which factors should be important in stormwater acceptance, but rather, allows participants to determine which drivers are important to them through discussion. A team of researchers then analyse/code the data separately, categorising the data based on thematic similarities, and then converge to establish consistency in the results determining which dominant factors emerge. More than one researcher is usually involved in the data collection and analysis to minimise coding biases. In the present context of assessing possible stormwater options, qualitative analysis (Mankad, et al., 2013) has shown that social factors that could be relevant in the stormwater context include: (a) social acceptance of stormwater (favourable attitudes to stormwater and willingness to use it), (b) public trust of the capability of the water relevant authorities to deliver water of the required quality and/or reliability; (c) willingness-to-pay for harvested stormwater for various end uses. These factors can be assessed by a survey or through the use of focus groups.

The purpose of qualitative data, in this assessment program, is to determine key variables that are important to the community with respect to stormwater. However, a weakness of the qualitative approach is that it is unable to determine the extent to which these views and attitudes towards stormwater are prevalent within the community, and findings, therefore, cannot be generalised to the wider population. A quantitative method is required to measure wider community perceptions, and this is included in the next stage of the social assessment.

A quantitative approach is typically structured around theoretical principles which best fit the findings of the qualitative data, and can include a survey of a sub-sample of the population that is affected (or potentially affected) by the proposed stormwater scheme(s). The survey may be conducted by mail, phone interview or online and will aim to collect a representative sub-sample of the population of interest, with respect to key demographic indicators (e.g. gender, age, income, occupation, etc.). A major challenge with stormwater research is that many people have a very limited understanding of the issues so it is important to find ways of conveying information about stormwater management. Pictures or diagrams can be helpful in this regard. Often respondents are offered more than one water source or treatment option (e.g. stormwater vs. desalinated water), so that comparisons of their preferences can be made. The importance of the factors identified in the qualitative research and preferences among water sources are typically analysed using social statistical programs.

So far, the methodology has used a standard CBA approach that combines standard CBA of economic and environmental values without double counting. This needs to be closed off with a formal selection of a sub-set of options to be passed through to the MCA.

2.4 Multi-criteria decision analysis (Step D)

Once the performance of the various stormwater harvesting alternatives has been assessed in relation to the selected economic, environmental and social criteria, the alternatives can be ranked using multi-criteria decision analysis (MCDA) so as to identify the best alternative(s). As all assessment criteria are generally not considered equally important by stakeholders, weightings are assigned to each of the criteria. There are many methods for assigning these weights (Al-kloub et al., 1997; Hajkowicz et al 2000; Kheireldin and Fahmy 2001, Polyhonen and Hamalainen 2001; Bottomley and Doyle 2001); however, there is no general agreement as to which method generates the best results (Barron, and Barrett, 1996). A practical method to tackle this problem can be the exploration of the effect of different weights on the ranking of the alternatives using sensitivity analysis methods (Jessop 2004 and Rios Insua 1990). While this does not improve the weight values, it demonstrates the extent to which the different weights have a significant effect on the ranking the alternatives.

Once the weights for the various criteria have been determined, an MCDA technique may be used to combine values of the performance criteria and criteria weights in order to identify the preferred option(s). Several MCDA techniques have been presented in the literature, e.g. ELECTRE, CP, NAUT (Duckstein et al., 1982), PROMETHEE (Brans et al. 1986), AHP (Karni et al. 1990), SAW (Hobbs et al 1992), SMART (Larichev et al, 1993), MAUT (Olson et al., 1995), stochastic dominance (Bell et al., 2001), and NAIDE, ORESTE methods (Lerche et al., 2002). However, it is impossible to identify a single best MCA methodology (Zanakis et al., 1998). More information about the comparison of MCDA techniques and their specific properties can be found in Duckstein et al. (1982), Al-Shemmeri et al (1997), and Mahmoud and Garcia (2000).

3. Case Study : The Parafield Stormwater Harvesting Scheme

The Parafield stormwater harvesting scheme is part of an integrated network for managing stormwater in the Salisbury area, north of Adelaide, South Australia. The scheme was developed for harvesting urban stormwater in the City of Salisbury and utilises water treatment in a reedbed followed by aquifer storage and recovery (ASR).

The layout of catchments, wetlands and ASR facilities in the Cities of Salisbury, Playford and Tea Tree Gully is shown in Figure 3.1. A network of pipes (called the "ring main") that allows for transfers between stormwater harvesting sites and sites where the harvested stormwater is used. Stormwater is diverted from the Parafield Drain into a series of detention and treatment basins (Marks *et al* 2005). After treatment, the water is supplied directly to industrial and residential water users. Any excess water is stored in aquifers for use during dry periods. The Parafield scheme began operation in 2003 and has undergone a series of modifications since that time. The total capital cost of the Parafield stormwater harvesting scheme over its period of construction was $13m (Matthew Coldwell, Salisbury Water, pers. comm., March 9, 2012). Of this cost, approximately $4m was associated with the Parafield scheme without ASR, $2m for the cost of ASR and an additional $7m for cost of reticulation (Bruce Naumann, Salisbury Water, pers. comm., May 13, 2013).

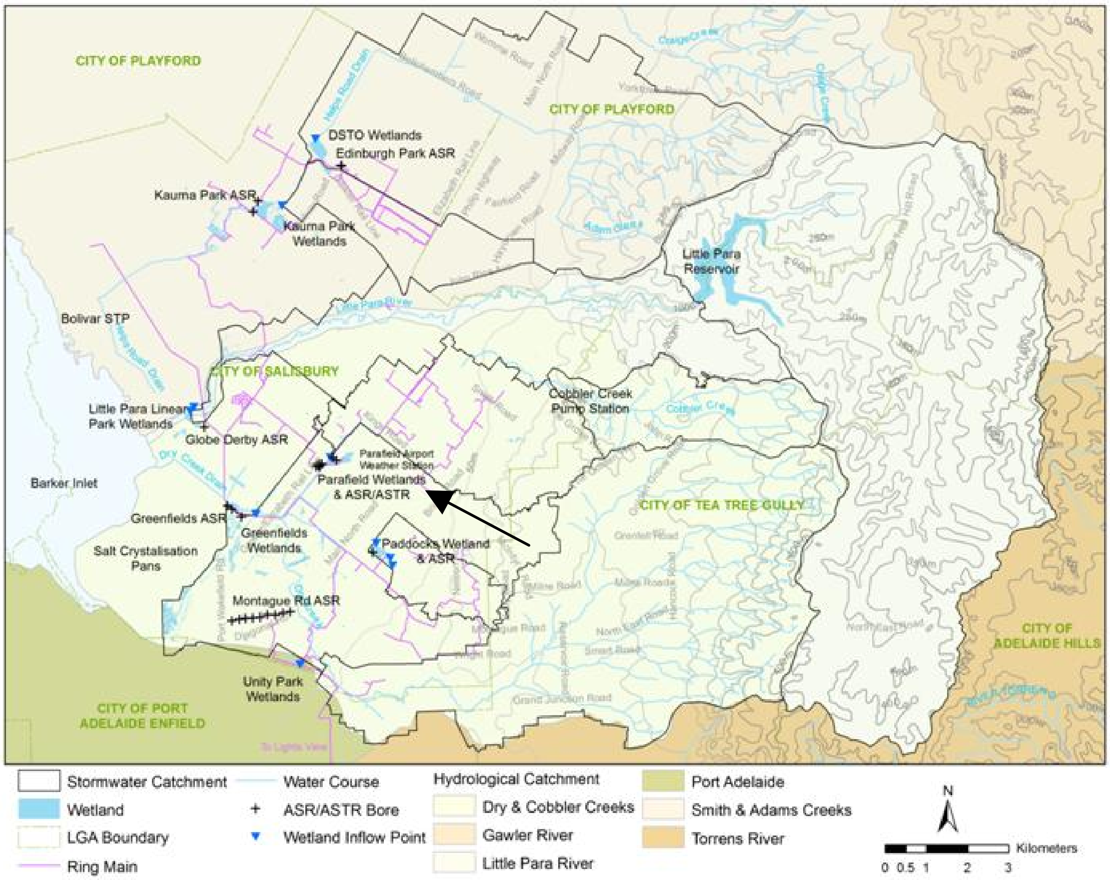


Figure 3.1: Layout of catchments, wetlands and ASR facilities in the Cities of Salisbury, Playford and Tea Tree Gully

In addition to the Parafield ASR, there is an existing pipeline and pumping station that allows recycled wastewater from the Bolivar treatment plant to be transferred to Greenfields. At Greenfields, there is an existing storage and pumping station to deliver water to residential consumers at Mawson Lakes. The cost of this infrastructure is estimated to be $3.7m for the pipe and pump from Bolivar to Greenfield and in $1.37m for the infrastructure in Greenfield (Appendix D).

The maximum rate of injection in the Parafield Aquifer Storage and Recovery System (ASR) is 8 ML/day (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013). The main consumers from the Parafield scheme are households in Mawson Lakes who use the water for garden watering and toilet flushing, and G.H. Michell and Sons who use the water as part of the wool scouring process. As a follow on to the development of the ASR project, an ASTR (Aquifer Storage, Transfer and Recovery system) project was developed at the site with the objective of assessing whether water of drinking quality could be produced. In contrast with ASR, which uses the same wells for injection into and recovery from an aquifer, separate wells are used for injection and recovery in ASTR. The aim of this operation is to facilitate treatment of the stormwater as it travels through the aquifer.

Stormwater runoff in the Parafield catchment is part of a complex network of waterways that flow into the Barker inlet of the Gulf Saint Vincent, a marine environment consisting of mangroves and seagrass meadows that are important for South Australia's fishing industry and recreational use. The marine ecology of the Barker inlet has in recent years been degraded by the flow of stormwater and wastewater into the inlet. The Parafield stormwater harvesting facility is a significant contributor to recent efforts to harvest and treat stormwater runoff flowing into the Barker inlet, as shown later in an assessment of environmental benefits.

General land use types in the catchment include residential areas with parklands, and industrial land (Table 3.1). Urbanisation has mainly taken place in the upper parts of the catchment (Figure 3.2). Due to extensive urban coverage of the Parafield area resulting in large roofed and paved areas the catchment is expected to convert rainfall to runoff with high efficiency. The middle and lower parts of the catchment are urbanised with a lower housing density resulting in less rainfall run-off. The industrial areas include a tyre manufacturing facility, a pharmaceuticals factory, a wool processing plant, a dairy processing facility, a beverage manufacturing factory and a variety of small to medium metal and cement manufacturing industries. A variety of commercial properties (5% of the catchment area) are also found, including a automotive service and repair businesses and a warehousing facilities. There are also a number of small market garden horticultural properties and one livestock grazing paddock adjacent to the harvesting off-take point.

The Parafield scheme consists of several components and facilities (see Figure 3.3) including:

- A weir that diverts stormwater from the Parafield drain into the in-stream basin;
- A series of inter-linked basins and treatment storages. The system includes an in-stream basin (47 ML) fed from a diversion weir with overflow, a holding storage (48 ML) and a reedbed (25 ML) with a minimum operating volume of 7.5 ML;
- A pump and pipe system capable of delivering up to 50 ML/day from the in-stream basin to the holding storage;
- Six injection wells. There is a single injection pump able to deliver 8 ML/day;
- Four wells are currently used for extraction (up to 6 ML/day);
- Two above ground storage tanks each with a capacity of 300 kL (Karen Barry, CSIRO, pers. comm., April 3, 2013);

- Five pumps able to deliver 10 ML/day at 600kPa to the distribution system, and
- Pumps, pipelines and monitoring and control facilities.

Table 3.1. General land use types in the Parafield catchment (Page et al, 2013a)

Land Use	**Area (ha)**	**% Catch.**
Commercial	72	5
Horticulture	3.4	0.2
Industrial	125	8
Institution	61	4
Livestock	21	1
Mining	82	5
Recreational	15	1
Reserve	115	7
Residential	574	36
Rural Residential	0.5	<0.1
Roads/Rail	308	19
Vacant	213	13
Total Catchment Area (ha)	**1,590**	

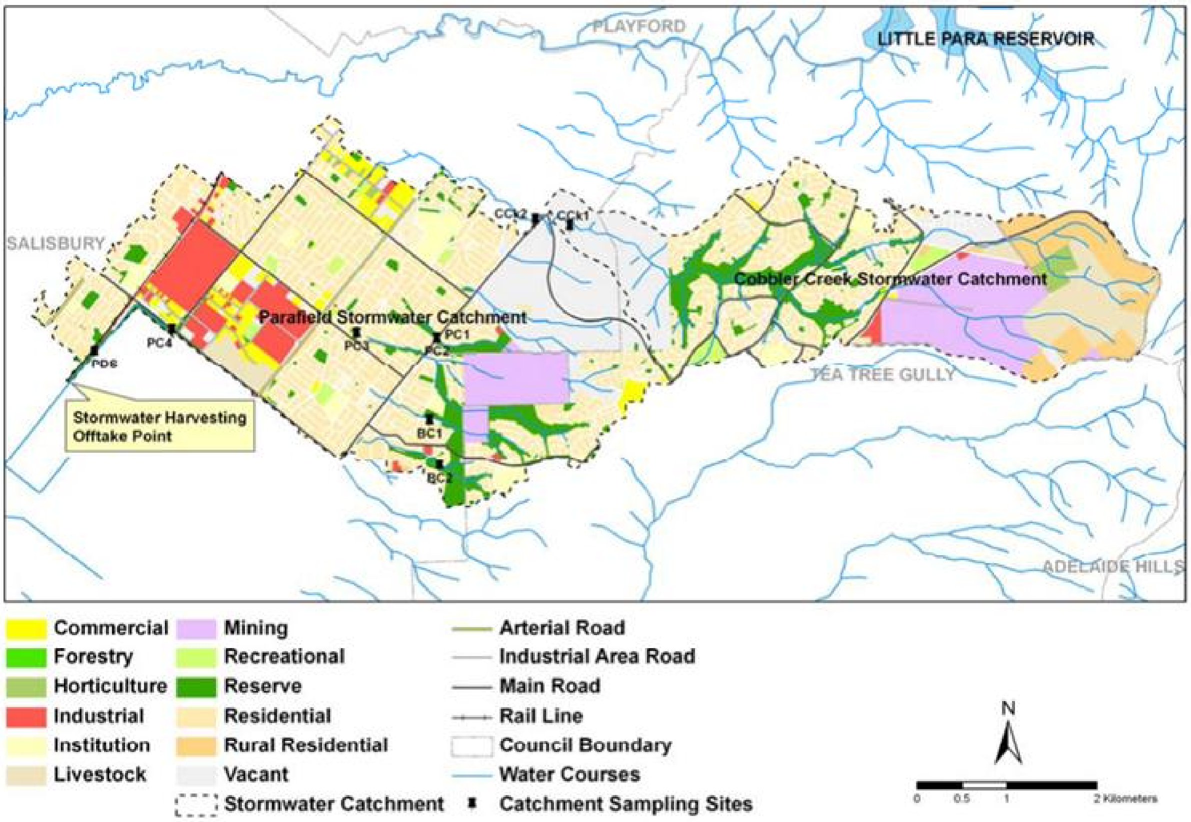


Figure 3.2: Land Use in the Parafield Catchment

Currently, the water from the reedbed is always injected into the aquifer so as to reduce variation in water quality; then well pumps are used to transfer the water from the aquifer to two existing tanks. From here, another set of pumps distributes the water to the users (Figure 3.3). For the purpose of this analysis it is assumed that these pumps can transfer 1.1 GL/year with a pressure head equal to 30 m. The supply main to Michell consists of 3 km of 225 mm Class 9 mPVC, while the pipe that connects Mawson Lakes blending tank is 2.2 km long and is a 225 mm diameter mPVC (Class 12). In the tank stormwater mixes with recycled water from the Bolivar Sewage Treatment Plant and Recycling Plant in order to keep the salinity of blended water acceptable for garden irrigation.

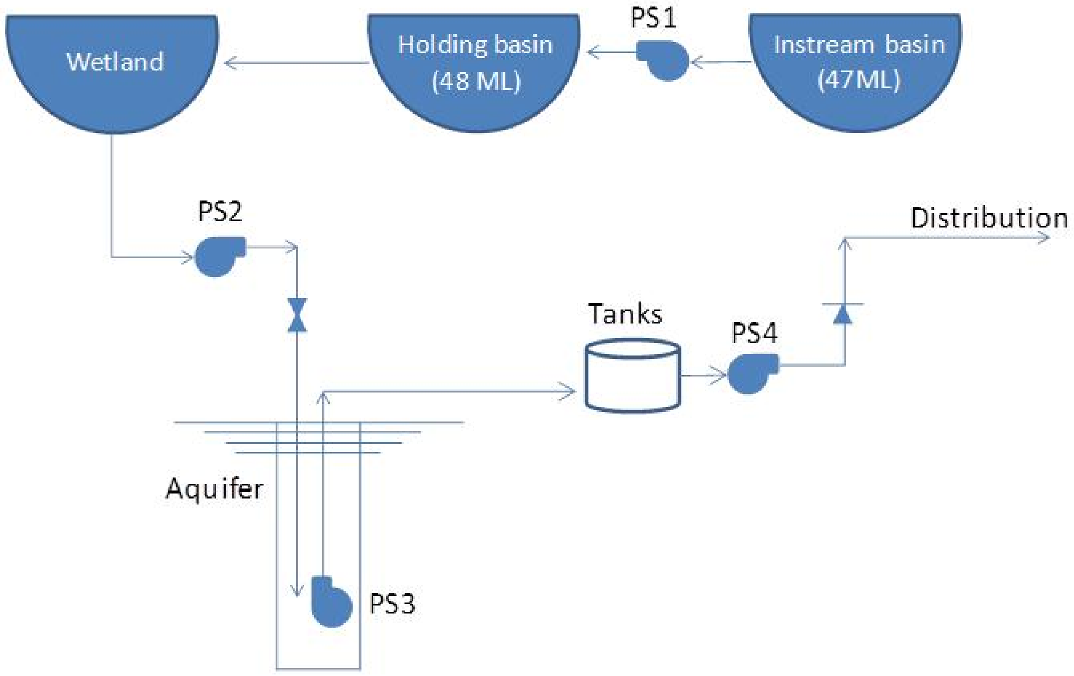


Figure 3.3: The current layout of the Parafield Stormwater Harvesting Scheme

Data on the existing facilities at Parafield were provided by Bruce Naumann (Salisbury Water, pers. comm., April 17, 2013). Data relating to the pipe system are from Marks et al. (2005).

4. Application of the Methodology to the Case Study

The methodology of Section 2 will now be applied to the Parafield case study on a step-by-step basis. Note that this case study is illustrative only and is based on the best information that was available at the time the study was carried out. The outcomes of the analysis depend on the assumptions that are made. The case study is not intended to provide general recommendations for the use or non-use of stormwater for the options considered.

Ideally, a robust sensitivity analysis would be carried out to assess the sensitivity of the outcomes of the case study to the various assumptions made. This was beyond the scope of this project. Furthermore, a number of the externalities could not be assessed due to the limited availability of data.

It is clear that the economic viability of the various stormwater options is sensitive to the assumed yields and benefits per kilolitre of harvested stormwater supplied to the consumer. Careful consideration of the variability and certainty of all assumptions should be undertaken before committing to an investment strategy.

4.1 Problem definition and data gathering (Step A)

Figure 4.1 is a schematic that shows the 12 generic options that have been identified in the proposed case study using the methodology detailed in Step A of Figure 2.2. The options are grouped in terms of end water uses i.e., irrigation of open space (Options 1-4), 3rd pipe supplies to households for toilet, washing machine and garden uses (Options 5-8) and potable uses (options 9-12). The dots in Figure 4.1 signify the inclusion of the process shown at the top of the figure. Treatments within a column are not necessarily the same; they are fit for purpose for the end use bearing in mind the whole of the treatment train. A description of these potential options is provided in Table 4.1.

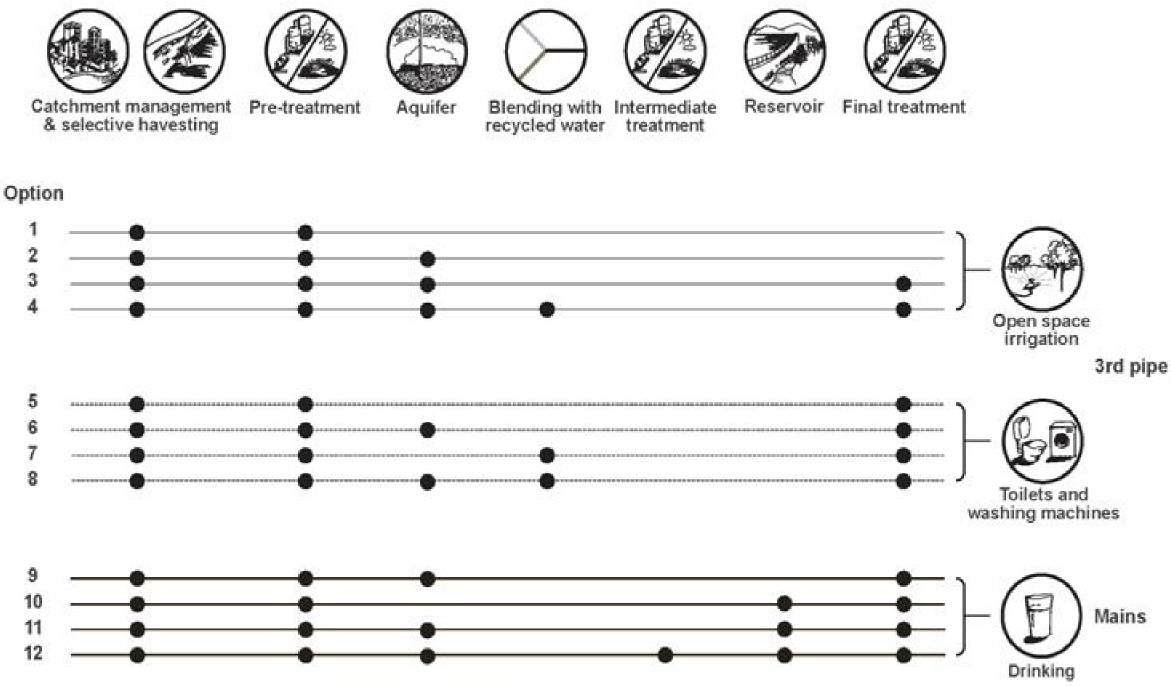


Figure 4.1:MARSUO options

Table 4.1 Descriptions of available options for storage, treatment and blending of stormwater for three classes of uses; open space irrigation, third pipe non-potable supplies and drinking water supplies

Options	Description
	Open space irrigation – external use only
1	Without aquifer storage (former practice)
2	With aquifer storage and recovery (current practice)
3	Option 2 followed by disinfection.
4	Option 2 followed by blending with tertiary treated wastewater and disinfection.
	Third pipe system – external and internal household usesfor toilet flushing, washing machine and for garden watering
5	Without aquifer storage and then disinfection.
6	With aquifer storage and recovery then disinfection.
7	Option 5 (no aquifer) and blending with treated wastewater and disinfection (former practice).
8	Option 6 followed by aquifer, and blending with treated wastewater and disinfection (current practice).
	Drinking water uses
9	With aquifer storage and recovery followed by treatment and disinfection then injected directly into mains water distribution system.
10	Without aquifer storage. Transfer to the Little Para Reservoir, then treatment and disinfection.
11	With aquifer storage and recovery then transfer to the Little Para Reservoir followed by treatment and disinfection.
12	Same as Option 11with intermediate treatment between aquifer and reservoir.

In this step, boundaries are defined and impacts relating to technological alternatives, stages of the water cycle, spatial limits and temporal limits. The physical boundary of the Parafield scheme and catchment is defined in Section 3. However, given that the options include distribution for watering of public open spaces, distribution to residential consumers through third pipe systems and possible potable use through direct injection into the water supply mains or by transport to a reservoir, it is important to ensure that the physical boundary include all these facilities.

The next step is to identify the criteria that will be used to identify benefits and costs. The benefits and costs include economic, environmental and social benefits and costs. These will be considered in turn for the Parafield scheme.

4.1.1 Economic Benefits and Costs

The basic economic criterion is the net present value of economic benefits minus costs (Commonwealth of Australia, 2006)

The costs will include the direct costs of constructing and operating the infrastructure associated with the stormwater harvesting scheme and the economic benefits will include the savings in cost associated with the alternative sources of supply. As noted in Section 2.3, the estimation of benefits and costs will strongly depend on the assumptions and boundaries defined for the analysis.

In the Parafield case study, the existing infrastructure has been developed over more than a decade. As noted earlier, the total capital cost spent on the scheme was $13m. This includes the basins, reedbed, ASR wells, pumps, tanks and pipes to distribute the water to the industrial consumers and to Mawson Lakes, but excludes the conventional urban drainage infrastructure which would be required whether or not the scheme was implemented. The cost of this stormwater harvesting infrastructure needs to be included when considering the project as a new scheme, but is considered a sunk cost when evaluating as an incremental scheme. Thus for an incremental scheme only the capital costs of new facilities are included in the analysis. The operating and maintenance costs of all facilities associated with the scheme should be included. Both calculations, with and without sunk costs, are performed for transparency as a national exemplar to inform urban planners and water utilities.

4.1.2 Environmental Benefits and Costs

Table 4.2 is the result of screening the more comprehensive listing of environmental impacts for the Parafield catchment using the process introduced in Figure 2.3. Some environmental impacts were deemed to be quite insignificant or irrelevant for an existing site such as the Parafield, however a number of impacts were quantified where it was possible to quantify the impacts. The selected impacts are categorized as shown in Figure 2.3.

Table 4.2. Impacts and related ecosystems services associated with the operation of stormwater harvesting at Parafield (Y is for impacts assessed quantitatively, y-qualitatively, and N - impacts not assessed during this stage of the analysis)

Ecosystem service type	Ecosystem Service value	Quantified /qualitative /Not estimated.	Discussion
Cultural services	Conservation ethic	**N**	The magnitude of this "feel good" effect is unknown and it is unclear how to quantify
Provisioning Services	Fish production values and marine biodiversity	**Y**	Commercial fishing is not allowed in the Barker inlet, but it is a breeding ground for commercial fisheries. The effects of N and SS on seagrass die off were taken as a scalar on habitat that supports a wide range of marine life including fish.
	Freshwater provision	**Y**	This is covered directly in the cost-benefit analysis
	Recreation	**N**	Recreation values of detention areas are much more limited than other catchments, as the Parafield storage areas and wetland are fenced and netted and there is no public access.
Amenity	Coastal/Estuarine Amenity – coastal water clarity	**y**	Improved water colour and clarity is a benefit for recreation, tourism and affects coastal property values
	Coastal/Estuarine Amenity – beach restoration	**Y**	Loss of seagrass leads to mobilisation of sand, loss of beach protection in storms and loss of sand on recreational beaches. A sand pumping program is underway to replenish beaches, at a known cost that could be avoided by reducing N and SS in coastal discharges thereby reducing seagrass loss and sand drift.
	Amenity Space	**Y**	If water that otherwise wasn't available is used on open space, then the value of these areas may be capitalised in surrounding areas.
Regulation services			
	Flood mitigation	**N**	This was not estimated. The scale of ASR operation are unlikely to significantly affect volumes of stormwater runoff during peak flood events
	Erosion control	**N**	Degree of erosion and channel scouring (which may have ecological impacts) are unknown
	Climate/Air quality regulation	**Y**	Total GHG emissions are estimated from construction through to operating phases
Supporting Services	Species in estuarine and coastal area	**N**	Maintenance of habitat which supports marine biodiversity is likely to be the best ecological indicator to focus on

4.1.3 Social Assessment

The social assessment was carried out by two web-based surveys of Adelaide residents. The key questions that were addressed in relation to this study were the residents' attitude towards the use of harvested stormwater, in particular:

a) Did they support this option for treatment and delivery of harvested stormwater

b) Would they trust water authorities to ensure the quality of the water

c) How much would they be willing to pay for water from this source

In order to reduce possible confusion on the part of the respondents, they were asked to consider only the following three options:

(1) Treatment through a wetland and aquifer storage and recovery and then delivery to their house via a separate third pipe network where it could be used garden watering, toilet flushing and in the washing machine.
(2) Treatment through a wetland, aquifer storage and recovery and delivery to a water supply reservoir for blending with other source water before being further treated through a water treatment plant. The water would then be distributed through the water supply mains for drinking and other purposes.
(3) Treatment through a wetland and aquifer storage and recovery and then direct injection into the water supply mains for drinking and other purposes.

Note that these surveys were not intended to provide an accurate assessment of the willingness-to-pay of the consumers for stormwater for various end uses. The willingness-to-pay question provides information on whether the consumers are willing to pay more, the same or less than the current water price for stormwater for various end uses.

4.1.4 Data and information gathering

For the water harvesting system, the database consists of ecological and financial data (e.g., the cost of water supply), geographic information (e.g., topography, land use), water quality data (e.g., salinity, and pollution levels), and meteorological and hydrological characters of the basin (e.g., daily rainfall and runoff coefficients). The principal data (such as dimension of the available infrastructure, current water network) were provided by the City of Salisbury. The water quality, flow data and GIS land uses were prepared by CSIRO, while the rainfall and evaporation data were obtained from SILO (an enhanced climate database hosted by the Queensland Climate Change Centre of Excellence (QCCCE)). Possible climate change effects have not been included.

4.1.5 Effects of Climate Change

The likely effects of climate change on rainfall and runoff in Adelaide and the Mount Lofty Ranges are highly uncertain. Paton et al (2013) found that the forecast changes in rainfall for the Adelaide region depend on the global circulation model (GCM) used and the emission scenario assumed. The CSIRO Ozclim website provides projections of the likely changes in mean rainfall at various locations in Australia as modelled by various GCMs for different emission scenarios up to the year 2050.

For example the CSIRO Mark 3.5 model forecasts for Adelaide for 2050 are for a 22 per cent reduction in mean annual rainfall in 2050 compared to 1990 for the A2 emission scenario. The corresponding values for the B1 and A1B scenarios are reductions of 18 per cent and 23 per cent respectively. For rural catchments (such as the Mount Lofty Ranges catchments), it have been found that the percentage change in runoff as a result of climate change is likely to be 2 to 2.5 times the percentage change in rainfall. Therefore a 22% reduction in rainfall will produce a 44% to 55% reduction in runoff. On the other hand the annual runoff from urban catchments is approximately proportional to the annual rainfall, so that a 22% reduction in rainfall will produce a 22% reduction in runoff. Therefore, urban stormwater is likely to be less affected by climate change than the runoff from rural catchments.

Furthermore, the proportion of impervious area in urban catchments, including those that feed the Parafield stormwater harvesting system is expected to increase into the future due to urban consolidation. Wallbridge and Gilbert (2009) estimated that climate change effects to the year 2050 would reduce the yield of urban stormwater from catchments in Adelaide by between 10 and 20%, however this could be fully offset by an increase of 10% in the impervious area in these catchments due to urban consolidation.

4.2 Infrastructure system design (Step B)

A simulation model of the catchment was developed using Watercress software (Clark and Associates, 2001) to estimate the stormwater yield of the catchment for the rainfall period between 1980 to 2000 (Appendix E). The model output indicated a mean annual yield from the scheme of 1200ML/year with a standard deviation of 220 ML/year. A conservative figure of 1100 ML/ year (3 ML/day) of harvested water is used in the assessment. This figure is based on maximum injection and extraction rates per well of 20 to 25 L/s (Wallbridge and Gilbert, 2009; Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013). It should be noted, however, that, for schemes that involve ASR, 100% recovery of the water injected into the aquifer is not possible due to mixing with in-situ brackish groundwater. In this study a recovery rate of 80% is assumed so the average annual supply from a scheme in this study that includes ASR is 880 ML/year (i.e. 80% of the harvestable catchment yield).

For schemes without ASR, an average yield of 370 ML/year was estimated using the hydrologic model. That is, ASR more than doubled the harvestable volume at Parafield by and allowed storage until the time of the highest value use.

4.3 Evaluation of system performance (Step C)

Economic, environmental and social evaluation was undertaken for the 12 options given in Table 4.1. Each option has an associated water use. For example Options 1 to 4 involve water for irrigation use by transfer from the wetland or injection into the aquifer, subsequent extraction and transfer to the demand area. Options 5 to 8 are non-potable uses with the harvested water distributed for toilet flushing, washing machine and garden watering purposes. Options 9 to 12 involve treatment of the water so that it reaches drinking water quality and injecting it directly into the water supply mains or transfer to the Little Para Reservoir where it mixes with other water in the reservoir before passing through the existing water treatment plant which involves coagulation, filtration and chlorination.

4.3.1 Economic analysis

As noted in Section 2.3.1, the economic criterion used will be the net present value of benefits minus costs. For comparison with other studies, levelised costs will also be computed for each option. The concept of levelised cost is defined in Appendix F. The parameters used in the economic analysis are presented in Table 4.3.

Economic Costs

The first step in the economic analysis is to estimate the economic costs of the 12 options outlined in Section 4.1.

These costs include capital, operation and maintenance costs which will all be discounted to present value using the parameters given in Table 4.3. The details of the options and their costs is given in Appendix G, while Table 4.4 gives annual supply, present value cost and levelised costs of each option.

The risk management costs given in Table 4.3 were determined for the current options covered by the risk-based management plan (Page et al., 2013b) by ascribing labour, travel and operating costs, including laboratory analytical costs for samples, for the frequency of sampling and the analytes determined in the plan. The cost includes, time for inspection, monitoring, recalibrating monitoring equipment, training, reporting, meetings and audit. For other options estimates were made of the effort and analytical costs based on the level of exposure, and the anticipated monitoring requirements for confidence in the safety of the supply, using the same salary rates and overheads.

The risk management cost per kilolitre for Options 5 and 7 is higher than that applying to Options 6 and 8 as the former Options do not include ASR and hence supply a lower volume of water. Therefore, the fixed component of the risk management cost is averaged over a smaller volume. A similar situation applies to Option 1 compared to Options 2 to 4.

Table 4.3.Parameters used in the Economic Analysis

Parameter	**Assumed Value**
Discount Rate	6% p.a.
Project Life	25 years
Price charged for potable water	$3.45 /kL*
Price charged for harvested stormwater	$2.59 /kL
Cost of Electricity	$0.25 per kWh
Pump Efficiency	80%
Pump Standby Capacity	50%
Peaking Factor for Transfer between Storages	2.0
Maximum Hours of Pumping per Day	20
Pump Life	20 years
Recovery Fraction from ASR	0.80
Fraction losses in Little Para Reservoir	0.06
Injection head for pumping into aquifer	30 m
Extraction head for pumping from aquifer	60 m
Annual Pump Maintenance as a Fraction of Capital Cost	0.05
Annual Pipe Maintenance as a Fraction of Capital Cost	0.02
Annual Tank Maintenance as a Fraction of Capital Cost	0.05
Cost of water quality risk management (excluding treatment)	$0.20 per kL (irrigation, Option1) $0.12 per kL (irrigation, Options 2-4) $0.26 per kL (non-potable use, Options 5 and 7) $0.18 per kL (non-potable use, Options 6 and 8) $0.43 per kL (potable, direct injection, Option 9) $0.22 per kL (potable, pumping to Little Para Reservoir, Options 10 - 12)

* Based on tier 2 (consumption of between 30 kL and 130 kL per quarter for a dwelling), SA Water 2012/13 prices.

Table 4.4: Summary of the average annual supply, present value of costs and levelised costs of the various options (not including the cost of existing infrastructure for the Parafield scheme and the Bolivar-Greenfields –Mawson Lakes scheme)

Option	Average annual supply (ML/year)	Present Value of Cost ($m)	Levelised Cost ($/kL)
1	370	2.13	0.45
2	880	4.71	0.42
3	880	5.08	0.45
4	2100	17.06	0.64
5 (Greenfield)	370	12.11	2.56
5 (Brownfield)	370	20.25	4.28
6 (Greenfield)	880	24.57	2.18
6 (Brownfield	880	43.93	3.91
7 (Greenfield)	1000	27.30	2.14
7 (Brownfield)	1000	49.30	3.86
8(Greenfield)	2100	55.54	2.08
8 (Brownfield)	2100	101.43	3.80
9*	880	22.19	1.97
10*	1034	15.45	1.17
11*	827	14.75	1.40
12*	827	17.73	1.68

*These options do not include distribution costs as they utilise the existing (potable) water distribution network

The costs presented in Table 4.4 do not include the costs of the existing infrastructure for the Parafield scheme. The present values of the costs of existing infrastructure are estimated to be the following:

(1) $4m for the Parafield scheme without ASR
(2) $6m for the Parafield scheme with ASR
(3) An additional $7m for the distribution system (excluding the third pipe network in residential areas
(4) $3.7m for the options that involve blending with wastewater (Options 4, 7, 8)
(5) $1.37m for options that involve transfer of water from Greenfields (Options 4, 5, 6, 7, 8)

Table 4.5 summarises the present value of costs for the various options taking into account existing infrastructure and are indicative of the costs of an entirely new scheme.

Table 4.5: Summary of the average annual supply, present value of costs and levelised costs of the various options (including the cost of existing infrastructure for the Parafield scheme and Bolivar-Greenfields-Mawson Lakes existing scheme)

Option	Average annual supply (ML/year)	Present Value of Cost ($m)	Levelised Cost ($/kL)
1	370	13.13	2.78
2	880	17.71	1.57
3	880	18.08	1.61
4	2100	35.13	1.31
5 (Greenfield)	370	24.48	5.18
5 (Brownfield)	370	32.62	6.90
6 (Greenfield)	880	38.94	3.46
6 (Brownfield	880	58.30	5.18
7 (Greenfield)	1000	43.37	3.39
7 (Brownfield)	1000	65.37	5.11
8(Greenfield)	2100	73.61	2.74
8 (Brownfield)	2100	119.50	4.45
9*	880	28.19	2.51
10*	1034	19.45	1.47
11*	827	20.75	1.96
12*	827	23.73	2.24

*These options do not include distribution costs as they utilise the existing (potable) water distribution network.

Economic Benefits

The second step in the analysis is to estimate the economic benefits of the various options. In this process, the three possible end uses of the harvested stormwater need to be distinguished. If the harvested stormwater is used for watering public open space it is basically a substitute for using potable mains water for this purpose (Bruce Naumann, Salisbury Water, pers. comm., May 19, 2013).

If the harvested stormwater is used for third pipe distribution to residential consumers, harvested stormwater is provided to these consumers at a lower price than mains water. Therefore it is expected that the average consumption per house will be higher than if all water were to be paid for at the price of mains water. It has been observed for the period 2007/08 to 2011/12 that the average annual consumption per house at Mawson Lakes is 23% greater than the average annual consumption of properties of similar land area elsewhere in Adelaide Metropolitan area (Steve Kotz, SA Water, pers. comm., September 11, 2013). Hence, the fact that blended stormwater and treated wastewater is provided at a cheaper price than mains water has led to a greater total consumption than would have occurred if all water was provided at the price of potable mains water. This situation will be analysed in more detail below.

When harvested stormwater is used as a potable source it is a direct substitute for the use of the conventional potable supply for this purpose.

The economic benefits comprise the following components:

(1) Savings in supply cost from conventional sources

(2) Benefits to consumers of having additional water available (for cases where consumption increases as a result of the lower price of harvested stormwater)
(3) Reduction in cost to consumers due to reduced salinity of the harvested stormwater

These three factors will be considered in turn.

Savings in Supply Cost from Conventional Supplies

Commonwealth of Australia (2006) recommends that all costs used in a cost-benefit analysis should be marginal costs. Assessing the value of a reduction in potable use is challenging, and should preferably reflect the Long Run Marginal Cost (LRMC) of water supply (Marsden Jacobs Associates, 2013 and RMCG, 2013). The rationale for using the LRMC is discussed in Section 2.3.1 above.

According to the Government of South Australia (2011) and Government of South Australia (2012), the LRMC of supply for Metropolitan Adelaide is in the range \$2.00 to \$2.75 per kL and this was used in setting the tier 2 water price for residential consumers of \$2.75 /kL in 2011/12. The tier 2 price in 2012/13 was \$3.45 per kL.

Hence, in this case study, the savings in supply costs from conventional sources will be estimated using a LRMC of \$2.75 per kL, with a sensitivity analysis being carried out using a LRMC of \$2.00 per kL. Coincidentally, this is consistent with a figure of \$2.00 per kL estimated as the LRMC of supply for the Sydney water system (Abrams et al., 2011).

Benefits to consumers of having additional water available (for cases where consumption increases as a result of the lower price of harvested stormwater)

This is described in more detail in Appendix H. The benefit is based on the increased willingness-to-pay of consumers for the additional supply of water via the third pipe system and is given by the following equation:

$$NAB = (Q_1 - Q_2) \cdot \left(\frac{P_1 + P_2}{2}\right) + C_P(Q_2) - C_N(Q_1) \qquad (4.1)$$

Where NAB = net annual benefit (\$)

Q_1 = outdoor and toilet flushing use via the non-potable supply (kL/year)

Q_2 = outdoor and toilet flushing use if all water was charged at the potable price (kL/year)

P_1 = price of non-potable supply (\$/kL)

P_2 = price of potable supply (\$/kL)

C_N (Q_1) = cost of supplying quantity Q_1 via the non-potable network

C_P (Q_2) = cost of supplying quantity Q_2 via the potable network

As indicated in Appendix H, it is estimated for Mawson Lakes that $Q_2 = 0.67\ Q_1$

i.e outdoor and toilet flushing consumption would be expected to be around 33% lower at Mawson Lakes if all water were supplied from the mains supply and charged at the tier 2 potable price instead of at the price for harvested stormwater.

Reduction in Cost to Consumers due to Reduced Salinity of Harvested Stormwater

High salinity levels can cause damage to household plumbing fixtures and fittings, hot water systems, water filters and water softeners. General commercial and industrial salinity damage can affect cooling towers, and boilers.

Incorporating less-saline treated stormwater into the existing mains water supply system for potable households use and commercial and industrial water use in the Parafield catchment may benefit water users through reduced salinity damage replacements costs. Careful planning of stormwater schemes should take into account the impact from saline groundwater as the salinity from stormwater harvesting schemes can vary considerably depending on the local conditions.

The salinity damage replacement costs that would be incurred by households and commercial industries with and without treated stormwater were estimated. The salinity benefit of treated stormwater was thus estimated as the difference in salinity damage replacement costs under the two scenarios.

Household and commercial industrial salinity damage replacement cost equations, based on regression analysis by Allen Consulting (2004), also applied by CSIRO (2011) were used in this project. The regression analysis determined separate linear regressions of costs against salinity and hardness, and while the goodness-of-fit of the estimated relationship was indicated by the correlation coefficient to be high (R^2 = 0.89), this was largely because there were a small number of data points (Allen Consulting, 2004).

Household damage replacement costs were estimated using the equation:

$$\mathrm{HouseholdCost}\left(\frac{\frac{\$}{\mathrm{household}}}{\mathrm{yr}}\right) = 0.2458 \cdot \mathrm{T} + 135 \qquad (4.2)$$

Industrial salinity damage replacement costs were estimated using the equation:

$$\mathrm{CommercialCost}\left(\frac{\frac{\$}{\mathrm{kL}}}{\mathrm{yr}}\right) = 0.00063 \cdot \mathrm{T} + 0.35 \qquad (4.3)$$

Where T is salinity of composite mains water consisting of water from alternative sources in specified proportions measured in total dissolved solids (TDS), milligrams/litre.

The value of T was estimated as the composite salinity of mains water calculated as the volume-weighted salinity of water from various sources including local catchments, River

Murray, desalination, and harvested stormwater. Salinity for water from local catchments was estimated to lie between 80 mg/L and 900 mg/L (EPA, 2000) with a median value of 300 mg/L; River Murray water salinity was estimated to be between 279 mg/L and 828 mg/L (CSIRO, 2011) with median salinity levels estimated at 400 mg/L; the median salinity levels of harvested stormwater were estimated to range between 125 mg/L from the wetland outlet (prior to ASR injection), and 240 mg/L (recovered from the Parafield ASR wells) (Page et al., 2013a);, salinity for water from the desalination plant was estimated at 160 mg/L (Karen Rouse, SA Water, pers. comm.) and from recycled wastewater from Bolivar was estimated at 1200 mg/L.

The supply of water from each source will vary from year-to-year depending on rainfall and other climate variables. ATSE (2012) estimated that, over the period 2010 to 2050 (and in the absence of climate change), an average supply from the existing sources is 50% from the local catchments, 40% from the River Murray and 10% from the desalination plant. Based on these percentages, the salinity of mains water, T, without treated stormwater was estimated to lie between 168 mg/L and 797 mg/L with a median value of 326 mg/L. For comparison, SA Water's 2012/13 Drinking Water Quality report gave the average salinity from the Little Para Treatment Plant as 356 mg/L and the range at customers' taps to be 170 mg/L and 410 mg/L. Therefore, 326 mg/L is a reasonable long term average.

Options 1 to 4 involve using the harvested stormwater for watering of public open space. As Equations 4.2 and 4.3 are based on a reduction in corrosion of water using appliances, it is assumed that the salinity benefits of using stormwater for these options are negligible.

Options 5 to 8 involve the distribution of harvested stormwater via a third pipe network for garden watering or toilet flushing. The present value of benefits of reduced salinity for each option was estimated based on the following assumptions:

(1) The harvested stormwater or blended stormwater and wastewater are substitutes for potable mains water;
(2) The third pipe system supplies residential consumers only;
(3) The total water consumption of the average household is 180 kL per year of which 72 kL per year is outdoor use (Department for Water, 2009);
(4) Of the indoor use of the average household (108 kL per year), 25% (or 27kL per year) is used for toilet flushing (department for Water, 2009);
(5) Equation 4.2 can be applied to indoor use only, as the benefits of lower salinity for outdoor use are negligible.

Table 4.6 gives a summary of the net benefits of Options 5 to 8 under these assumptions. In this table the number of houses supplied is based on an average annual consumption of harvested stormwater of 100kL per household.

It can be seen that Options 5 and 6 have positive net benefits as the salinity of harvested stormwater is lower than potable mains water. On the other hand, the salinity of blended stormwater and wastewater (being around 800 mg/L) has negative net benefits.

Options 10 through 12 involve transferring harvested stormwater to Little Para Reservoir where it is mixed with water in the reservoir prior to being treated through the Little Para water treatment plant and being distributed to consumers. The economic benefits for reduced salinity for these options have been estimated based on the following assumptions:

(1) The harvested stormwater is a substitute for potable mains water;
(2) The average annual supply of potable water from the reservoir is 15,000 ML;
(3) 70% of the water from the reservoir is distributed to residential consumers and 30% to industrial and commercial consumers (National Water Commission, 2013);
(4) The average annual residential consumption is 180 kL/ household (South Australian Water Corporation, 2012);

The benefits for these schemes are summarised in Table 4.7. In this table the number of houses supplied is based on a total average annual consumption of 180 kL per household.

Option 9 involves direct injection of the harvested stormwater into the mains after treatment to potable quality. It is similar to Option 11 in terms of the salinity effects except that it will be mixed with an unknown volume of mains water. As equations 4.2 and 4.3 are linear in terms of the final salinity, the benefits will be insensitive to the volume of potable water involved in the mixing, so the benefits for this case will be assumed to be the same as for Option 11 (i.e. $1.04m).

Table 4.6: Benefits due to reduced salinity of stormwater compared to mains water for third pipe options

Option	Average annual supply (ML/year)	Number of houses supplied	Average salinity of mains water (mg/L)	Average salinity of stormwater (or blend) (mg/L)	Average weighted salinity (mg/L)	Annual savings/HH ($)	Total Annual Savings ($m)	PV of benefits ($m)
5	370	3700	326	125	275.75	12.35	0.046	0.58
6	880	8800	326	240	304.5	5.28	0.047	0.59
7	1000	10000	326	800	444.5	-29.13	-0.291	-3.72
8	2100	21000	326	800	444.5	-29.13	-0.612	-7.82

Table 4.7: Benefits due to reduced salinity of stormwater compared to mains water for potable supply options

Option	Total Supply from Stormwater (ML/year)	Salinity of Stormwater (mg/L)	Salinity of Mixed Water (mg/L)	Residential Supply (ML/year)	Industrial Supply (ML/year)	Number of Houses Supplied	Residential Benefit ($/HH/year)	Total Residential Benefit ($m/year)	Industrial Benefit ($m/year)	Total Benefit ($m/year)	PV Benefit ($m)
10	1034	125	312.1	10500	4,500	58333	3.41	0.199	0.039	0.238	3.04
11	827	240	321.3	10500	4,500	58333	1.17	0.068	0.013	0.081	1.04
12	827	240	321.3	10500	4,500	58333	1.17	0.068	0.013	0.081	1.04

4.3.2 Economic evaluation using benefit-cost analysis

The options are now compared in terms of their net present values. These are summarised in column 8 of Table 4.8. In this table, the present values of the costs of the various options include the cost of existing infrastructure at Parafield. These have been taken from Table 4.5.

In Table 4.8, the present value of savings in supply costs from conventional sources are based on a LRMC of $2.75 per kL. The options may be compared in terms of their NPV as well as the NPV per GL of water supplied.

Table 4.8: Net present value of Options 1-12 including the cost of existing infrastructure (LRMC = $2.75 /kL)

Option	Average annual supply (ML/year)	Present Value of Incremental Cost ($m)	Present Value of Existing Capital Works ($m)	PV of Savings in Supply Cost from Conventional Sources ($m)	PV of Benefits of Additional Water Supply ($m)	PV of Savings in Salinity Damage Costs ($m)	Net Present Value ($m)	Net Present Value per GL Supplied ($m/GL)
1	370	2.13	11	13.01	0	0	-0.12	-0.33
2	880	4.71	13	30.94	0	0	13.23	15.03
3	880	5.08	13	30.94	0	0	12.86	14.61
4	2100	17.06	18	73.82	0	0	38.76	18.46
5 (Greenfield)	370	12.11	12	8.71*	4.68	0.58	-10.14	-27.41
5 (Brownfield)	370	20.25	12	8.71*	4.68	0.58	-18.28	-49.41
6 (Greenfield)	880	24.57	14	20.73*	11.13	0.59	-6.12	-6.95
6 (Brownfield	880	43.93	14	20.73*	11.13	0.59	-25.48	-28.95
7 (Greenfield)	1000	27.30	16	23.55*	12.65	-3.72	-10.82	-10.82
7 (Brownfield)	1000	49.30	16	23.55*	12.65	-3.72	-32.82	-32.82
8 (Greenfield)	2100	55.54	18	49.46*	26.57	-7.82	-5.33	-2.54
8 (Brownfield)	2100	101.43	18	49.46*	26.57	-7.82	-51.22	-24.39
9	880	22.19	6	30.94	0	1.04	3.79	4.30
10	1034	15.45	4	36.35	0	3.04	19.94	19.28
11	827	14.75	6	29.07	0	1.04	9.36	11.32
12	827	17.73	6	29.07	0	1.04	6.38	7.72

*Based on supply of 67% of non-potable demand from conventional sources due to the higher price of water to the consumer

From Table 4.8 it can been seen that the following Options have positive values of NPV:

(1) Three of the options that involve watering of public open space (in the following order of preference: Option 4, 2 and 3);
(2) All of the potable use options (in the following order of preference: Option 10, 11, 12and 9); and
(3) None of the third pipe systems for residential supply

The overall order of ranking of preferred options in terms of NPV is: 4, 10, 2, 3, 11,12 and 9.

It is interesting to note that all of the options involving potable use have positive values of NPV. This indicates that these options can supply potable water prior to distribution at a cost less than the long run marginal cost (LRMC) for the conventional water supply system. They are therefore attractive for this purpose. Costings are based on these options reliably meeting all of the health criteria for potable use.

Note that the economic viability of the various options as well as their overall ranking are sensitive to the assumed yields and benefits per kilolitre of harvested stormwater supplied to the customer. If the assumed yields aren't realised due to either lack of demand or low rainfall, then this will affect the ranking of the options. Careful consideration of the variability and certainty of all the assumptions should be undertaken before committing to an investment strategy.

Table 4.8 also gives the NPV/GL of water supplied for each option in column 9. If the options are ranked in terms of NPV/GL of water supplied, the rank order of preferred options is as follows: 10, 4, 2, 3, 11, 12 and 9, which is the same as using NPV except for the switching of Options 4 and 10.

A sensitivity analysis was carried out of the economic viability of projects to the assumed value of LRMC for conventional water supplies. In this case, a value of $2.00 per kL was used for the LRMC. The economic assessment for all Options is summarised in Table 4.9. With this lower value of LRMC the projects that have positive values of NPV are:

(1) Three of the options that involve watering of public open space (in the following order of preference: Option 4, 2, and 3); and
(2) Three of the potable use options (in the following order of preference: Option 10, 11 and 12).

Note in this case, Option 9 (involving direct potable injection) is not justified on economic grounds. Option 12 is only marginally economically viable. As in the previous case, none of the third pipe options are economically viable. The order of ranking in terms of NPV is: 4, 10, 2, 3, 11 and 12 .The order using NPV/GL is: 10, 4, 2, 3, 11 and 12.

Table 4.9: Net present value of Options 1-12 including the cost of existing infrastructure (LRMC = $2.00/kL)

Option	Average annual supply (ML/year)	Present Value of Incremental Cost ($m)	Present Value of Existing Capital Works ($m)	PV of Savings in Supply Cost from Conventional Sources ($m)	PV of Benefits of Additional Water Supply ($m)	PV of Savings in Salinity Damage Costs ($m)	Net Present Value ($m)	Net Present Value per GL Supplied ($m/GL)
1	370	2.13	11	9.46	0.00	0	-3.67	-9.92
2	880	4.71	13	22.50	0.00	0	4.79	5.44
3	880	5.08	13	22.50	0.00	0	4.42	5.02
4	2100	17.06	18	53.69	0.00	0	18.63	8.87
5 (Greenfield)	370	12.11	12	6.34	4.68	0.58	-12.51	-33.82
5 (Brownfield)	370	20.25	12	6.34	4.68	0.58	-20.65	-55.82
6 (Greenfield)	880	24.57	14	15.07	11.13	0.59	-11.78	-13.38
6 (Brownfield	880	43.93	14	15.07	11.13	0.59	-31.14	-35.38
7 (Greenfield)	1000	27.3	16	17.13	12.65	-3.72	-17.24	-17.24
7 (Brownfield)	1000	49.3	16	17.13	12.65	-3.72	-39.24	-39.24
8 (Greenfield)	2100	55.54	18	35.97	26.57	-7.82	-18.82	-8.96
8 (Brownfield)	2100	101.43	18	35.97	26.57	-7.82	-64.71	-30.81
9	880	22.19	6	22.50	0.00	1.04	-4.65	-5.29
10	1034	15.45	4	26.44	0.00	3.04	10.03	9.70
11	827	14.75	6	21.14	0.00	1.04	1.43	1.73
12	827	17.73	6	21.14	0.00	1.04	-1.55	-1.87

4.3.3 Cost-benefit analysis from the perspective of major stakeholders

As noted in Section 2, a cost-benefit analysis compares the economic benefits of a project to its economic costs, regardless of to whom those benefits accrue. That is, it attempts to assess the costs and benefits from the perspective of society as a whole. For any stormwater harvesting scheme, the various stakeholders may have different perspectives on the costs and benefits that accrue to them. In the case of the Parafield scheme, two of the major stakeholders are the City of Salisbury who undertook the scheme and SA Water who has partnered with Salisbury Council as a customer of stormwater and could have a small reduction in the consumption of potable water from their mains supply due to the use of stormwater harvested from the scheme. For Options 9 through 12, SA Water is also directly affected by the harvested stormwater being used for potable purposes and hence becoming a source of water is added to their other potable supply sources either through direct injection into the water supply mains or by transfer into a water supply reservoir. The cost-benefit analysis carried out in Section 4.3.2 will be modified in this Section to account for these different perspectives.

While the costs of the Parafield scheme outlined previously give a reasonable estimate of the costs from the perspective of the City of Salisbury, the benefits are quite different. The City of Salisbury operates its stormwater harvesting scheme though a separate business entity called Salisbury Water (SW) which is expected to be financially self-supporting. The City of Salisbury considers any harvested stormwater that it supplies to have a benefit equal to the cost of mains water, as it is a substitute for water from this source. Although SW may sell harvested stormwater to industrial and other users at a price less than that paid for mains water, the difference is considered to be a benefit to industry in the City. Using the tier 2 figure for residential consumers given in Table 4.3, this price is $3.45 per kL. This is also the rate charged to non-residential consumers for all consumption. This figure will be used to estimate the benefits of the various stormwater harvesting schemes from the perspective of the City of Salisbury. This figure will be assumed to include the benefits of additional water supply for third pipe schemes (i.e. column 6 in Table 4.8). Furthermore, the benefits due to salinity reduction are not included as they are not considered by the City of Salisbury. Table 4.10 summarises the costs and benefits of the various supplies from the perspective of the City of Salisbury.

From Table 4.10 it can be seen that the following options have a positive NPV from the City of Salisbury's perspective:

(a) All of the options that involve watering of public open space (in the following order of preference: Option 4, 2, 3, 1)

(b) All of the potable use options excluding distribution costs (in the following order of preference: Options 10, 11, 12 and 9)

(c) Three of the third pipe options for Greenfield developments (in the following order of preference: Options 8, 7 and 6)

(d) It should be noted that the NPVs for Greenfield Options 7 and 6 are just positive.

The overall ranking in terms of NPV is as follows: 4, 10, 2, 3, 8G, 11, 12, 9, 1, 7G and 6G. In terms of NPV per GL supplied, the ranking is: 4, 10, 2, 3, 11, 12, 9, 8G, 1, 7G and 6G. This is the same ranking as that obtained using NPV except that 8G dropped from 5th to 8th in the ranking.

Table 4.10: Net present value of Options 1-12 including the cost of existing infrastructure (City of Salisbury perspective using a benefit of $3.45 per kL)

Option	Average annual supply (ML/year)	Present Value of Incremental Cost ($m)	Present Value of Existing Capital Works ($m)	PV of Benefits ($m)	Net Present Value ($m)	Net Present Value per GL Supplied ($m/GL)
1	370	2.13	11	16.32	3.19	8.62
2	880	4.71	13	38.81	21.10	23.98
3	880	5.08	13	38.81	20.73	23.56
4	2100	17.06	18	92.62	57.56	27.41
5 (Greenfield)	370	12.11	12	16.32	-7.79	-21.06
5 (Brownfield)	370	20.25	12	16.32	-15.93	-43.06
6 (Greenfield)	880	24.57	14	38.81	0.24	0.27
6 (Brownfield	880	43.93	14	38.81	-19.12	-21.73
7 (Greenfield)	1000	27.3	16	44.10	0.80	0.80
7 (Brownfield)	1000	49.3	16	44.10	-21.20	-21.20
8 (Greenfield)	2100	55.54	18	92.62	19.08	9.08
8 (Brownfield)	2100	101.43	18	92.62	-26.81	-12.77
9	880	22.19	6	38.81	10.62	12.07
10	1034	15.45	4	45.60	26.15	25.29
11	827	14.75	6	36.47	15.72	19.01
12	827	17.73	6	36.47	12.74	15.41

Given the existing level of security in SA Water's water resources, the benefits of harvested stormwater from SA Water's perspective is considered to be the saving in operating cost. Operating costs for various sources of Adelaide's water supply were estimated by ATSE (2012). As noted in Section 4.3.1, ATSE (2012) reports on the results of modelling Adelaide's water supply headworks for the period 2010 to 2050. It was found that the average supply from the various sources was 50% from the Mt Lofty Ranges catchments, 40% pumped from the River Murray and 10% from the desalination plant. If harvested stormwater is used as a substitute for potable supply, the supply from the more expensive sources (desalination and the River Murray) will be reduced. As desalinated water is not likely to be required every year it is assumed that the mix of sources for the saving in mains water supply through the use of harvested stormwater will be 80% River Murray water and 20% desalinated water. The operating costs of these supply sources was estimated by ATSE (2012) to be 44 cents per kL and $1.00 per kL for River Murray water and desalinated water, respectively. Taking a weighted average of these two figures, an average figure of $0.55 per kL is estimated for the savings in operating cost. This figure will be used to assess the savings in supply cost from SA water's perspective.

Table 4.11 summarises the costs and benefits of the various options from the perspectives of SA Water. It should be noted that none of the stormwater harvesting options have a positive NPV.

Table 4.11 Net present value of Options 1-12 including the cost of existing infrastructure (SA Water perspective using a savings in cost from conventional sources of $0.55 per kL)

Option	Average annual supply (ML/year)	Present Value of Incremental Cost ($m)	Present Value of Existing Capital Works ($m)	PV of Savings in Supply Cost from Conventional Sources ($m)	PV of Benefits of Additional Water Supply ($m)	PV of Savings in Salinity Damage Costs ($m)	Net Present Value ($m)	Net Present Value per GL Supplied ($m/GL)
1	370	2.13	11	2.60	0	0	-10.53	-28.46
2	880	4.71	13	6.19	0	0	-11.52	-13.09
3	880	5.08	13	6.19	0	0	-11.89	-13.51
4	2100	17.06	18	14.76	0	0	-20.30	-9.66
5 (Greenfield)	370	12.11	12	1.74*	4.68	0.58	-17.11	-46.24
5 (Brownfield)	370	20.25	12	1.74*	4.68	0.58	-25.25	-68.24
6 (Greenfield)	880	24.57	14	4.15*	11.13	0.59	-22.70	-25.80
6 (Brownfield	880	43.93	14	4.15*	11.13	0.59	-42.06	-47.80
7 (Greenfield)	1000	27.3	16	4.71*	12.65	-3.72	-29.66	-29.66
7 (Brownfield)	1000	49.3	16	4.71*	12.65	-3.72	-51.66	-51.66
8 (Greenfield)	2100	55.54	18	9.89*	26.57	-7.82	-44.90	-21.38
8 (Brownfield)	2100	101.43	18	9.89*	26.57	-7.82	-90.79	-43.23
9	880	22.19	6	6.19	0	1.04	-20.96	-23.82
10	1034	15.45	4	7.27	0	3.04	-9.14	-8.84
11	827	14.75	6	5.81	0	1.04	-13.90	-16.80
12	827	17.73	6	5.81	0	1.04	-16.88	-20.41

*Based on supply of 67% of non-potable demand from conventional sources due to the higher price of water to the consumer

4.3.4 Comparative analysis

It is clear that the economic viability of the various stormwater options is sensitive to the assumed benefit per kilolitre of harvested storm water supplied to the consumer. Various values have been used for this in Sections 4.3.2 and 4.3.3 ranging from $0.55 per kL to $3.45/kL.

Any option will have a positive NPV if the total benefit per unit of water supplied ($/kL) exceeds its levelised cost ($/kL). The levelised costs for the various stormwater harvesting options are given in Table 4.5 which is repeated here as Table 4.12 for completeness.

Table 4.12: Summary of the average annual supply, present value of costs and levelised costs of the various options (including the cost of existing infrastructure for the Parafield scheme and Bolivar-Greenfields-Mawson Lakes existing scheme)

Option	Average annual supply (ML/year)	Present Value of Cost ($m)	Levelised Cost ($/kL)
1	370	13.13	2.78
2	880	17.71	1.57
3	880	18.08	1.61
4	2100	35.13	1.31
5 (Greenfield)	370	24.48	5.18
5 (Brownfield)	370	32.62	6.90
6 (Greenfield)	880	38.94	3.46
6 (Brownfield	880	58.30	5.18
7 (Greenfield)	1000	43.37	3.39
7 (Brownfield)	1000	65.37	5.11
8(Greenfield)	2100	73.61	2.74
8 (Brownfield)	2100	119.50	4.45
9	880	28.19	2.51
10	1034	19.45	1.47
11	827	20.75	1.96
12	827	23.73	2.24

Figure 4.2 gives a plot of the levelised costs for each option. The levels of benefit per kL supplied are shown in this Figure are:

(1) $3.45 per kL representing the tier 2 price of water for residential consumers;

(2) $2.75 per kL representing the upper estimate of the LRMC of supply;

(3) $2.00 per kL representing the lower estimate of the LRMC of supply; and

(4) $0.55 per kL representing the operating cost per kL

This figure indicates which stormwater options are viable at various levels of values for the assumed unit benefit of the harvested stormwater. These are the options for which the benefit per unit of supply exceeds the levelised cost.

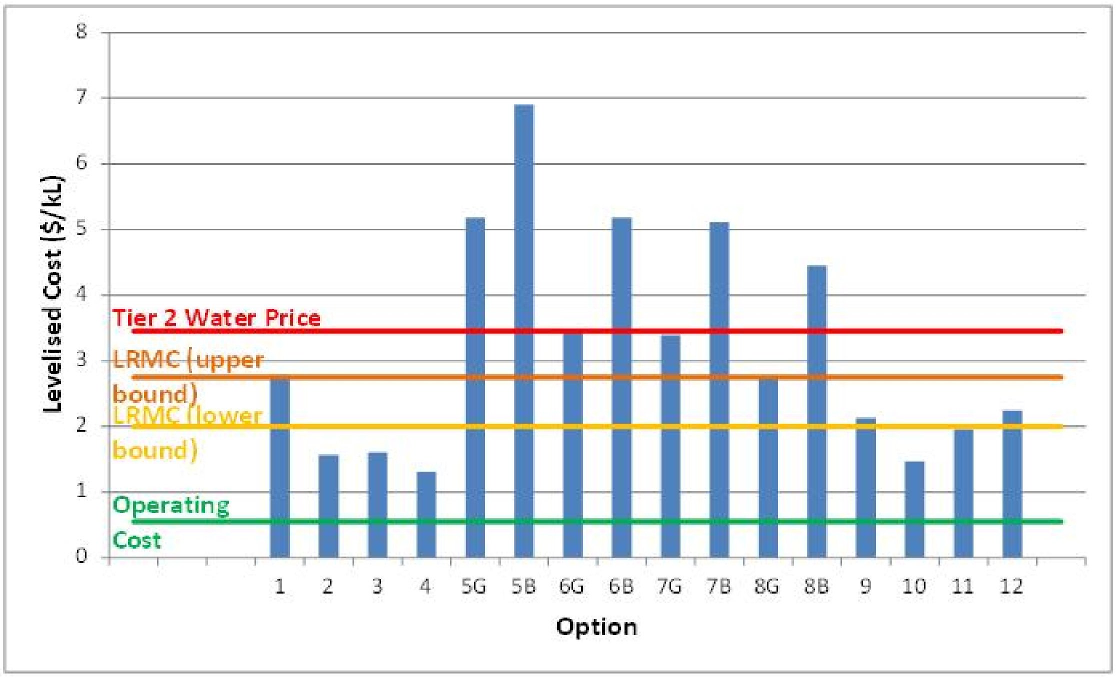


Figure 4.2: Comparison of levelised cost of the various options (including the cost of existing infrastructure) with values of the benefit per kL supplied.

4.3.5 Environmental Assessment

Energy and Greenhouse Gas Emissions

The general energy and greenhouse gas emission evaluation process including capital and operating energy and emissions (outlined in Appendix B) has been applied to the case study. Capital emissions are associated with the total embodied energy involved in the construction of the new infrastructure. All infrastructure including wetlands, ASR bores, pipes, tanks, pumps and treatment plants contribute to the embodied energy and capital emissions. The operating energy and greenhouse gas emissions are due to electricity and fuel consumption related to the operation of the system over its economic life. In this study it is assumed that electricity is the main source of energy consumption.

Any energy or greenhouse gas savings must be assessed relative to a base case. For this project, the base case is what would happen in the absence of stormwater harvesting at the Parafield scheme.

As noted in Section 4.3.1, the average consumption of water from the various sources (with the current infrastructure) for the period up to 2050 is expected to be 50% from the Mount Lofty Ranges, 40% from the River Murray and 10% from the desalination plant. It is assumed that harvested stormwater will replace desalinated water first followed by pumping from the River Murray as these are the most expensive and second most expensive sources (respectively). The modelling reported by ATSE (2012) indicates that desalinated water will not be required every year. Therefore it is assumed that, of the volume of harvested stormwater supplied to the system, 80% will replace River Murray water and 20%

desalinated water. These percentages were used to estimate the savings in energy and greenhouse gases by using harvested stormwater.

A distinction is drawn between gross greenhouse gas emissions and net greenhouse gas emissions. Gross emissions have been estimated using an emission factor of 0.79 kg CO_2 –e/kWh to convert energy into greenhouse gas emissions. This figure is based on the average mix of all sources of electricity used in South Australia. This is consistent with the National greenhouse gas and energy reporting system measurement: Technical guidelines for the estimation of greenhouse gas emissions by facilities in Australia (Department of Climate Change and Energy Efficiency, 2012b). These guidelines were used by SA Water in the estimation of the greenhouse gas emissions associated with their facilities (including the desalination plant in 2011/12 (SA Water, 2012).

Net greenhouse gas emissions allow for the purchase of carbon offsets or green energy by the water utility or other authority. This should be assessed in accordance with the National Carbon Offset Standard Carbon Neutral Program Guidelines (Australian Government Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education, 2013).

It is understood that SA Water purchases 100% green energy for its desalination plant and so is entitled to fully offset its greenhouse gas emissions from this source

The detailed analysis of energy and gross greenhouse gas emissions for each option is given in Appendix I.

Summary

The estimated energy savings for all options when the existing infrastructure is taken into account are given in Table 4.13 while the savings in gross greenhouse gas emissions under the same conditions are given in Table 4.14.The emissions are compared with those produced by an equivalent volume of water from the River Murray (80%) and from desalination (20%). It should be noted that SA Water purchases green energy for their desalination plant and this offsets most of their greenhouse gas emissions from this source. A negative value in these tables indicates that that particular option involves greater energy consumption and gross greenhouse gas emissions compared to the supply from the River Murray and desalination plant.

Table 4.13: A summary of energy consumption per year for all options (including the embodied energy of existing infrastructure for the Parafield scheme and the Bolivar-Greenfield infrastructure)

Option	**Volume of Water Supplied (GL/year)**	**Incremental Energy consumption (MWh/year)**	**Embodied energy of existing infrastructure (MWh/year)**	**Energy consumption of equivalent volume of water supplied from the River Murray and the desalination plant (MWh/year)**	**Reduction in energy consumption (MWh/year)**	**Levelised reduction in energy consumption (MWwh/ML)**
1	0.37	102	274	932	556	1.50
2	0.88	554	277	2218	1387	1.58
3	0.88	554	277	2218	1387	1.58
4	2.10	1855	457	5292	2980	1.42
5	0.37	558	284	621*	-221	-0.60
6	0.88	1635	291	1479*	-447	-0.51
7	1.00	1651	451	1680*	-422	-0.42
8	2.10	3719	457	3528*	-648	-0.31
9	0.88	1222	166	2218	830	0.94
10	1.034	1238	163	2772**	1371	1.33
11	0.827	1272	166	2218**	780	0.94
12	0.827	1633	166	2218**	419	0.51

*Based on supply of 67% of non-potable demand from conventional sources due to the higher price of water to the consumer

**Allows for 6% evaporation loss in the Little Para Reservoir

Table 4.14: A summary of gross GHG emissions for all options (including the existing infrastructure for the Parafield scheme and the Bolivar-Greenfield –Mawson Lakes infrastructure)

Option	**Volume of Water Supplied (Gl/year)**	**Gross GHG emissions (Tonnes CO_2 -e per year)**	**GHGs due to embodied energy of existing infrastructure (Tonnes CO_2 -e per year)**	**Gross GHG emissions of equivalent volume of water supplied from the River Murray and the desalination plant (Tonnes CO_2 -e per year)**	**Reduction in Gross GHG emissions (Tonnes CO_2 -e per year)**	**Levelised reduction in Gross GHG emissions (kg CO_2 –e/kL)**
1	0.37	80	128	737	529	1.43
2	0.88	438	130	1752	1184	1.35
3	0.88	438	130	1752	1184	1.35
4	2.10	1462	262	4181	2457	1.17
5	0.37	441	129	491*	-79	-0.21
6	0.88	1291	131	1168*	-254	-0.29
7	1.00	1304	260	1327*	-237	-0.24
8	2.10	2935	262	2787*	-410	-0.20
9	0.88	961	42	1752	749	0.85
10	1.034	978	40	2190**	1172	1.13
11	0.827	1005	42	1752**	705	0.85
12	0.827	1288	42	1752**	422	0.51

*Based on supply of 67% of non-potable demand from conventional sources due to the higher price of water to the consumer

**Allows for 6% evaporation loss in the Little Para Reservoir

Amenity Services - River Murray

Water for the Adelaide metropolitan area comes from the Adelaide Mt. Lofty Ranges, the River Murray and the Port Stanvac desalination plant. The amount of water coming from the River Murray varies from about 40 per cent in a normal rainfall year to as much as 90 per cent in a dry year (ATSE, 2012). SA Water currently has a non-tradeable license of 130GL of water and use of this entitlement is subject to a rolling five-year total of 650 GL for metropolitan Adelaide.

In order to estimate the benefits of reduced extraction of water from the River Murray, it will be assumed that this water could be used for environmental purposes. It is noted that this would be a policy decision for both state and federal governments to make. The benefit of this water can be assessed using the average price paid for water that will be returned to the environment under the "Restoring the Balance in the Murray-Darling Basin" program (www.environment.gov.au/water/policy-programs/entitlement-purchasing/progress.html, accessed on Sept 26, 2013). As at July 31, 2013 more than 4500 individual trades had been made under this program with an estimated average annual yield of 1,137 GL.

For the South Australian Murray, the average price paid for high security water was $2,099 /ML. In fact, water entitlements rather than water allocations are purchased, but this figure is based on the estimated average annual yield. This is one method for establishing a value for water returned to the River for environmental purposes as the increased flow in the river will have a similar benefit to the water purchased under the Restoring the Balance in the Murray-Darling Basin program. If less water can be taken from the River Murray by SA Water on an ongoing basis, the present value of the increased volume of flow in the Murray (for environmental purposes) is taken to be $2,099 per ML.

As explained in Section 4.3.3, it is assumed that 80% of the harvested stormwater will replace water pumped from the River Murray and 20% will replace desalinated water. Hence, a stormwater scheme that provides 1000 ML/year of harvested stormwater will reduce the intake from the River Murray by an average of 800 ML/year. This will have a present value benefit of $1.679 m.

An alternative approach to value the reduced extraction from the River Murray is to assume that the increased flow will add to the environmental flow to the Lower Lakes and Coorong. Under current government policy this would occur if and only if entitlements to this water are transferred to the Commonwealth Environmental Water Holder or other equivalent body. Appendix J estimates a benefit on this basis. The value of this benefit is $0.739m/GL/year in present value terms. This involves scaling a much larger willing-to-pay benefit of $3768m for a release of 5100 GL/year. It is questionable whether this scaling can be applied given the uncertainty of when this additional flow will be available during the water year and hence this estimate has not been used in the case study.

Amenity Services – Recreational Parklands

The provision of harvested stormwater to water public open space that would not have otherwise been watered can be estimated using property values close to recreational parklands. Appendix K presents an evaluation of this benefit for the Salisbury area. The present value of benefits estimated in Appendix K is rather small ($11,424). It is not included in this case study as it is assumed that harvested stormwater is being used as a substitute for watering that would have occurred in any case.

Amenity Services – Urban wetlands

Urban wetlands have been observed to increase the value of adjacent residential properties (Tapsuwan et al, 2009). Although no studies have been carried out to determine the effects of urban wetlands on property values in the Adelaide region, Tapsuwan et al (2009) applied hedonic pricing to investigate this value in northern Perth (WA). An analysis is presented in Appendix L that applies the results of the study by Tapsuwan et al (2009) to suburban Adelaide. The results show that the present value of benefits could be as high as $7m for a 2 hectare wetland. However, these results assume that properties could surround the wetland and be adjacent to it. As the Parafield wetland is located on the grounds of the Parafield airport, it only has properties on one side. These are separated from the wetland by a fence and a road, so the increase in property values is likely to be small and will be neglected in this study.

Amenity Services: Adelaide Coastal Waters

Appendix M gives background on various aspects of the impact of stormwater on Adelaide's coastal waters. In summary there are a number of issues related to the impact of stormwater on the waters of Gulf St Vincent. These include the impact of nitrogen and suspended solids in the stormwater on the following:

(a) seagrasses in the Gulf; and
(b) the aesthetic value of the coastal waters

The loss of seagrass can affect the productivity of fisheries as well as beach erosion and restoration. While it is possible to estimate the value of beaches to Adelaide and the cost of beach restoration measures, it is extremely difficult to link this to a reduction in cost associated with small reduction in input of stormwater into the Gulf.

On the other hand it is possible to estimate a value of the impact on fisheries if it is assumed that there is a linear relationship between reductions in stormwater inputs and productivity of fisheries. This leads to a present worth of $7,000 per GL of stormwater harvested per year. This is small compared to the other costs and benefits in this study. The aesthetic values of improved water quality can be estimated using data from a study in Auckland, New Zealand (Appendix K). This has not been used in this study because of the question of whether these values can be transferred from Auckland to Adelaide and because it is not clear how much of these benefits will be achieved by stormwater harvesting in the Salisbury area where the coast is surrounded by mangroves and there are no swimming beaches or adjacent houses and hotels.

Summary: Amenity Services

Table 4.15 summarises the amenity values for stormwater removal that have been estimated for the Parafield stormwater harvesting scheme. The benefits for a particular scheme depend on the annual yield and volume of stormwater harvested. These may be different depending on losses in ASR or Little Para Reservoir. For the blended options, this benefit applies only to the harvested stormwater component.

Table 4.15: Estimated present value of amenity services for Parafield stormwater harvesting schemes

Amenity Service	Present Value
River Murray	$1.679m per GL of stormwater supplied to customers per year
Parklands	Not applicable at Parafield
Urban Wetlands	Not applicable at Parafield
Coastal Waters (Fisheries)	$0.007m per GL of stormwater harvested per year

4.3.6 Social Assessment

The social assessment of stormwater harvesting options was carried out through two web based surveys, the details of which are reported elsewhere (Alexander et al., 2012; Mankad et al., 2013).

The first survey (Alexander et al., 2012) was undertaken in October 2011 and included 1043 residents of Adelaide. The respondents were asked to consider the following three options for stormwater harvesting:

(1) Treatment through a wetland and aquifer storage and recovery and then delivery to their house via a separate third pipe network where it could be used for garden watering, toilet flushing and in the washing machine.
(2) Treatment through a wetland, aquifer storage and recovery and delivery to a water supply reservoir for blending with other source water before being further treated through a water treatment plant. The water would then be distributed through the water supply mains for drinking and other purposes.
(3) Treatment through a wetland and aquifer storage and recovery and then direct injection into the water supply mains for drinking and other purposes.

Three measures that were considered to be important as measures of the acceptability of the three options presented are summarised in Figure 4.3to Figure 4.5which are taken from Alexander et al (2012).

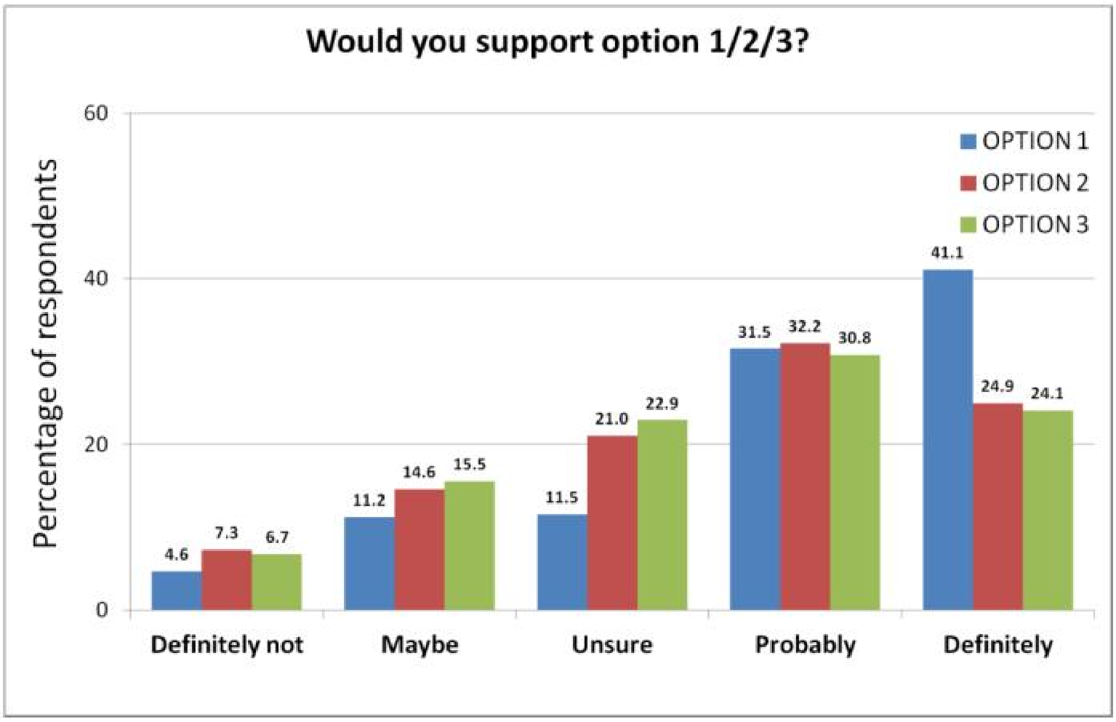


Figure 4.3: Support for Three Options for Harvested Stormwater (Alexander et al, 2012)

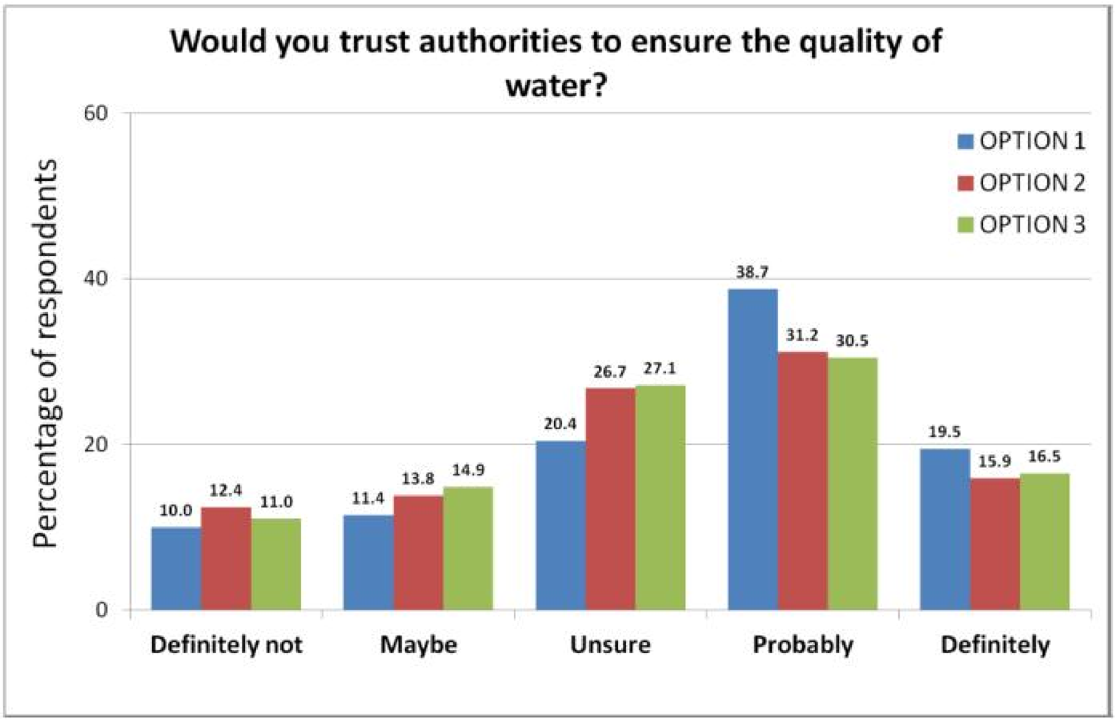


Figure 4.4: Trust that Water Authorities can ensure the Quality of Stormwater for Three Options (Alexander et al, 2012)

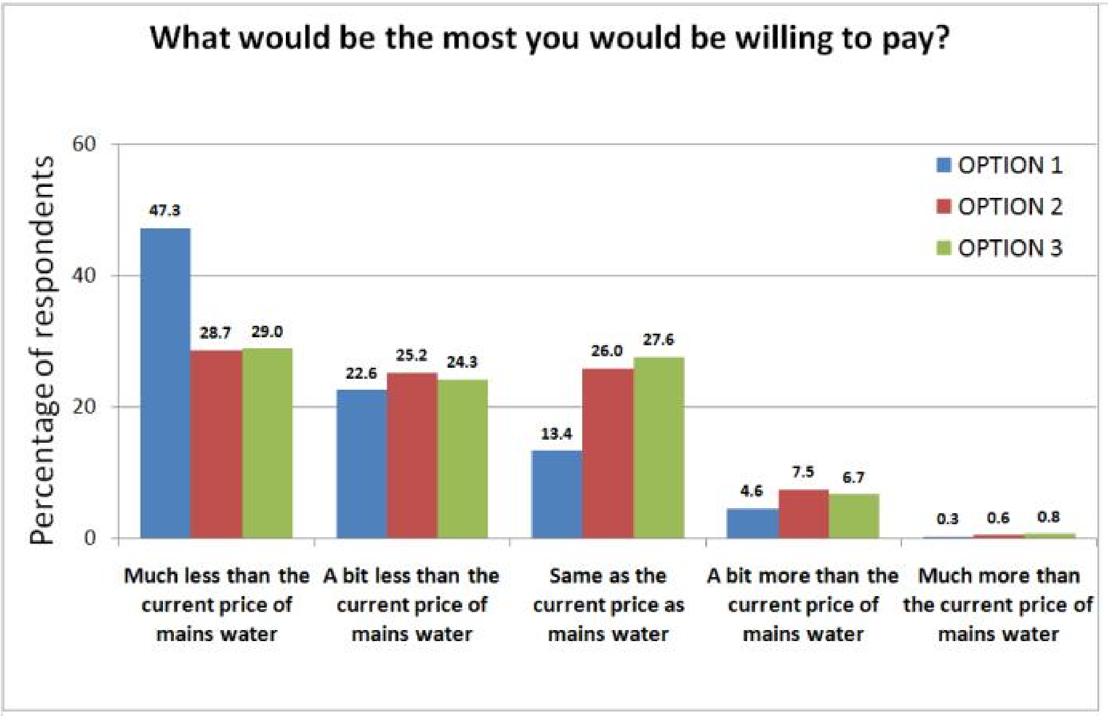


Figure 4.5: Willingness to pay for harvested Stormwater from the Three Options (Alexander et al., 2012)

Three measures of social acceptability of the stormwater for various uses have been extracted from this data and these are summarised in Table 4.16. In this table, Support for the option is indicated by the percentage answering "probably" or "definitely". A similar interpretation applies to Trust. Willingness-to-pay is given by the percentage who indicated that they were willing to pay the same as the current price of mains water or more for the stormwater option. Note that this survey was not intended to provide an accurate assessment of the willingness-to-pay of the consumers for stormwater for various end uses.

Table 4.16: Percentage of Respondents from the First Survey with a Positive Response in Relation to the Various Measures for each Stormwater Option

Measure	**Option 1 (Non-potable)**	**Option 2 (Potable)**	**Option 3 (Potable)**
Support (%)	72.6	57.1	54.9
Trust (%)	58.2	47.1	47.0
Willingness-to-pay (%)	18.3	34.1	35.1

The second survey was undertaken in March 2013 and included 1172 residents of Adelaide. The survey was carried out using six separate groups with three of the groups being asked to consider the use of treated stormwater for drinking purposes with a treatment train that included a wetland, aquifer storage and recovery and delivery to a water supply reservoir for blending with other source water before being further treated through a water treatment plant. The respondents were assured that the water would be safe to drink. The other three groups were asked to consider the use of treated stormwater for toilet flushing, in the laundry and for garden watering following treatment through a wetland and aquifer storage and recovery and delivery to their house via a separate third pipe network. The respondents were assured that the water would be safe for its intended purposes. Varying levels of background information about the water supply train were supplied to each of the six groups.

In the second survey, all respondents were presented with a series of statements and asked whether they agreed or disagreed on a five point scale. The responses to these questions have been grouped into similar categories to those used in the Alexander et al (2012) survey i.e. support of the option, trust of water authorities to deliver water of suitable quality and willing-to-pay for water from this source. The results for the groups who were asked to consider use of treated stormwater for non-potable purposes are summarised in Table 4.17. The data were supplied by Aditi Mankad (CSIRO, pers. comm., April 4, 2013). Note that the response categories for Questions 6 and 18 have been averaged for each individual as have the response categories for Questions 16 and 17.

Similar results for the groups who were asked to consider the use of treated stormwater for drinking purposes are summarised in Table 4.18.

Table 4.17: Responses of Those Who were Questioned in Relation to Non-Potable Uses of Treated Stormwater (Aditi et al, 2013)

<u>ACCEPTANCE (individual items)</u>

Q6. I would be willing to use treated stormwater as a supplement to our existing non-potable water supplies

Response scale: 1 = strongly disagree, 5 = strongly agree

Q18. To what extent are you in favour of using treated stormwater as a supplement to your existing non-potable water supplies?*Response scale: 1 = strongly opposed, 5 = strongly in favour*

<u>**Final 'ACCEPTANCE' scale -** individual items averaged</u>

		Frequency	Valid Percent	Cumulative Percent
Valid	1.00	3	.5	.5
	1.50	2	.3	.9
	2.00	7	1.2	2.0
	2.50	14	2.4	4.4
	3.00	49	8.3	12.8
	3.50	37	6.3	19.0
	4.00	81	13.8	32.8
	4.50	66	11.2	44.0
	5.00	329	56.0	100.0
	Total	588	100.0	

<u>TRUST (individual items)</u>

Q16. I trust my water provider (e.g. State Government water provider) to safely deliver treated stormwater

Q17. I trust my water provider (e.g. State Government water provider) to reliably deliver treated stormwater

Response scale: 1 = strongly disagree, 5 = strongly agree

<u>**Final 'TRUST' scale -** individual items averaged</u>

		Frequency	Valid Percent	Cumulative Percent
Valid	1.00	14	2.4	2.4
	1.50	1	.2	2.6
	2.00	23	3.9	6.5
	2.50	6	1.0	7.5
	3.00	108	18.4	25.9
	3.50	30	5.1	31.0
	4.00	180	30.6	61.6
	4.50	28	4.8	66.3
	5.00	198	33.7	100.0
	Total	588	100.0	

WILLINGNESS TO PAY (single item)

Q20. I would be willing to pay..........than I am currently paying, for the use of treated stormwater

Response scale: 1 = a little more than, 2 = a little less than, 3 = the same as

		Frequency	Valid Percent	Cumulative Percent
Valid	a little more than	95	16.2	16.2
	a little less than	212	36.1	52.2
	the same as	281	47.8	100.0
	Total	588	100.0	

Table 4.18: Responses of Those Who were Questioned in Relation to Drinking Water (Aditi et al, 2013)

ACCEPTANCE (individual items)

Q6. I would be willing to use treated stormwater as a supplement to our existing drinking water supplies

Response scale: 1 = strongly disagree, 5 = strongly agree

Q18. To what extent are you in favour of using treated stormwater as a supplement to your existing drinking water supplies?*Response scale: 1 = strongly opposed, 5 = strongly in favour*

Final 'ACCEPTANCE' scale - individual items averaged

		Frequency	Valid Percent	Cumulative Percent
Valid	1.00	21	3.6	3.6
	1.50	7	1.2	4.8
	2.00	21	3.6	8.4
	2.50	33	5.7	14.0
	3.00	90	15.4	29.5
	3.50	47	8.0	37.5
	4.00	118	20.2	57.7
	4.50	60	10.3	68.0
	5.00	187	32.0	100.0
	Total	584	100.0	

TRUST (individual items)

Q16. I trust my water provider (e.g. State Government water provider) to safely deliver treated stormwater

Q17. I trust my water provider (e.g. State Government water provider) to reliably deliver treated stormwater

Response scale: 1 = strongly disagree, 5 = strongly agree

Final 'TRUST' scale - individual items averaged

		Frequency	Valid Percent	Cumulative Percent
Valid	1.00	33	5.7	5.7
	1.50	2	.3	6.0
	2.00	38	6.5	12.5
	2.50	14	2.4	14.9
	3.00	110	18.8	33.7
	3.50	27	4.6	38.4
	4.00	178	30.5	68.8
	4.50	24	4.1	72.9
	5.00	158	27.1	100.0
	Total	584	100.0	

WILLINGNESS TO PAY (single item)

Q20. I would be willing to pay...........than I am currently paying, for the use of treated stormwater

Response scale: 1 = a little more than, 2 = a little less than, 3 = the same as

		Frequency	Valid Percent	Cumulative Percent
Valid	a little more than	87	14.9	14.9
	a little less than	196	33.6	48.5
	the same as	301	51.5	100.0
	Total	584	100.0	

The results from the second survey can be summarised in a similar form to those for the first survey. The summary is given in Table 4.19. It can be seen that the second survey gave a higher percentage of positive responses in all categories.

Table 4.19: Percentage of Respondents from the Second Survey with a Positive Response in Relation to the Various Measures for each Stormwater Option

Measure	Non-Potable Use (%)	Potable Use (%)
Support	87.3	70.5
Trust	74.2	66.3
Willingness-to-pay	64.0	66.4

In comparing the two sets of responses, a number of factors should be borne in mind. These include the following:

(a) For the first survey, the same set of individuals we asked to assess the three uses for treated stormwater (within-subjects design); for the second survey, one set of individuals assessed potable use and another assessed non-potable use (between-subjects design).
(b) The questions on the two surveys had slightly different wording.
(c) For the first survey, all individuals were given the same background information; for the second survey the background information provided varied between subgroups as an experimental design
(d) The sample size for the first survey was 1043, and 1172 for the second survey (n = 588 for non-potable sample; n = 584 for potable sample).

The results from the first survey (Table 4.16) will be used in this study as it included all three major end uses of the harvested stormwater and the same set of respondents evaluated all three options. It is, therefore, expected that they will give a more consistent evaluation of the options. However, the responses to the willingness-to-pay question will not be used in the multi-criteria analysis as there appear to be inconsistent results between the two surveys.

There were no questions specifically related to the use of harvested stormwater for watering public open space. As this is an existing use of stormwater that has been carried out for a number of years, it is assumed that there is 100% public support for it. Furthermore, it is assumed that the trust of water authorities to ensure water of suitable quality for this option will be at least as high as for in-house use via a third pipe network as the former is an existing use.

4.4 Multi-criteria decision analysis (Step D)

Section 4.3 presents a number of economic, environmental and social criteria that are used to evaluate the stormwater harvesting options for the Parafield case study. In Section 4.3.2 a cost-benefit analysis has been undertaken to produce a preliminary ranking of options. Although some of the options are not justified on economic grounds (as they have negative values of the NPV), all options were carried for the full multi-criteria analysis as they may be attractive in terms of the other, non-economic criteria.

In this section, multi-criteria analysis is used to compare the options. As discussed in Section 2.4 a large number of multi-criteria decision analysis methods are available in the literature. In this case study the weighted sum method is used. This method has the advantage of being easy to understand and apply. Furthermore, the sensitivity of the chosen option(s) to the assumed weights can easily be assessed.

In this study the options were evaluated according to the following criteria:

(C1) Net present value of the scheme ($m)
(C2) Present Value of Benefits for Reduced Supply from River Murray ($m)
(C3) Present Value of Benefits for Reduced Flow of Stormwater contaminants to the Gulf ($m) (C4) Reduction in Energy Consumption (MWh/year)
(C5) Public support for stormwater harvesting options (%)
(C6) Public trust of authorities to ensure water quality (%)

Table 4.20 presents the values for the options considered. In this table, the third pipe options have been separated into greenfield developments (denoted by a G) and brownfield developments (denoted by a B).

There are a number of ways to analyse the data in Table 4.20 to identify the preferred option(s), including the following:

(a) A traditional cost-benefit analysis using the NPV of each project;
(b) An extended cost-benefit analysis including environmental benefits and costs together with market benefits and costs; and
(c) A full multi-criteria analysis

Traditional cost-benefit analysis

A traditional cost-benefit analysis ranks the options based purely on their net present values (Column C1). This was carried out in Section 4.3.2 and Column C1 is taken from Table 4.8 that includes the cost of existing infrastructure and assumes that the savings in supply costs from conventional sources is $2.75 per kL (based on the LRMC of supply). It was found that the following Options have positive values of NPV:

(1) Three of the options that involve watering of public open space (in the following order of preference: Option 4, 2, and 3);
(2) All of the potable use options (in the following order of preference: Option 10, 11, 12 and 9); and

None of the third pipe options have a positive NPV.

The order of ranking in terms of NPV is: 4, 10, 2, 3, 11, 12 and 9.

Extended cost-benefit analysis

An extended cost-benefit analysis involves adding the environmental benefits and costs that can be qualified in dollar terms to the NPV to give the present value of economic and environmental benefits. These values are given in column 6 of Table 4.20. In this case study, because the environmental values are relatively small, they do not have a major impact on the relative ranking of the various options. In fact the same Options have positive net benefits as those that have a positive NPV according to the traditional cost-benefit analysis with the addition of Option 1. The ranking is the same as for NPV with Option 1 being added as the eight ranked option.

Table 4.20: Summary of Net Benefits and Multi-Criteria Analysis

		C1	C2	C3	C1+C2+C3	C4	C5	C6
Option	**Average annual supply (ML/year)**	**Net Present Value ($m)**	**PV of Benefit for Reduced Supply from River Murray ($m)**	**PV of Benefit for Reduced Flow of Stormwater to the Gulf ($m)**	**Present Value of Economic and Environmental Benefits ($m)**	**Reduction in Energy Consumption (Mwh/year)**	**Public support for stormwater harvesting (%)**	**Public trust of authorities for safety (%)**
1	370	-0.12	0.62	0.03	0.53	556	100	58.2
2	880	13.23	1.48	0.10	14.80	1387	100	58.2
3	880	12.86	1.48	0.10	14.43	1387	100	58.2
4	2100	38.76	3.53	0.10	42.39	2980	100	58.2
5 (Greenfield)	370	-10.14	0.42*	0.03	-9.69	-221	72.6	58.2
5 (Brownfield)	370	-18.28	0.42*	0.03	-17.83	-221	72.6	58.2
6 (Greenfield)	880	-6.12	0.90*	0.10	-5.12	-447	72.6	58.2
6 (Brownfield	880	-25.48	0.90*	0.10	-24.48	-447	72.6	58.2
7 (Greenfield)	1000	-10.82	1.12*	0.03	-9.67	-442	72.6	58.2
7 (Brownfield)	1000	-32.82	1.12*	0.03	-31.67	-442	72.6	58.2
8 (Greenfield)	2100	-5.33	2.36*	0.10	-2.87	-648	72.6	58.2
8 (Brownfield)	2100	-51.22	2.36*	0.10	-48.76	-648	72.6	58.2
9	880	3.79	1.48	0.10	5.37	830	54.9	47
10	1034	19.94	1.85**	0.09	21.88	1371	57.1	47.1
11	827	9.36	1.48**	0.09	10.93	780	57.1	47.1
12	827	6.38	1.48**	0.09	7.94	419	57.1	47.1

*Based on supply of 67% of non-potable demand from conventional sources due to the higher price of water to the consumer

** Allows for 6% loss of River Murray water in Little Para Reservoir due to evaporation

Full multi-criteria analysis

For a full multi-criteria analysis, weights need to be put on each of the criteria to obtain a weighted score for each option. Some of the weights may be zero. The weights will reflect the relative importance placed on each criterion by the assessor.

Before assessing these weights, it is important to scale all of the criteria to a common range so that those with large units will not dominate those with small units. For example, a comparison of the reduction in energy consumption (column C4) with NPV (Column C1) shows that values of the former are two orders of magnitude greater than the latter and so would carry a lot more weight if the numbers were simply added together. To overcome this problem, the criteria have been scaled from zero (worst) to one (best) using a linear scaling. The scaled values are shown in Table 4.21. As the values of environmental benefits that are evaluated in dollar terms (Columns C2 and C3) are quite small compared to NPV only the Present Value of Economic and Environmental Benefits (PVEEB) will be included in the multi-criteria analysis. As the social values are expressed in percentage terms, they are simply converted into a fraction so that a value of one represents 100% support and zero represents no support.

The relative weights to be placed on each criterion, needs to be determined by questioning and interacting with the key stakeholders.

In discussions with Bruce Naumann (Manager of Salisbury Water) it was clear that any investments in stormwater harvesting need to be justified on a financial basis using the price of potable water for non-residential consumers as a measure of benefits (as discussed in Section 4.3.3). While the social and environmental factors were considered to be important, projects still needed to be justified in financial terms. He did think that energy was important because of potential greenhouse gas considerations and the fact that energy prices were likely to increase in the future.

SA Water's position (as discussed with Grace Jennings, Manager, Water Security Planning, SA Water) is governed by their need to focus on "Delivering water and wastewater services in efficient, responsive, sustainable and accountable ways" (South Australian Water Corporation, 2012). As SA Water is regulated by the Essential Services Commission of South Australia (ESCOSA) if has a need to ensure prudent and efficient delivery of water supply services. Therefore,any projects need to be evaluated in economic terms while it is recognised that social and environmental requirements also need to be satisfied to the extent that SA Water's customers are prepared to pay for them.

In order to demonstrate the multi-criteria approach used in this study, three sets of relative weights have been included in the last two rows of Table 4.21. The first set of relative weights (W1) give a relative weight of one to PVEEB and reduction in energy consumption with relative weights of 0.5 to each of the social criteria. Thus the two social criteria have a combined weight of one. The second set of relative weights (W2) gives a value of 0.5 to PVEEB with the other values unchanged. This effectively gives more weight to the reduction in energy consumption and the social criteria. The third set of relative weights (W3) give a value of 2 to PVEEB with the other relative weights unchanged. This gives more weight to the economic criterion.

It should be noted that the final scores using the relative weights are arbitrary so that a value of 1.06 for one option using relative weights W1 can't be compared with a value of 0.85 for the same option using relative weights W2.

The ranking of projects using the sets of relative weights W1, W2, and W3 are given in Table 4.22. It is notable that Options 10 (involving indirect potable reuse) ranks below Options 2 and 3 for all three sets of weights. This is due to the much higher public acceptability of using harvested stormwater for watering of public open space than for indirect potable use. Also Option 1 ranks higher than Options 9 and 12 for all sets of weights, again reflecting the higher public acceptability of using harvested stormwater for watering public open space. Option 9 (involving direct potable reuse) ranks higher than Option 12 (indirect potable reuse after some treatment) for all three sets of weights although the differences are all quite small.

Of the third pipe options, Options 5 and 6 (supply after wetland treatment but without ASR) for greenfield sites rank the highest after considering social and environmental factors. However, as noted earlier none of the third pipe options are justified on purely economic grounds.

Table 4.21: Scaled and weighted values of the various criteria

Option	Average annual supply (ML/year)	Present Value of Economic and Environmental Benefits ($m)	Reduction in Energy Consumption (Mwh/year)	Public support for stormwater harvesting (%)	Public trust of authorities for safety (%)	Weighted Average (W1)	Weighted Average (W2)	Weighted Average (W3)
1	370	0.54	0.33	1.00	0.58	1.66	1.39	2.20
2	880	0.70	0.56	1.00	0.58	2.05	1.70	2.74
3	880	0.69	0.56	1.00	0.58	2.04	1.70	2.74
4	2100	1.00	1.00	1.00	0.58	2.79	2.29	3.79
5 (Greenfield)	370	0.43	0.12	0.73	0.58	1.20	0.99	1.63
5 (Brownfield)	370	0.34	0.12	0.73	0.58	1.11	0.94	1.45
6 (Greenfield)	880	0.48	0.06	0.73	0.58	1.19	0.95	1.67
6 (Brownfield	880	0.27	0.06	0.73	0.58	0.98	0.85	1.25
7 (Greenfield)	1000	0.43	0.06	0.73	0.58	1.14	0.93	1.57
7 (Brownfield)	1000	0.19	0.06	0.73	0.58	0.90	0.81	1.09
8 (Greenfield)	2100	0.50	0.00	0.73	0.58	1.16	0.91	1.66
8 (Brownfield)	2100	0.00	0.00	0.73	0.58	0.66	0.66	0.66
9	880	0.59	0.41	0.55	0.47	1.51	1.22	2.11
10	1034	0.77	0.56	0.57	0.47	1.85	1.47	2.63
11	827	0.65	0.39	0.57	0.47	1.56	1.24	2.22
12	827	0.62	0.29	0.57	0.47	1.43	1.12	2.05
W1		1	1	0.5	0.5			
W2		0.5	1	0.5	0.5			
W3		2	1	0.5	0.5			

Table 4.22: Rank order of options using various sets of relative weights (Rank 1 = best)

Rank	NPV or PVEEB	W1	W2	W3
1	4	4	4	4
2	10	2	2	2
3	2	3	3	3
4	3	10	10	10
5	11	1	1	11
6	12	11	11	1
7	9	9	9	9
8	N.A.	12	12	12
9	N.A.	5G	5G	6G
10	N.A.	6G	6G	5G

5. Summary and Conclusions

This report presents a general framework to assess the net benefits of different uses of harvested stormwater for projects in Australia. This framework is demonstrated through a case study involving managed aquifer recharge in the Parafield catchment in the City of Salisbury. The framework and tools consider a broad scope of economic, environmental and social criteria for a number of stormwater harvesting options in the study area.

The general framework will assist authorities to define the scope for evaluation of their projects. Techniques for analysing a wide array of economic benefits and costs, water supply and water quality issues, environmental and social impacts are outlined and demonstrated in the Parafield case study. The proposed framework should assist authorities to assess the following aspects of proposed stormwater reuse schemes:

- The net present value of direct economic benefits and costs via a traditional cost-benefit analysis
- Environmental benefits and costs (assessment of externalities such as energy, greenhouse gas emissions, improved water quality, impact on the quality of receiving waters and urban amenity through increased land values)
- Social values of the key stakeholders and the community
- A broader multi-criteria analysis (MCA) of factors not easily incorporated in a standard cost-benefit analysis

A MCA allows for relative weights to be placed on each of the economic, environmental and social criteria. The choice of these weights is a transparent process that explicitly enables differences in values between key decision makers to be identified. When all the components are brought together in a multi-criteria decision framework, authorities will be in a position to choose between the various options for treatment and end use of the harvested stormwater.

The results obtained for the case study depend on the assumptions and data used and are presented here as indicative outcomes only. The results are sensitive to the assumed cost savings from traditional potable water sources.

It is noted that different stakeholders have different economic frameworks for decision-making based on the cost and benefits to their organisations, as opposed to the total economic costs and benefits to the state.

In the case where a value of $2.75 per kL is assumed for the cost savings from traditional potable sources (based on the long run marginal cost of potable supply), the following stormwater harvesting options have positive economic benefits for the Parafield scheme:

(3) Three the options that involve watering of public open space (in the following order of preference: Option 4, 2, and 1);
(4) All of the potable use options (in the following order of preference: Option 10, 11, 12 and 9); and

None of the third pipe options have a positive NPV. The ranking of these options is given in Table 4.22. When a full multi-criteria analysis is carried out including environmental and social criteria, the same nine options are ranked highly in a slightly changed order. The third pipe options 5 and 6 Greenfield are the most favoured options from this group when a full multi-criteria analysis is carried out. However, they rank below all of the options involving watering of public open space or potable uses.

In the case of the Parafield scheme, the environmental costs and benefits when expressed in dollar terms were relatively small compared to the economic costs and benefits. This is not regarded as typical, but the analysis was completed in order to act as a prototype for other assessments.

Appendix A: Comparison of Multi-criteria Analysis and Cost-Benefit Analysis for Assessment of Stormwater Harvesting Options

A multi-criteria analysis framework (UK Department of Transport, 2000; Mendoza and Martins, 2006) is used in this report. A fundamental part of that assessment is a traditional cost-benefit analysis (Department of Finance and Administration, Commonwealth of Australia, 2006).

The cost-benefit approach is illustrated by RMCG (2013) who present an economic framework for the analysis of stormwater harvesting options. This framework is shown in Figure A.1. The RMCG framework includes market and non-market benefits and costs as well as other cultural, social and environmental benefits.

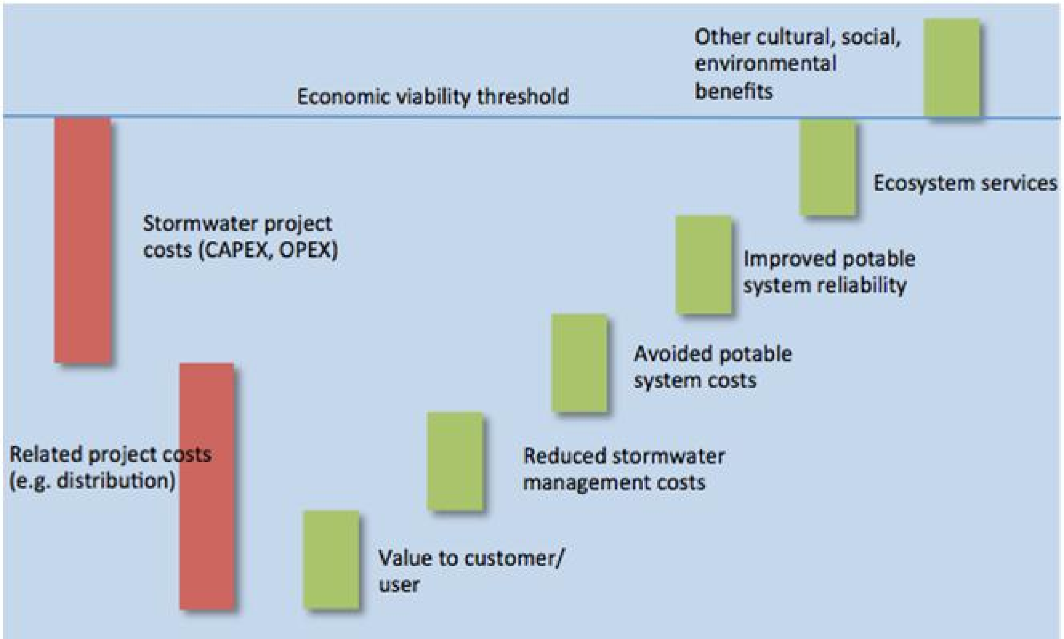


Figure A.1: Stormwater project economic framework (Reference: RMCG, 2013, adapted from Marsden Jacobs Associates, 2013)

The market benefits and costs include the stormwater project costs, related project costs, value to customer/user, reduced stormwater management costs, avoided potable system costs and improved potable system reliability. The non-market benefits and costs include the environmental benefits that are assessed using an ecosystem services framework. Other cultural, social and environmental benefits are not quantified in dollar terms but may be qualitative.

The distribution of benefits and costs is a separate issue and needs to be considered outside of the economic framework.

In a multi-criteria analysis (MCA), separate criteria are considered with the final option(s) being chosen using a suitable technique such as the weighted sum of the individual criteria (UK Department of Transport, 2000; Mendoza and Martins, 2006). The weights to be applied to each criterion need to be chosen by the key stakeholders.

In the framework presented in this report a multi-criteria analysis approach has been taken with the criteria divided into economic benefits (the traditional cost-benefit measure), environmental benefits (using an ecosystem services approach) and social criteria (including distributional issues, public perception and trust of the water utility).

The advantages of using a multi-criteria analysis compared to cost-benefit analysis are summarised below:

(1) MCA can include all criteria (either quantitative or qualitative) that are relevant to the problem being addressed; cost-benefit analysis concentrates on those benefits and costs that can be expressed in dollar terms;
(2) MCA can include the net present value of economic benefits and costs as one of the criteria, so that the traditional cost-benefit measure will be explicitly included within the analysis;
(3) Cost-benefit analysis aims to maximise the net benefits of the project regardless of to whom they occur; the distribution of these benefits and costs needs to be considered separately;
(4) MCA can consider the distribution of benefits and costs in conjunction with maximising net benefits; and
(5) MCA allows the key stakeholders to express preferences for the various criteria; cost-benefit analysis weights all benefits and costs equally

Appendix B: Analysis of Greenhouse Gas Emissions

Given the rising concerns about scarce energy resources and global climate change, a generalized life-cycle diagram focusing on energy use and greenhouse gas (GHG) emissions is recommended in water supply projects. The issue of GHG emissions has been investigated in different areas of water studies, e.g., water distribution system optimization (Sarbu and Borza, 1998; Baran et al. 2005; Lopez-Ibáñez et al. 2005, and Ulanicki et al. 2007), and water planning and management (Lundie et al. 2004; Filion et al. 2004; Filion 2008; Wu et al. 2010). Considering these research works, a generalised framework is developed for GHG emission studies in stormwater harvesting projects. The framework consists of four processes within the water supply phase of the life cycle as:

1-water supply headworks construction and operation,
2- raw water control and pumping,
3- water treatment and pumping,
4-distribution system and pumping.

Figure B.1 illustrates the life-cycle energy and GHG flow diagram and the corresponding processes. Each process consists of a sub-section that describes material requirements/energy (e.g. chemical, pipes, pumps, energy, etc) for the process. In each sub-section, GHG emissions are associated with the total embodied energy involved in the manufacture of the required materials or the main inputs of the process. Energy/material requirements inside each sub-section as well as GHG emissions should be estimated. In each main process, GHG emissions are mainly associated with the manufacture and installation of the water supply network and its components (such as pipes, pumps, valves, storage, and tanks) and operating GHG emissions.

The emissions associated with the installation of water supply network are called capital emissions and occur at the beginning of the project. The operating GHG emissions are caused by electricity and fuel consumption and are related to the operation of the system over its economic life.

GHG emissions associated with the energy requirements can be easily calculated by multiplying the amount of energy by the corresponding emission factor expressed in kilograms of CO_2 equivalent per kwh. Emission factors for Australia are defined in Department of Climate Change and Energy Efficiency (2012a) and are divided into scope 1,2 and 3 emissions. The definitions of these are given below (Department of Climate Change and Energy Efficiency, 2012a):

"Direct (or point-source) emission factors *give the kilograms of carbon dioxide equivalent (CO2-e) emitted per unit of activity at the point of emission release (i.e. fuel use, energy use, manufacturing process activity, mining activity, on-site waste disposal, etc.).*
These factors are used to calculate ***scope 1 emissions****.*

☐***Indirect emission factors*** *are used to calculate* ***scope 2 emissions*** *from the generation of the electricity* ***purchased and consumed*** *by an organisation as kilograms of CO2-e per unit of electricity consumed. Scope 2 emissions are physically produced by the burning of fuels (coal, natural gas, etc.) at the power station.*

☐***Various emission factors*** *can be used to calculate* ***scope 3 emissions****. For ease of use, this workbook reports* ***specific 'scope 3' emission factors*** *for organisations that:*
(a) burn fossil fuels: to estimate their indirect emissions attributable to the extraction, production and transport of those fuels; or

(b) consume purchased electricity: to estimate their indirect emissions from the extraction, production and transport of fuel burned at generation and the indirect emissions attributable to the electricity lost in delivery in the transmission and distribution network."

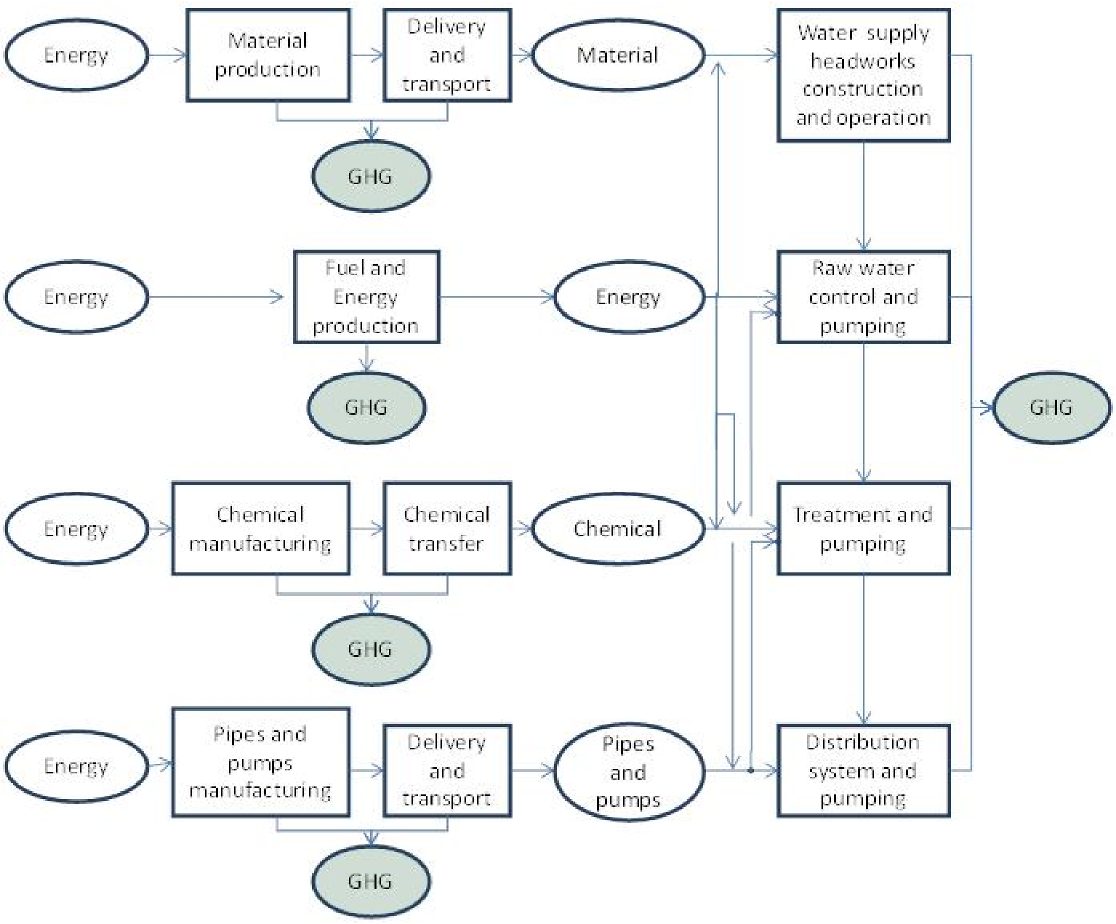


Figure B.1:Life-cycle energy and GHG flow diagram in water supply projects

For water supply projects, scope 2 and 3 emissions associated with electricity production, transmission, distribution and consumption are the most relevant. TableB.1 gives a summary of average emission factors for each state and territory in Australia.

Table B.1: Scope 2 and 3 emissions factors - consumption of purchased electricity by end users (adapted from Department of Climate Change and Energy Efficiency, 2012a):

State or Territory	Emission Factor for Scope 2 Emissions (kg CO2-e/kWh)	Emission Factor for Scope 3 Emissions (kg CO2-e/kWh)	Fuel Cycle Emission Factor for Scope 2 plus Scope 3 emissions (kg CO2-e/kWh)
NSW/ACT	0.88	0.18	1.06
Victoria	1.19	0.15	1.35
Queensland	0.86	0.12	0.98
South Australia	0.65	0.14	0.79
Western Australia	0.82	0.10	0.92
Tasmania	0.26	0.02	0.29
Northern Territory	0.71	0.08	0.79

Technical guidelines for the estimation of greenhouse gas emissions by facilities in Australia are presented in Department of Climate Change and Energy Efficiency (2012b). In relation to the estimation of scope 2 emissions, this document says:

"The scope 2 emission factors are state-based emission factors from on-grid electricity generation calculated systematically from the physical characteristics of the electricity grid. The state-based emission factor calculates an average emission factor for all electricity consumed from the grid in a given state, territory or electricity grid. All emissions attributable to a state territory or grid's electricity consumption are allocated amongst individual consumers in proportion to their relative level of consumption. In effect, the likelihood of a particular generator supplying a particular consumer is assumed to reflect each generator's relative level of supply to the grid. The reason for this approach is that within an electricity grid it is impossible to physically trace or control the actual physical source of electricity received by each customer.
This approach minimises information requirements for the system and produces factors that are relatively easy to interpret and apply, and which are used to support a range of specific government programs and policies. Consistent adoption of these physical state-based emission factors ensures the emissions generated in each state are fully accounted for by the end-users of the purchased electricity and double counting is avoided".

It should be noted that a number of water utilities and local government authorities purchase green energy or carbon offsets. Where these offsets have been purchased, the greenhouse gas emissions calculated using state-based emission factors should be listed as gross greenhouse gas emissions. Net emissions can then be calculated by reducing the gross emissions by the amount of the green energy or carbon offset purchased.

Figure B.2 shows the overall process for estimating the capital and operating GHG emissions at each main process in a stormwater harvesting project. The GHG emissions considered in this framework is defined as the sum of the capital emissions and operating emissions. Although a number of authors recommend that future greenhouse gas emissions be discounted in a similar way to future economic benefits and costs, in this study it is recommended that capital emissions be spread over the life of the project without discounting. That is, capital emissions can be converted into annual emissions by dividing by the life of the facility.

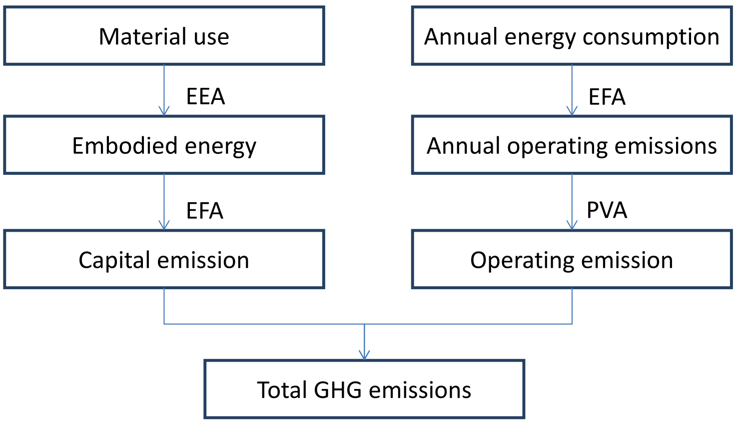


Figure B.2:the overall process for estimating the capital and operating GHG emissions at each main process in a water supply project (PVA = present value analysis; EFA = emission factor analysis; EEA = embodied energy analysis)

Appendix C: Detailed Catchment Level Analysis of Impacts

This Appendix outlines more of the detail of the transferable methodology for assessing potential catchment-level environmental costs and benefits (hereafter impacts) of stormwater harvesting noting that the magnitude of the impacts would vary depending on various contextual factors. These include, but are not limited to, procedures by which stormwater is harvested, stored, treated, distributed, used, and discharged.

The method of analysis proposed in this section is a modification of the methodology for externality analysis proposed as part of the External E project (European Commission, 1998). The method consists of two main stages involving definition of boundaries of analysis (This stage was previously discussed in section 2), and analysis of impacts. The next subsections only explore the second stages in detail. The method is applied to assess, and where possible quantify impacts of stormwater harvesting and use in the Parafield catchment.

C.1 Description of impact pathways

A clear understanding of how stormwater harvesting is linked with each one of the key impacts identified is needed before the impacts are valued. In this case for example, stormwater harvesting is linked with impacts on salinity damage replacement costs because stormwater is less saline than existing water sources, and we expect water users to save on expenditures associated with salinity damage replacement if harvested stormwater is introduced in the mains water supply system for household and commercial industry use.

C.2 Quantification of biophysical impacts

Identification and quantification of key biophysical attributes linked with the key impacts identified are necessary before impact valuation can be carried out. For example, to value all impacts associated with the discharge of nitrogen (N) and suspended solids (SS) to the sea from the Parafield catchment, quantification of N and SS emissions and thresholds with and without stormwater harvesting (with surface water detention) is required. Similarly, quantification of the volume of stormwater run-off discharged into rivers, and in drainage systems in the Parafield catchment, and flood threshold levels need to be understood before the value of flood mitigation from stormwater harvesting can be estimated. Some information was generated in the Adelaide Coastal Waters Study (CSIRO 2007). However, some processes have yet to be understood and communicated in ways adequate for economic analysis.

C.3 Description of receiving environment

The use of the impact pathway approach for assessing impacts requires a detailed definition of the scenario under analysis with respect to both time and space. Relevant examples of this include, but are not limited to: meteorological conditions affecting dispersion and chemistry of pollutants in stormwater runoff, location, age and health of coastal ecosystems relative to the source of pollutants, status of ecological resources, and value systems of individuals benefiting from coastal amenity services.

C.4Quantification of impacts

The complexity of the impact pathway analysis varies greatly. In some cases impacts can be estimated by multiplying together as few as three or four parameters whilst in others it is necessary to use a series of sophisticated process models.

The impacts of changes in a wide range of biophysical attributes from stormwater harvesting may need the use of a wide array of dose-response functions to quantify magnitudes, and identify thresholds.

C.5 Economic valuation

The ecosystem services concept provides a useful framework for considering a broad range of ecosystem services impacted by stormwater harvesting (Millennium Ecosystem Assessment 2005; Bateman et al. 2006; Tong et al. 2007; Yang et al. 2008; UKNEA, 2011). In the ecosystem service framework, typical ecosystem services impacted by stormwater harvesting operations include, but are not limited to water quality regulation, flood mitigation, provision of fresh water, and amenity services.

To value a particular ASR ecosystem service, one would need to compare the state of the world as it exists with a well-defined prediction of what would exist should that specific service be eliminated. In addition to this, we would need to include impacts on other ecosystem services (Bockstael et al., 2000).

Once biophysical impacts of stormwater harvest have been identified and quantified, they can be valued to obtain a monetary value for the impacts. In economic value theory, the value of some change in the provision (or regulation) of an ecosystem service is assessed in terms of the change in social welfare that it generates; this value is often referred to as a benefit (cost) if it raises (lowers) social welfare.

In applied welfare economics, such as in cost-benefit analysis, monetary value estimates are often used. The underlying economic principle in monetary valuation is to elicit the willingness to pay (WTP) of the affected individual to avoid a negative impact, or the willingness to accept (WTA) payment as compensation if a negative impact takes place. The rationale is that values should be based on individual preferences and choices as expressed through decisions and tradeoffs they make (Freeman, 2003) given certain constraints – income, time, which are translated into money terms through individual WTP and WTA.

WTP and WTA measure how much of other goods and services individuals are willing to give up for the ecosystem service with monetary values as the medium of exchange. Economic values for ecosystems accept consumer sovereignty and can be interpreted as descriptions of the tradeoffs involved in evaluating well-defined changes to specific ecosystems. A Social welfare function is considered to be aggregate of the welfare functions of individuals.

Where markets exist, impacts of changes in ecosystem services can be valued using market prices. Utility theory, a concept in economics, ranks alternatives in order of preference to the consumer. Since a consumer’s choice is constrained by the price and the income of the consumer, the rational consumer will not spend money on an additional unit of good or service unless its marginal utility (WTP) is at least equal to or greater than that of a unit of another good or service.

The price of a good or service is thus related to its marginal utility and the consumer will rank his or preferences accordingly. The market demand (WTP) curve can thus can be derived from the marginal utility curve, and the market price gives the minimum value of the service to the consumer. Where market data including price and demand and supply functions exist, changes in social welfare resulting from changes in ecosystem services can be valued by quantifying changes in consumer and/or producer surplus.

For a wide range of impacts, however, such as loss of recreational values from poor coastal water quality (without stormwater harvesting), there are no direct market prices that can be used. Three non-market valuation techniques are widely used in this context including contingent valuation method, hedonic price method, and travel cost method. Hedonic and travel cost techniques elicit revealed preferences while contingent valuation techniques elicit stated values.

The contingent valuation method uses survey and experimental techniques to elicit personal valuations of a quantifiable improvement in a specified environmental quality contingent upon a hypothetical market. The hedonic price method attempts to infer the willingness to pay for a quantifiable improvement in a specified environmental quality usually done by means of a multiple regression technique. The travel cost method infers willingness to pay values associated with recreational sites by estimating changes in access costs for a recreation site including time and travel cost expenses incurred to visit the sites.

Where direct markets for ecosystem services do not exists and resource constraints make it impracticable to carry out non-market valuation, cost-based approaches can be used to estimate economic impacts instead of stated and revealed preference methods (Liu et al., 2010; WERF, 2010). This involves cataloguing and estimating actual expenditures that would be incurred by consumers, government agencies, various NRM Boards, and water utilities, assessing the cost implications of replacing some level of ecosystem service currently provided by stormwater harvesting with a technological alternative or other means. Alternatively, estimates of expenditures incurred to avoid or mitigate damages caused by the loss of services otherwise provided by stormwater harvesting can be used.

One criticism of cost-based approaches is that they produce an incomplete set of disconnected values for a subset of ecosystem services, and do not incorporate social preferences and social welfare, the underlying principal in economic valuation theory (Holland et al., 2010; Bockstael et al., 2000). This is because cost-based approaches do not incorporate information on whether or not individuals would prefer to forego replacement of ecosystem services if they consider the opportunity cost (value of next best alternative) to be higher than the value they place on replacing the ecosystem services.

Whilst cost-based approaches do not give a measure of the value of ecosystem services as they do not capture changes in welfare or consumer/producer surplus, they provide a minimum low-end estimable value of the cost of replacing or avoiding loss of ecosystem services given limited information (WERF, 2010). Assuming near-perfect market conditions where marginal cost is approximately equal to marginal benefit, and the market price, cost-based approaches may offer a good approximation of value of ecosystem services. Where these conditions do not exist, it is difficult to understand what is being measured.

Perfect market conditions thus assume a good or service’s market value is its economic value. In practice, however, the market price only indicates the amount people actually pay rather than what they are willing to pay. This can lead to underestimation of benefits of ecosystem services. Nevertheless, in some specific circumstances, the cost of replacing an ecosystem service with a human-engineered system can be used as a measure of the economic value of the function itself (Bockstael et al., 2000).

Bockstael et al (2000) argue that replacement cost can be a valid measure of economic value if the following three conditions are met: (i) that the human-engineered system provide functions that are equivalent in quality and magnitude to the natural function; (ii) that the human-engineered system offers the least cost alternative way of performing this function; and (iii) that individuals in aggregate would in fact be willing to incur these costs if the natural function were no longer available.

One important distinction is between impact values arising from the use of the environment by the individual and values that arise even when there is no identifiable use made of that environment. These are called use values (consisting of direct, indirect and option values) and non-use values respectively. Non-use values are also sometimes referred to as existence or intrinsic values.

Impacts can be valued directly through the collection of primary data on preferences or using meta-analysis and benefit transfer approaches where similar studies exist. A meta-analysis combines the results of several studies that address a set of relevant values. Benefits transfer uses monetary values from a particular valuation study to an alternative or secondary policy decision setting, often in another geographic area than the one where the original study was performed.

The issue of temporal differences in impacts is addressed in economic valuation using discounting techniques. Discounting is the practice of placing lower numerical values on future benefits and costs as compared to present benefits and costs. The basic rationale for discounting is that individuals attach less weight to a benefit or cost in the future than they do to a benefit or cost now. In the context of stormwater harvesting, it is an important issue because some of the impacts of stormwater harvesting may occur many years after the stormwater harvesting commences operation.

Appendix D: Estimate of the cost of the existing infrastructure: Bolivar-Greenfields and Greenfields-Mawson Lakes

In this Appendix the cost of the existing infrastructure located outside the Parafield scheme is estimated. This is not included in the $13m of sunk costs at Parafield mentioned in Section 3. This cost is estimated so as to evaluate all options for the case where there is no existing infrastructure and it all must be provided from scratch. Options 1-3 and 9-12 do not require this infrastructure, as they do not involve blending with recycled wastewater from Bolivar or pumping from Greenfields to Mawson Lakes.

In option 4, 7 and 8, recycled wastewater is blended with stormwater: it is assumed that the pipeline from Bolivar to Greenfields has a diameter of 280 mm and a length of 9 km, resulting a cost of about $3m. The capital cost of the pumping station in Bolivar is estimated based on the pump power required. These costs are estimated using the equations and data given in Appendices N and O and are summarised in Table D.1.

After being pumped and blended with stormwater, water is stored in a clearwell storage. The existing capacity of this tank is 2.6 ML, with an estimated cost equal to $0.79m. The existing pumping system in Greenfields is able to provide 4 ML/day to Mawson Lakes. Assuming a pump head equal to 100 m, an efficiency equal to 80% and 50% standby power, the capital cost of this pumping station is estimated to be $0.58m. A summary of the cost estimation process is given in Table D.1.

Options 5 and 6 do not require blending with stormwater, but they use the existing storage and pumping facility in Greenfields. TableD.2 gives a summary of the costs of the existing infrastructure outside Parafield.

Table D.1: Summary of cost estimation for Bolivar-Greenfields and Greenfields-Mawson Lakes infrastructure

Component	Properties	Equation	Cost ($m)
Pipe Bolivar-Greenfields	Length: 9 km Diameter: 0.280 m Cost per metre=$333/m	Cost ($)=Cost per metre*Length	3.00
Pumps Bolivar-Greenfields	Q=8.2 ML/day H=77.7 m P=90 kW Standby = 50%	Cost ($)=47,370*(P*1.5)^0.6299	0.70
Pumps Greenfields to Mawson Lakes	Q=4 ML/day H=100 m P=68 kW Standby = 50%	Cost ($)=47,370*(P*1.5)^0.6299	0.58
Existing storage at Greenfields	Capacity=2.6 ML	Cost ($) = 199,620*Capacity+268901.3	0.79

Table D.2: Summary of the costs of the existing infrastructure in Bolivar-Greenfields and Greenfields-Mawson-Lakes.

Option	Pipe Bolivar-Greenfields ($m)	Pumps Bolivar-Greenfields ($m)	Existing storage at Greenfields ($m)	Pumps Greenfields to Mawson Lakes* ($m)	TOTAL ($m)
4	3.00	0.70	0.79	0.58	5.07
5	0.00	0.00	0.79	0.58	1.37
6	0.00	0.00	0.79	0.58	1.37
7	3.00	0.70	0.79	0.58	5.07
8	3.00	0.70	0.79	0.58	5.07

*For Option 4, the blended wastewater and stormwater would be distributed to suitable reserves within the region

Appendix E: Estimation of Catchment Yield for Parafield

The Parafield scheme was developed for harvesting urban stormwater in the City of Salisbury and utilises ASR (Aquifer Storage and Recovery).

A hydrologic model of the Parafield catchment was developed using the WaterCress software. Figure E.1shows the overall framework of the simulation model developed for this option. The Parafield catchment is represented by four urban/industrial nodes (nodes 3, 5, 7, 2) and two rural areas (nodes 1 and 6). The Ayfield catchment has 2 urban nodes (nodes 10, 8) and 1 rural (node 9), respectively.

The simulation model was calibrated for the period July 2002 to October 2006. This represents all of the available flow data at the Parafield site. The average annual rainfall during the years 2002 to 2006 at Parafield was 380.4 mm compared to 457.2 mm for the period 1970 to 2007. Hence the model was calibrated during a drier period than average. It should, therefore give more reliable estimates of the lower annual yields of the system.

Studies in the literature suggest that this period of data is adequate for model calibration. For example, Ancil et al. (2004) found that 3 to 5 years of calibration data worked best for modelling the runoff from a catchment in France while Shin et al (2013) found that a minimum of five years of data were required to adequately assess parameter sensitivities for 5 catchments in the Australian Capital Territory.

A plot of the modelled versus the measured monthly flows is given in Figure E.2 and this shows reasonable agreement.

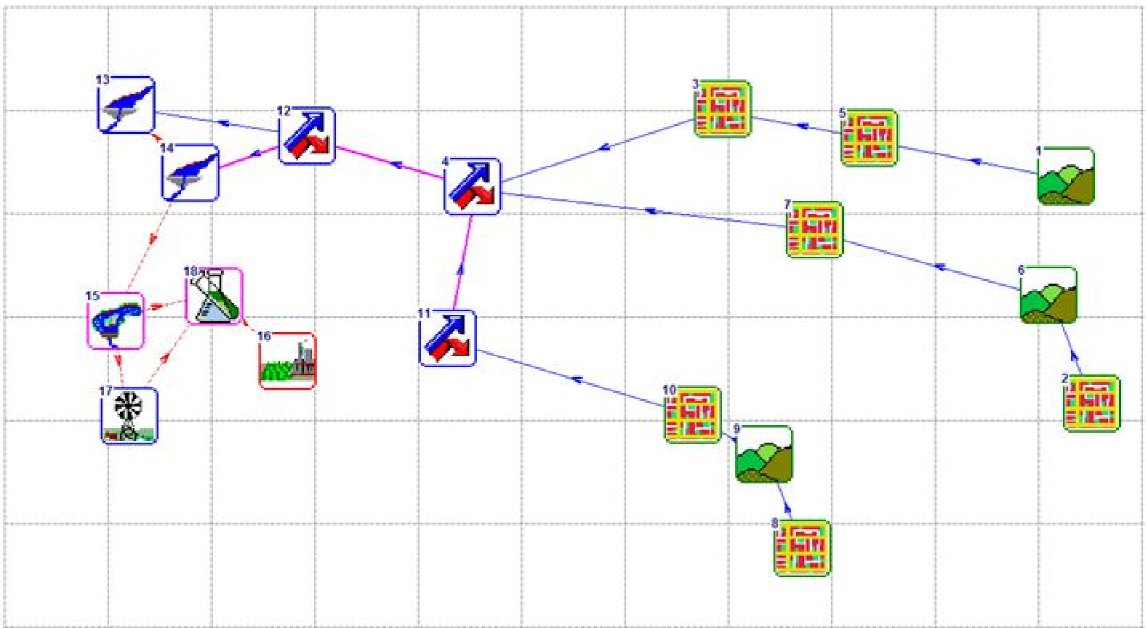


Figure E.1: The simulation model of Parafield catchment as developed for the current study

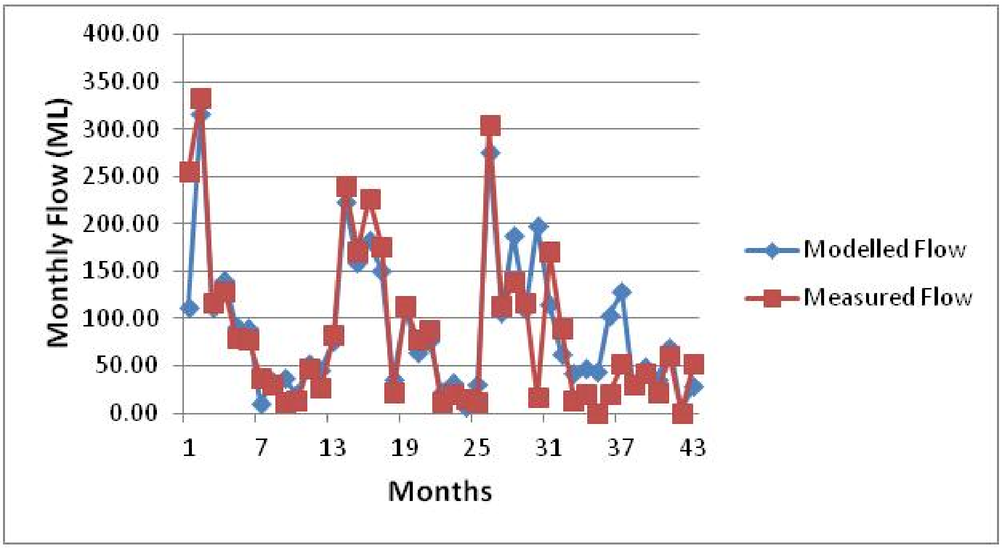


Figure E.2: Calibration Plot for Parafield Catchment Runoff

The hydrologic model was run using daily rainfall and evaporation data for the period 1980 to 2000 from the patched point data set for Parafield (http://www.longpaddock.qld.gov.au/silo/ppd/index.php).

A minimum retention of 3 days was maintained in the reedbed to ensure a reasonable level of treatment. Figure E.3 shows a histogram of the annual harvested yield for the Parafield catchment. Statistical analysis of the data gives a mean annual yield of 1200 ML/year with a standard deviation of 220 ML/year. Similar results were reported by Clark and Associates (2001) and Wallbridge and Gilbert (2009). In order to be conservative, an average annual yield of 1100 ML was assumed in this report.

The WaterCress model was rerun without ASR. In this case water was stored in the holding basin and reedbed and then supplied to directly to consumers. The demand was assumed to be 6 ML/day in October through March and zero in the months April through September. If 6 ML/day was not available, the maximum possible volume was supplied while maintaining a volume of at least 7.5 ML in the reedbed. In this case, an average annual yield of 371 ML was obtained.

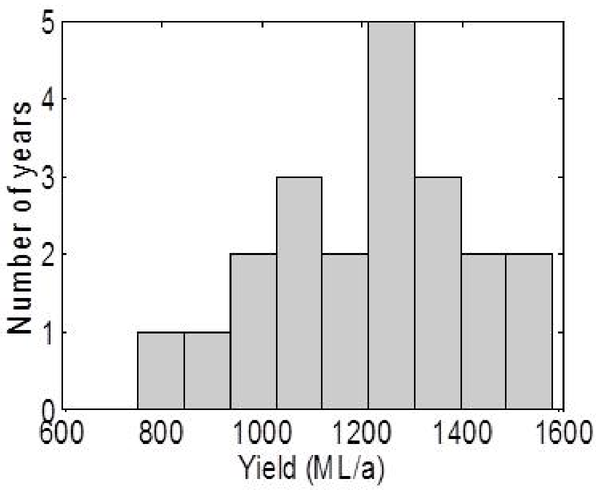


Figure E.3:Histogram of simulated yield (reed-bed output) values for the Parafield catchment (1980 to 2000)

Appendix F: 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.

$$L = (C*crf + O + M + R) / Q \qquad (F1)$$

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

$$crf = i / [1 - (1+i)^{-n}] \qquad (F2)$$

Levelised cost can be used to compare water from various sources regardless of their size. In some cases, the annual capacity of the system is used to determine levelised cost instead of the annual output. This can be misleading for a system that runs at less than full capacity.

Appendix G: Costs of the Various Options

The capital and operating costs for the 12 options are presented in this appendix. The equations used for the design of pumps and pipes are given in Appendix N, while Appendix O has the equations used for estimating the capital, operating and maintenance costs of hydraulic and water treatment infrastructure. Pump characteristics (flow, pressure head, power) that have been used to compute capital, operational and management costs for each option can be found in Appendix P.

Capital, operational and management costs estimated in this section are incremental to the current infrastructure. The present values of the costs of existing infrastructure are estimated to be the following:

(1) $4m for the Parafield scheme without ASR
(2) $6m for the Parafield scheme with ASR
(3) An additional $7m for the distribution system (excluding the third pipe network in residential areas.
(4) Costs for the Bolivar to Greenfields and Greenfields to Mawson Lakes infrastructure given in Appendix D.

In order to compare the cost with a totally new scheme these capital costs would need to be added.

G.1 Options 1-4: Open space irrigation

As stated earlier, Options 1-4 involve harvesting of urban stormwater through a harvesting system, treatment through a wetland (Options1-4), storage in an aquifer (Options 2-4), and disinfection (Options 3-4). Option 4 involves includes blending with recycled water prior to disinfection.

Options 1 and 2 are currently undertaken in the Parafield system. For Options 1-3, it is assumed that the existing VSD distribution pumps can be used for water distribution via the existing pipe infrastructure. For Option 4, water will be transferred to the Greenfield site for blending with tertiary treated wastewater and disinfection.

G.1.2 Option 1:Stormwater harvesting without ASR followed by open space irrigation

This option involves stormwater harvesting and treatment through a wetland without ASR (Figure G.1). The water is then delivered for irrigation purposes. It is assumed that the existing pipes (300 mm PVC pipeline to Mitchell Wool Pty Ltd and 225 mm mPVC to Mawson Lakes) will be able to deliver harvested stormwater for watering of public open space. As noted in Section 4.2, in the absence of ASR the scheme can deliver an average of 370 ML/year.

To transfer stormwater from the in-stream basin to the holding basin, the Parafield scheme has 2 pumps (75 kW) and an additional 5.5 kW pump. As the pumps are able to empty the in-stream basin in one day (50 ML/day), no civil works are needed and only operational and maintenance costs are considered for this option. As pumps will be run whenever stormwater is flowing into the in-stream basin, it is assumed that they will run for the equivalent of 8 days for the year with a discharge of 50ML/day (giving a delivered volume of 400 ML for a year). Once the energy cost is actualised over 25 years, the present value of the operational cost is $0.07m. Maintenance costs are estimated to be 5% of the capital costs, which in turn are estimated considering an installed pump power equal to 155 kW.

It is assumed that the pumps currently used to pump from the storage tanks to the distribution system (5 pumps able to deliver up to 10 ML/day with a pressure of 600 kPa) can be used for pumping directly from the wetland. The average delivery rate from the wetlands is 370 ML/year (see Section 4.2) as it is estimated that, in the absence of a large storage, losses due to evaporation and spillage will occur. It is assumed that the pumps deliver 6 ML/day for 61.7 days per year while pumping for 20 hours per day. This volume is smaller than the volume pumped from the in-stream basin to the holding basin because of evaporation and leakage.

This option does not include a clearwell because this would require additional pumping (from the wetland to the storage and from the storage to the distribution system). As the purpose of this option is irrigation of open spaces, it is assumed that no emergency storage is required.

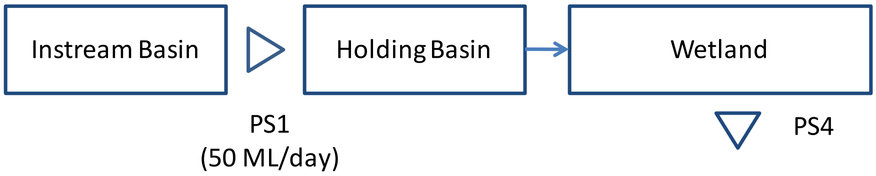


Figure G.1:Layout of Option 1.

According to Page et al. (2013a), the microbial health-based target is 1.6 log-removals of viruses from stormwater for irrigation water. The current treatment activities for Option 1 are water treatment through the wetland (zero log-removal) and exposure control such as irrigation at night, spray drift buffers and avoidance of irrigation in strong wind (2-log removal) (see Page et al., 2013a). Therefore, 1.6 log removals can be achieved without introducing any other treatment. If a higher log removal is necessary, the operating and capital costs for additional treatment options (e.g., treatment by injecting to aquifer storage, treatment and recovery (ASTR), chlorination, microfiltration, and etc) need to be considered. Costs associated with risk management were provided by Page et al (2013b). For irrigation of open space, the costs associated with risk management including maintenance of controls, monitoring and reporting are estimated to be $0.20/kL.

TableG.1gives the costs associated with Option 1.

TableG.1:The summary cost analysis (present values) for Option 1 considering a 25 year economic life

Item			**Present value cost ($m)**
Operating and Maintenance Costs($m)	Parafield	Pump Station PS1	0.56
		Pump Station PS4	0.62
Risk management costs ($0.20 /kL)			**0.95**
Total Present Value ($m)			**2.13**
Levelised Costs ($/kL) (Supply = 370 ML/year)			**0.45**

G.1.2 Option 2 Stormwater harvesting with ASR and open space irrigation

The activities for this option are stormwater harvesting and treatment through a wetland and aquifer (Figure G.2). As with Option 1, the required log removal is1.6. Currently, wetland treatment and ASR are not credited with viral log-removals, but source control offers 2 log removals. Hence, no additional treatment is required for this option.

The annual volume pumped from the in-stream basin to the holding basin will be the annual yield of 1.1 GL/year. The pumping station PS1 (50 ML/day capacity) has to operate 528 hours to pump that volume of water. After the wetland, the pumping station PS2 (a pump able to inject up to 8 ML/day) injects water to the aquifer. It is assumed that the pump pressure head is 30 m and the efficiency is 80%. Energy consumption has been computed for an average flow of 3ML/day and a peaking factor of 2.

Extraction is shared among 4 wells with a combined capacity of 6 ML/day (it is assumed that the pressure head delivered by the well pumps is 60 m, (Bruce Naumann, Salisbury Water, Pers. Comm., May 19, 2013). As noted earlier, the energy requirements for the extraction have been computed assuming aquifer recovery efficiency is 80%.

After extraction, the water is stored in two clearwell storage tanks each with a volume of 0.3 ML. As water can also be stored in the aquifer, the two existing tanks are considered sufficient. From the tanks, another group of pumps (PS4) is used to transfer the water to the final end uses. These distribution pumps have the same characteristics as those in Option 1. Allowing for an 80% recovery from ASR, Option 2 would deliver an average of 880 ML/year. TableG.2gives the costs associated with Option 2.

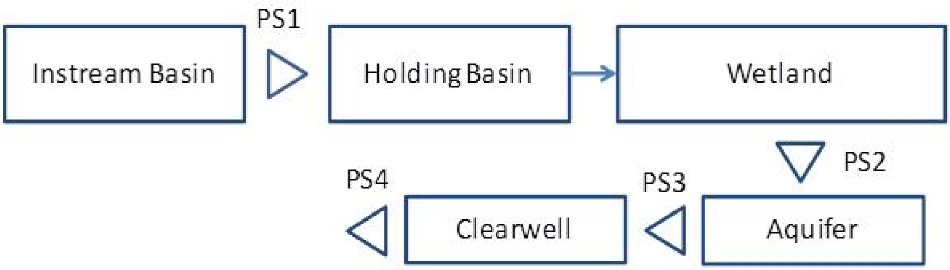


Figure G.2: Layout of Option 2.

TableG.2: The summary cost analysis (Present Values) for Option 2 considering a 25 year economic life

Item			**Present value cost ($m)**
Operating and Maintenance Costs($m)	Parafield	Pump station 1	0.74
		Pump station 2	0.57
		Pump station 3	0.84
		Pump station 4	0.96
		Storage tanks	0.25
Risk management costs ($0.12 /kL)			**1.35**
Total Present Value ($m)			**4.71**
Levelised Cost ($/kL) (Supply = 880 ML/year)			**0.42**

G.1.3 Option 3 Stormwater harvesting with ASR, chlorination and open space irrigation

The activities for this option are urban stormwater harvesting and treatment using a wetland and aquifer followed by chlorination (2-log removal) and exposure control (2-log removal; see Page et al., 2013a). The water is then distributed via the existing pipe network for watering of public open space. Additional treatment is not necessary to meet the water quality requirements for irrigation of open spaces, but it has been added for comparison with the other options. As with Option 2, this Option would deliver an average of 880 ML/year. Figure G.3 shows the layout of this option, while the economic evaluation is presented in TableG.3.

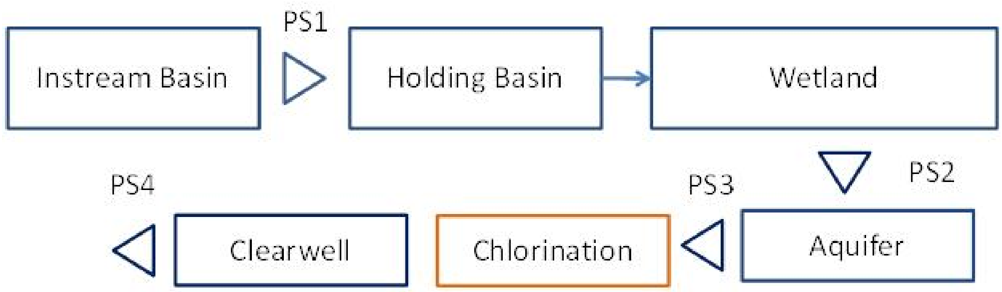


Figure G.3: Layout of option 3.

Table G.3:The summary cost analysis (Present Values) for Option 3 considering a 25 year economic life

Item			**Present value cost ($m)**
Capital Costs ($m)	Chlorination plant		0.20
Operating and Maintenance Costs($m)	Parafield	Pump station 1	0.74
		Pump station 2	0.57
		Pump station 3	0.84
		Pump station 4	0.96
		Storage tanks	0.25
		Chlorination	0.17
Risk management costs ($0.12 /kL)			1.35
Total Present Value ($m)			**5.08**
Levelised Cost ($/kL) (Supply = 880 ML/year)			**0.45**

G.1.4 Option 4 Stormwater harvesting with ASR, blending with treated wastewater and open space irrigation

The required activities for this option are urban stormwater harvesting and treatment through a wetland and aquifer, blending with recycled water followed by chlorination (2-log removal) and exposure control (2-log removal; see Page et al., 2013a; table 18) (Figure G.5 and Figure G.4).

The harvested water is transferred from Parafield to the Greenfield scheme and blended with treated wastewater from Bolivar WWTP (see map in Figure G.6). The mixed water is then chlorinated and distributed via the existing ring main for watering of public open spaces. Because stormwater is blended with treated wastewater, chlorination with 2-log removal is included in this option.

The recycled water is sourced from Bolivar wastewater treatment plant (WWTP). Bolivar WWTP is the largest plant in Adelaide having a typical maximum flow of 150 ML/d. A simple water balance equation was used to estimate the water mixing factors as presented in the following section.

Mixing fraction (r)

If the salinity of the harvested stormwater is C_{sw} , of the treated wastewater is C_{ww}, and of the mixed water is C_m, then the "mixing fraction", r can be estimated from the following mass balance equation:

$$r = \frac{C_{ww} - C_m}{C_{ww} - C_{sw}} \qquad \text{(G. 1)}$$

where *r* = the fraction of the total mix that is supplied by stormwater. The proposed harvested stormwater from Parafield wetland has a median salinity of 240 mg/L (Page et al., 2013a). The salinity of the treated wastewater is typically around 1200 mg/L. Furthermore, a limit of 800 mg/L has been established to meet acceptance criteria for watering of public open space. Based on the above values and using Equation (G.1), the minimum permitted value of *r* is ~0.42. That is, a mixture which contains no less than 42% stormwater (no more than 58% treated wastewater) is acceptable before the salinity of the recovered water becomes excessive. This means for an average transfer of2.4 ML/day of harvested stormwater(allowing for 80% recovery efficiency from ASR), the maximum volume of recycled wastewater is 3.3 ML/day given a total volume of mixed water of 5.7 ML/day.

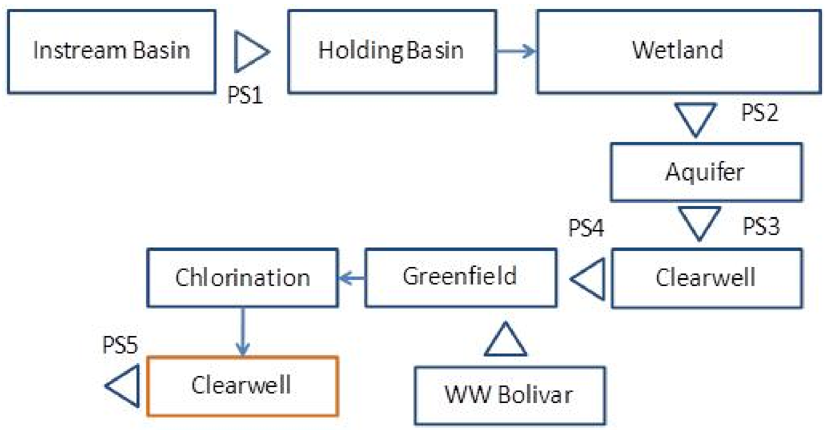


Figure G.4:Layout of option 4.

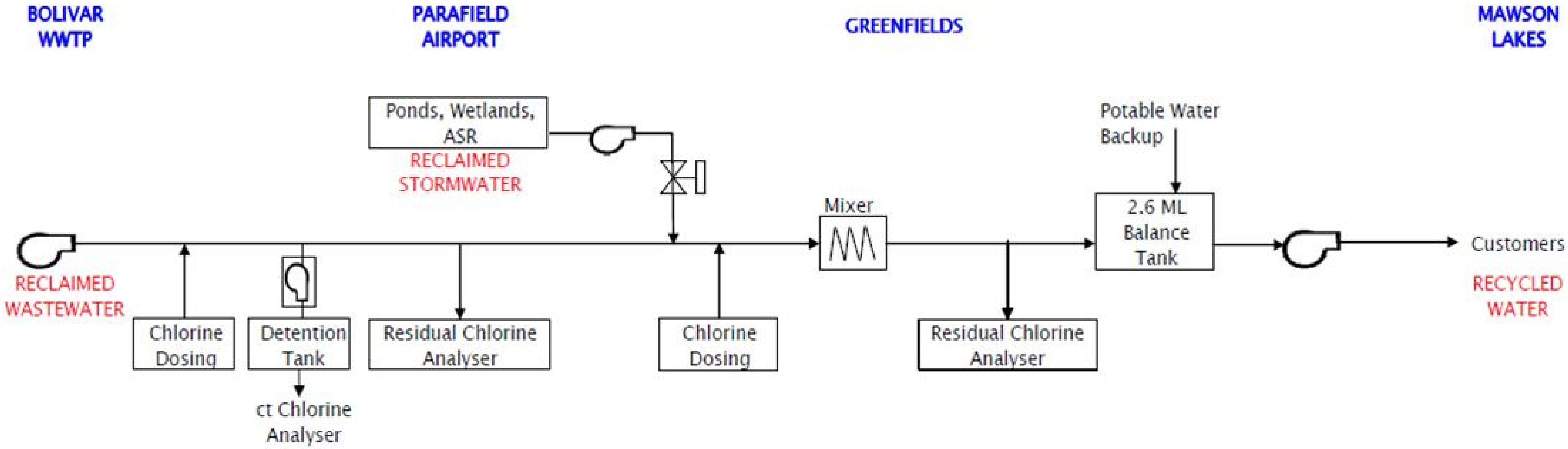


Figure G.5:A schematic presentation of pipeline network between Bolivar and Mawson Lake, SA (Rinck-Pfeiffer, 2004)

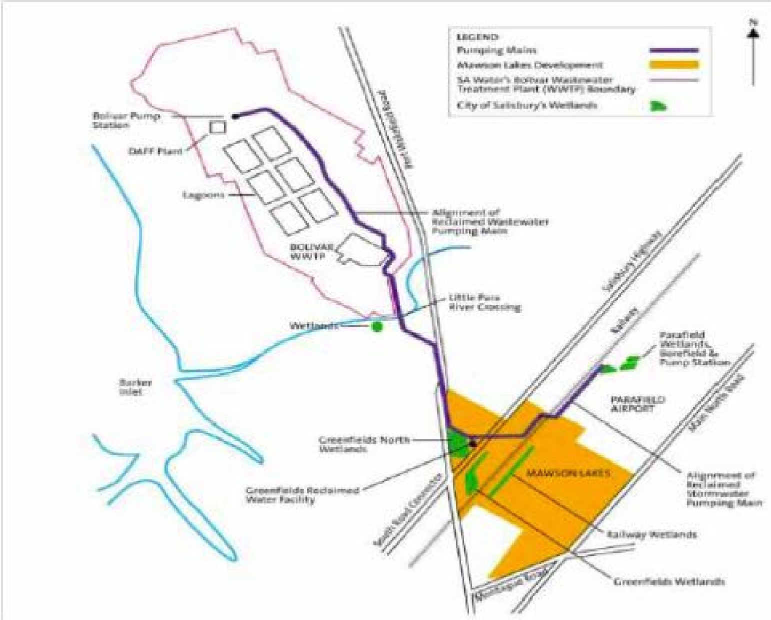


Figure G.6:The pipeline network between Bolivar and Mawson Lake, SA (Wescombe and Furness, 2004)

Therefore Option 4 will deliver an average volume of 2100 ML/year of blended wastewater and stormwater of which 880 ML/year is harvested stormwater and 1220 ML/year is treated wastewater.

As stated by Pavelic et al., (2004), there is a pipeline for transferring stormwater from Parafield to Greenfield. The total capacity of the pipeline is 77 L/s (5.54 ML/day), and the pumps will operate 20 hours/day: as Option 4 requires delivery of a peak volume of 4.8 ML/day, the pipe and pump capacity is considered sufficient and only operating and maintenance costs are computed. The diameter of the pipeline is equal to 225 mm.

Operational costs only are also considered for transfer of treated wastewater from Bolivar to Greenfield as the current pipeline and pump station has sufficient capacity for the required transfer for the 3 ML/day option. The Bolivar-Greenfield system has the capacity to deliver 8 ML/day(XJ Wang, SA Water, pers. comm., March 28, 2013) and hence it is able to deliver the 6.6 ML/day required (i.e. the average volume of 3.3 ML/day of wastewater times a peaking factor of 2).

For the Bolivar-Greenfield transfer, the operational costs need to include the additional DAFF treatment estimated to be $0.25/kL (Nick Swain, SA Water, pers. comm., April 3, 2013). It is assumed that the DAFF plant has the capacity to treat the required 6.6 ML/day of additional wastewater as it has a capacity of 90 ML/day and supplies up to 80-90 ML/day of water to Virginia (northern of Bolivar) for irrigation purposes.

The operational costs of the pumping between Bolivar and Greenfield have been estimated assuming a pipe diameter equal to 280 mm and a length equal to 9 km (Mawson Lakes et al. 2006). It is estimated that the pressure head provided by the pumping station at Bolivar is about 73 m: this takes into account friction losses and the elevation difference between Bolivar and Greenfield of 3 m.

The chlorination plant at the Greenfield site needs to be enlarged to treat the increased volume of blended stormwater and wastewater. The required peak capacity of the chlorination plant is 11.4 ML/day (assuming a peaking factor of 2). Capital, operational and maintenance costs have been computed accordingly (see Appendix O). Operational costs are based on the cost of the chlorine and on the labour costs. Note that labour costs are assumed to equal the cost of chlorine.

The Australian Drinking Water Guidelines are used to determine the appropriate chlorine dose. Chlorine dosages usually range from 1 to 5 mg/L (as available chlorine), with 2–3 mg/L typical. However, stormwater requires larger chlorine doses than other sources. Declan Page (CSIRO, Pers. Comm., May 12, 2013) reports that on average 5 mg/L is required (with peak doses equal to 8 mg/L). A conservative chlorine dose of 8 mg/l has been assumed in this case.

The clearwell storage tank (after the chlorination treatment) has been sized for 8 hours detention of the peak flow. This corresponds to 3.8 ML. Note that 2.6 ML of storage is already available at Greenfield, therefore the capital cost includes only a tank with the additional volume. An additional pumping station (PS5 in Figure G.4) is required to transfer water from the treatment plant to the users. As the existing pumps in Greenfield are currently able to pump 4 ML/day to Mawson Lakes (XJ Wang, SA Water, pers. comm., March 28, 2013), the pumping station PS5 needs to be upgraded. This new part of the pump station is sized considering the mixed flow and a peak factor equal to 2, a pressure head equal to 100 m and a pump efficiency equal to 80%. The pumping station will also be provided with 50% standby capacity.TableG.4 and TableG.5 summarise the new facilities and the costs associated with Option 4.

TableG.4:Summary of New Facilities for Option 4

Average annual supply	New Facilities
0.88GL/year	Upgrade of the pump station PS5 to194 kW
	Upgrade of the clearwell storage tank at Greenfield to a capacity of 3.8 ML
	Enlarged chlorination facility (to a capacity of 11.4 ML/day)

Table G.5:The summary cost analysis (PV) for Option 4 considering a 25 year economic life

Average Item			**Present Value Cost ($m)**
Capital Cost ($m)	New facilities (Treatment)	Pumps for treatment plant	0.86
		Clearwell water storage	0.51
		Chlorine disinfection	0.48
Operating and Maintenance Costs ($m)	Water Injection to GW	Pump station 1	0.74
		Pump station 2	0.57
		Pump station 3	0.84
		Water storage after PS3	0.25
	Water transfer from Parafield to Greenfield	Pump station 4	0.96
		Pipes	0.16
	Water transfer from Bolivar to Greenfield(existing facilities)	Pump station	1.40
		Pipe	0.77
	New facilities (Treatment)	Chlorine disinfection	0.66
		Clearwell Water Storage	0.66
		Pumps after treatment plant (PS5)	3.19
Other Costs ($m)		Pump Replacement (new facilities)	0.06
Cost of wastewater treatment at Bolivar (PV-$m) – DAFF treatment ($0.25/kL)			3.87
Risk management costs ($0.12 /kL)			1.34
Total Present Value ($m)			17.06
Levelised Cost ($/kL) (Supply = 2100 ML/year including 1220 ML/year of treated wastewater and 880 ML/year of harvested stormwater)			0.64

G.2 Options 5 – 8 Third pipe supply to households

G.2.1 Option 5 Stormwater harvesting, chlorination and supply to households via a third pipe network

Option 5 consists of harvesting stormwater and treating it through a wetland (Figure G.7). After transferring stormwater to Greenfield, the water is chlorinated and stored in a new clearwell tank, before being distributed by a third pipe system to residential consumers for toilet flushing and garden watering. A total log-reduction of 2.7 is required for Option 5. As a result, chlorination (3-log removal) is required for the treatment process as recommended by Page et al., (2013a). It is assumed that the 3 log removals can be achieved by increasing the dose of chlorine from 3 to 5 mg/L.

The existing tank at Greenfield (2.6 ML) will be used as storage after the chlorination treatment.

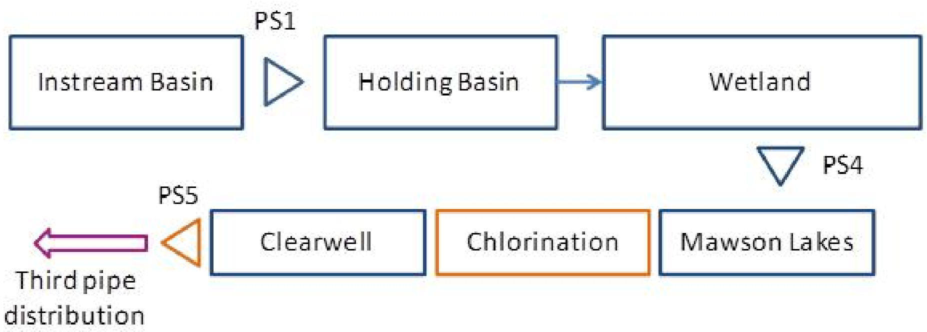


Figure G.7:Layout of Option 5.

An additional cost for this option (as well as for Options 6 to 8) is the cost of a third pipe system to distribute the water to households. The cost of this pipe system is estimated to be $1800 per house for a greenfield site and $4000 per house for a brownfield site (B. Naumann, City of Salisbury, pers. comm., November 30, 2012). Note that this assumes trenching for pipe installation in brownfield sites. Horizontal boring may reduce the costs of brown field implementation considerably. Assuming an average supply per household of 100 kL per year through the third pipe system, this equates to a present value of $6.66m (or a levelised cost of $1.41 per kL) for a greenfield site and a present value of $14.8m (or a levelised cost of $3.13 per kL) for a brownfield site.

As in Option 1, in the absence of ASR, it is assumed that only 370 ML/year can be effectively delivered to users. Therefore, the pumps PS2 needs to operate only 62 days per year to move water from the wetland to the third pipe distribution systems. Capital costs of the chlorination plant and of pumping station PS5 and operational costs are computed accordingly. These costs are smaller than those in Option 4 as Option 4 has been sized for harvested stormwater and treated wastewater. The pump station PS5 in Greenfield needs to be updated, if it is assumed that the pumps are still able to provide a peak flow of 6 ML/day. Finally note that a higher risk management cost is associated with Options 5 to 8, in which water is provided for toilet flushing and washing machines. This is $0.26/kL. A summary of the new facilities required is given in TableG.6 and the present value of costs is given in TableG.7.

Table G.6: Summary of New Facilities for Option 5

Average annual supply	New Facilities
0.37 GL/year	Upgrade pump station PS5 to 102 kW
	Chlorination facility at Greenfields
	Third pipe distribution network at Mawson Lakes

Table G.7: The summary cost analysis (Present Values) for Option 5 considering a 25 year economic life

Item			**Present Value Cost ($m)**
Capital Cost ($m)	New facilities (Treatment)	Pump station PS5	0.29
		Chlorine disinfection	0.25
Operating and Maintenance Costs ($m)	Parafield	Pump station 1	0.56
	Current facility (water transfer Parafield to Mawson Lakes)	Pump station PS4	0.62
		Pipe	0.16
	New facilities (Chlorination)	Pump station PS5	0.96
		Clearwell Water Storage	0.50
		Chlorine disinfection	0.12
Other Costs ($m)		Pump Replacement	0.04
Risk management costs ($0.26 /kL)			1.23
Total Present Value ($m)			5.45
Third pipe greenfield network ($1.41 /kL)			6.66
Total Present Value including third pipe for Greenfield site ($m)			12.11
Levelised Cost including third pipe greenfield network ($/kL)			2.56
Third pipe brownfield network ($3.13 /kL)			14.80
Total Present Value including third pipe for Brownfield site ($m)			20.25
Levelised Cost including third pipe brownfield network ($/kL) (Supply = 370 ML/year)			4.28

G.2.2 Option 6 Stormwater harvesting, ASR, chlorination and supply to households via a third pipe network

Option 6 differs from Option 5 because stormwater is injected and extracted from the aquifer (Figure G.8). As for Option 5, the current facilities for water transfer from Parafield to Mawson have enough capacity to supply an average of2.4 ML/day.

The required log-removal for this option is 2.7. The total log-removal achieved with the suggested treatments in Table 2.2 (chlorination) is 3 (also see Page et al., 2013a; Table 18 for suggested treatment and log-reduction). A summary of the new facilities required is given in TableG.8 and the present value of costs is given in TableG.9.

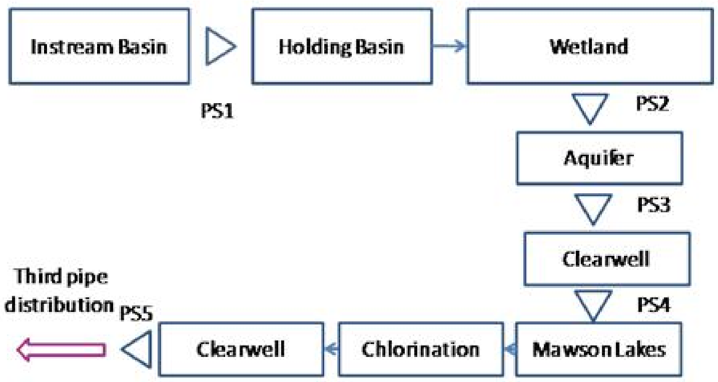


Figure G.8:Layout of Option 6.

Table G.8: Summary of New Facilities for Option 6

Average annual supply	New Facilities
0.88 GL/year	Upgrade pump station PS5 to 82 kW
	Chlorination facility
	Third pipe distribution network

Table G.9: The summary cost analysis (Present Values) for Option 6 considering a 25 year economic life

Item			Present Value of Costs ($m)
Capital Cost ($m)	New facilities (Treatment)	Pumps	0.16
		Chlorinedisinfection	0.20
Operating and Maintenance Costs ($m)	Parafield	Pump station 1	0.74
		Pump station 2	0.57
		Pump station 3	0.84
		Clearwell	0.25
	Current facility (water transfer Parafield to Mawson	Pump station PS4	0.96
		Pipe	0.16
	New facilities (treatment)	Pump station PS5	1.43
		Clearwell Water Storage	0.50
		Chlorine disinfection	0.28
Other Costs $m)		Pump Replacement	0.04
Risk management costs ($0.18 /kL)			2.02
Total Present Value ($m)			8.73
Third pipe greenfield network ($1.41 /kL)			15.84
Total Present Value including third pipe for Greenfield site ($m)			24.57
Levelised Cost including third pipe greenfield network ($/kL) (Supply = 880 ML/year)			2.18
Third pipe brownfield network ($3.13 /kL)			35.20
Total Present Value including third pipe for Brownfield site ($m)			43.93
Levelised Cost including third pipe brownfield network ($/kL)			3.91

G.2.3 Option 7 Stormwater harvesting, blending with treated wastewater, chlorination and supply to households via a third pipe network

For this option, water from the reedbed is transferred to Greenfield and is then blended with treated wastewater and used to supply households at Mawson Lakes and other developments (Figure G.9).

With no ASR the salinity of the harvested stormwater is 125 mg/L (Page et al., 2013a). Applying equation (G.1) with the salinity of wastewater being 1200 mg/L and an acceptable criterion of 800 mg/L for blended water entering the Mawson Lakes Mixing Tank, a maximum mixing fraction of 37% stormwater has been estimated. As a result of blending the harvested stormwater and treated wastewater, the total volume of transferred water has been increased to an average of 2.7 ML/day, which includes about 1.7 ML/day of recycled stormwater. The capacity of the Bolivar-Greenfield system is 6.8 ML/day and it will be able to deliver the recycled stormwater also considering a peaking factor equal to 2. Note that the pump power at the maximum flow multiplied the time necessary to pump 630 ML/day at the maximum flow has been used to estimate the energy requirements and the pump maintenance costs. A total log-reduction of 2.7 is recommended for option 7 by Page et al. (2013a). To reach the above level of removal, chlorination (3 log-removal) is proposed for the treatment process (see also Page et al., 2013a). A summary of the new facilities required for this option is given in TableG.10 and the present value of costs are given in TableG.11.

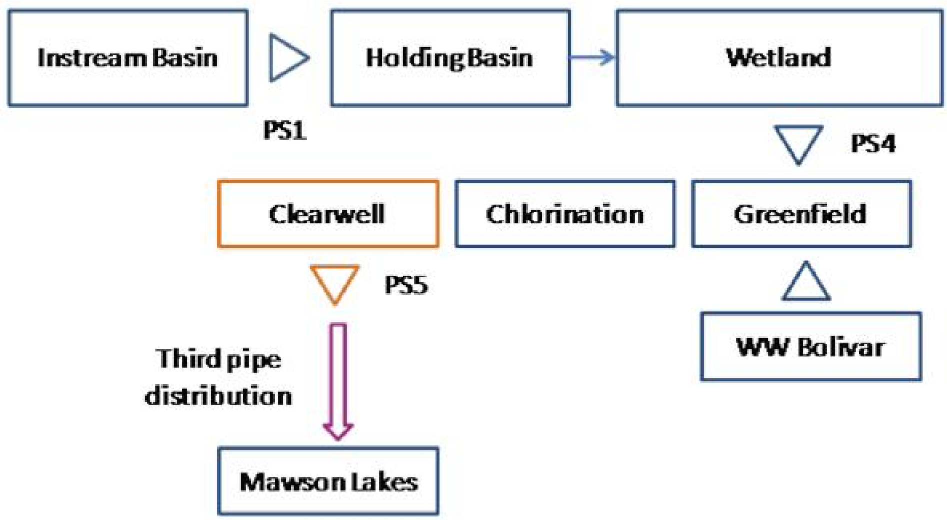


Figure G.9: Layout of option 7.

Table G.10: Summary of New Facilities for Option 7

Average annual supply	New Facilities
0.37 GL/year	Upgrade pump station PS5 to 93 kW
	Chlorination facility at Greenfields
	Third pipe distribution network at Mawson Lakes

Table G.11: The summary cost analysis (Present Values) for Option 7 considering a 25 year economic life

Item			**Present Value Costs ($m)**
Capital Cost ($m)	New facilities (treatment)	Pump station PS5	0.31
		Chlorine disinfection	0.23
Operating and Maintenance Costs ($m)	Parafield	Pump station 1	0. 56
	Current facility (water transfer Parafield to Greenfield)	Pump station 4	0.62
		Pipes	0.16
	Current facility (water transfer Bolivar to Greenfield	Pump	0.98
		Pipe	0.77
	New facilities (Treatment)	Chlorine disinfection	0.32
		Clearwell Water Storage	0.40
		Pump station PS5	1.66
Other Costs ($m)		Pump Replacement	0.06
Cost of wastewater treatment at Bolivar (PV-$m) – DAFF treatment			2.01
Risk management costs ($0.26/kL)			1.23
Total Present Value ($m)			9.30
Third pipe greenfield network ($1.41 /kL)			18.00
Total Present Value including third pipe for Greenfield site ($m)			27.30
Levelised Cost including third pipe greenfield network ($/kL)			2.14
Third pipe brownfield network ($3.13 /kL)			40.00
Total Present Value including third pipe for Brownfield site ($m)			49.30
Levelised Cost including third pipe brownfield network ($/kL) (Supply = 1000 ML/year including 630 ML/year of treated wastewater and 370 ML/year of harvested stormwater)			3.86

G.2.4 Option 8 Stormwater harvesting, ASR, blending with treated wastewater, chlorination and supply to households via a third pipe network

This option is the same as Option 7 except that ASR follows wetland storage, and the transfer to Greenfields is from tanks after extraction from ASR (Figure G.10). ASR is used to increase the reliability of the supply. A summary of the new facilities required for this option is given in TableG.12 and the present value of costs are given in TableG.13. Note that the Bolivar to Greenfield pipeline has enough capacity to transfer the wastewater necessary (a peak of 6.6 ML/day), and that the existing 2.6 ML tank in Greenfield is upgraded to 3.8 ML. The blending ratio and the volume of water supplied is the same as for Option 4 (i.e. 880 ML/year of harvested stormwater blended with 1220 ML/year of treated wastewater to give 2100 ML/year of blended water)

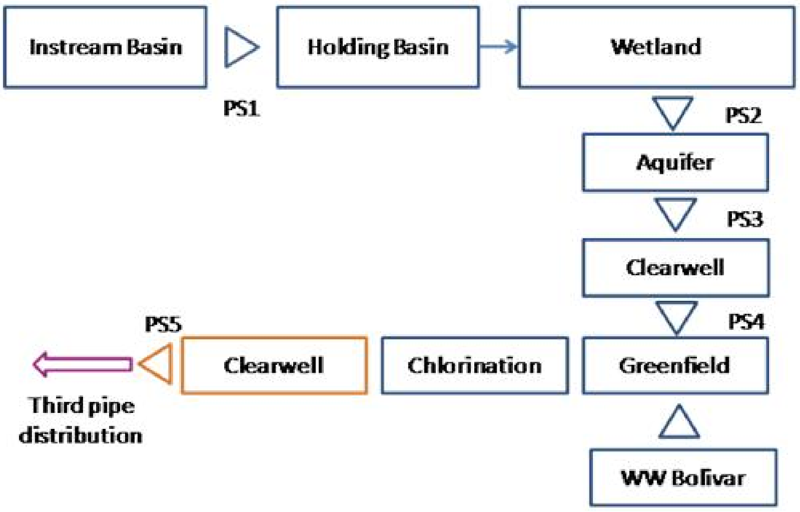


Figure G.10:Layout of option 8.

Table G.12: Summary of New Facilities for Option 8

Average annual supply	New Facilities
0.88 GL/year	Pumps at treatment facilities (194 kW)
	Upgrade of clearwater storage tank to 3.8 ML
	Chlorination facility at Greenfields
	Third pipe distribution network at Mawson Lakes

Table G.13: The summary cost analysis (Present Values) for Option 8 considering a 25 year economic life

Item			Present Value Costs ($m)
Capital Cost ($m)	New facilities (Treatment)	Pump station PS5	0.86
		Clearwell Water Storage	0.51
		Chlorine disinfection	0.48
Operating and Maintenance Costs ($m)	Parafield (injection & Abstraction)	Pump station 1	0.74
		Pump station 2	0.57
		Pump station 3	0.84
		Clearwater storage	0.25
	Current facility (water transfer Parafield to Mawson)	Pump station 4	0.96
		Pipe	0.16
	Current facility (water transfer Bolivar to Greenfield)	Pump	1.40
		Pipe	0.77
	New facilities (UV and disinfection)	Chlorine disinfection	0.66
		Clearwell Water Storage	0.66
		Pump station PS5	3.19
Other Costs ($m)		Pump Replacement	0.06
Cost of wastewater treatment at Bolivar (PV-$m) – DAFF treatment ($0.25/kL)			3.87
Risk management costs ($0.18 /kL)			2.02
Total Present Value ($m)			18.00
Third pipe greenfield network ($1.41 /kL)			37.54
Total Present Value including third pipe for Greenfield site ($m)			55.54
Levelised Cost including third pipe greenfield network ($/kL)			2.08
Third pipe brownfield network ($3.13 /kL)			**83.43**
Total Present Value including third pipe for Brownfield site ($m)			**101.43**
Levelised Cost including third pipe brownfield network ($/kL) (Supply = 2100 ML/year including 1220 ML/year of treated wastewater and 880 ML/year of harvested stormwater)			**3.80**

G.3 Options 9-12:

This set of options involve treating the harvested stormwater to drinking water quality and, either directly injecting the treated stormwater into the potable water supply mains (Option 9) or treatment and transfer into the Little Para Reservoir for Potable Use (Options 10-12). According to Page et al. (2013a), the microbial health-based target for drinking waterrequires5.8 log-removals for viruses. Page at el (2013a) also contains a discussion regarding these options in relation to pesticides. The results of the cost analysis for different options are presented below.

G.3.1 Option 9: Stormwater harvesting, ASR, treatment to drinking water quality and direct injection into the potable water supply mains

Option 9 involves stormwater capture, treatment and aquifer storage (Figure G.11). Water from the aquifer is then treated using micro-filtration (>4 log removals; see Page et. al., 2013a), UV and chlorine disinfection (2-log removal) before being injected into the mains close to the site (see the following subsection for details). These treatments provide the5.8 log-removalrequired for drinking water.

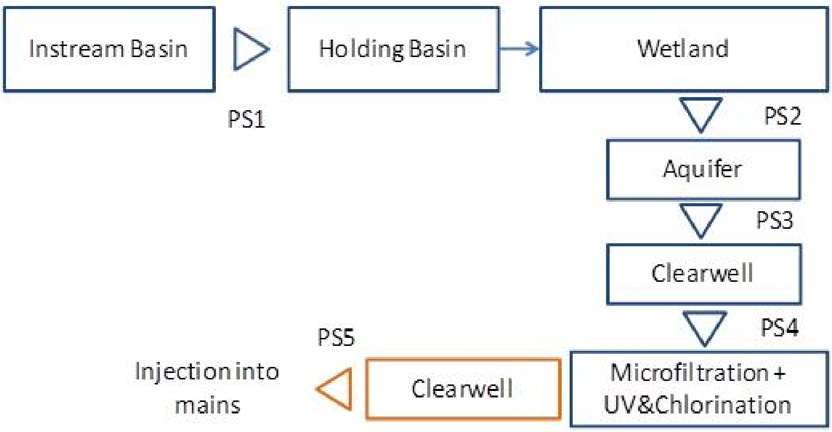


Figure G.11: Layout of option 9.

According to the National Water Quality Management Guidelines for drinking water, the maximum turbidity of potable water supplies is 5 NTU while 1 NTU is the desirable aesthetic maximum level of turbidity. Page et al. (2013a) reported 17 NTU as the quality of ASR output. One of the treatment options to achieve the desirable level of turbidity is to install a conventional treatment plant consisting of coagulation with rapid mixing followed by flocculation, sedimentation, granular media filtration with final disinfection by chlorine. As an alternative a micro-filtration process plant can be used. In this study, micro-filtration is considered for cost analysis.

In addition to microfiltration, UV and chlorination, pH adjustment and fluoridation facilities are required. Furthermore it is assumed that a land cost of $500,000 will be incurred.

It is assumed that pumps for injecting into the water mains deliver with a pressure head equal to 100 m. The injection point is assumed to be 1 km from Parafield. The actual point(s) of injection will need to be carefully chosen so that sufficient capacity exists in the distribution system to utilise the injected water and to avoid flow reversal. More information would be required from SA Water to assist in selecting these injection points.

A summary of the new facilities required for this option is given in TableG.14 and the present value of costs are given in TableG.15. Note that in this case the costs associated with the risk management are $0.43/kL (Declan Page, CSIRO, Pers. Comm., May 12, 2013).

Table G.14: Summary of New Facilities for Option 9

Average annual supply	New Facilities
0.88 GL/year	Pumps for injection (82 kW)
	Pipe 1 km long (250 mm dia.)
	Clearwater storage tank (1.6 ML)
	Microfiltration, UV, chlorination, pH adjustment and fluoridation facility at Parafield

Table G.15: Summary cost analysis (Present Values) for Option 9 assuming a 25-year economic life

Item			**Present Value Costs ($m)**
Capital Cost ($m)	New facilities (Microfiltration, UV, disinfection, pH adjustment and fluoridation)	Pumps	0.65
		Pipes for injection to main (1km)	0.28
		Water Storage for injection	0.59
		Turbidity removal (Microfiltration), UV, chlorine disinfection, pH adjustment and fluoridation	6.00
		Land cost	0.5
Operating and Maintenance Costs ($m)	Parafield (Greenfield)	Pump station 1	0.74
		Pump station 2	0.57
		Pump Station 3	0.84
		Clearwell storage	0.25
		Pump station 4	0.96
	New facilities (Microfiltration, UV, disinfection, pH adjustment and fluoridation)	Plant operations and maintenance	4.16
		Water Storage for injection	0.38
		Pump station 5	1.37
Other Costs ($m)		Pump Replacement	0.06
Risk management costs ($0.43/kL)			4.84
Total Present Value ($m)			22.19
Levelised Cost ($/kL) (Supply = 880 ML/year)			1.97

G.3.2 Option 10: Stormwater harvesting and transfer to Little Para Reservoir for potable use

Option 10 involves treating the water through a wetland followed by transfer to Little Para Reservoir where it is mixed with other water in the reservoir. From here, water will be treated through a conventional treatment at the Little Para water treatment plant and distributed to consumers. Page *et al* (2013a) found for pathogens that the 95th percentiles, median values, and proportion of samples with detections were lower in raw stormwater at Parafield than in samples from the Little Para Reservoir. Hence for consistency with the safety of existing water supplies it is assumed that no additional treatment is required at Little Para Treatment Plant for stormwater for Option 10. It is considered that the yield from the harvesting facility for this option is 1.1 GL/year because transfer of water from Parafield to Little Para Reservoir can occur whenever water is available from the wetland. Some small losses from reservoir evaporation are expected. Other options that store water in the initially brackish aquifer recover approximately 0.88GL/yr and other options that do not involve the aquifer or a reservoir recover only 0.37 GL/year due to lack of storage to balance supply and demand. This option foregoes the aquifer barrier for pathogens which is currently unvalidated for ASR in this aquifer.

The pipeline route from Parafield to Little Para reservoir (11.2 km) was assumed to be set up along a *nearby highway (Main North Road)*(see Figure G.12).Determining the best route through this area needs to be addressed effectively using GIS and remote sensing technologies, considering physical, environmental, political, social, economic and legal factors. It is estimated that a 300 mm (nominal) uPVC pipe is required. This allows for transfer of the annual yield by pumping for 20 hours per day for 6 months. A set of pumps providing 188 kW of power (allowing 50% standby) are also needed (see Appendix P).

The cost of conventional treatment at Little Para and the levelised cost of option 10 assume a 6% loss of the harvested water in the reservoir due to evaporation.

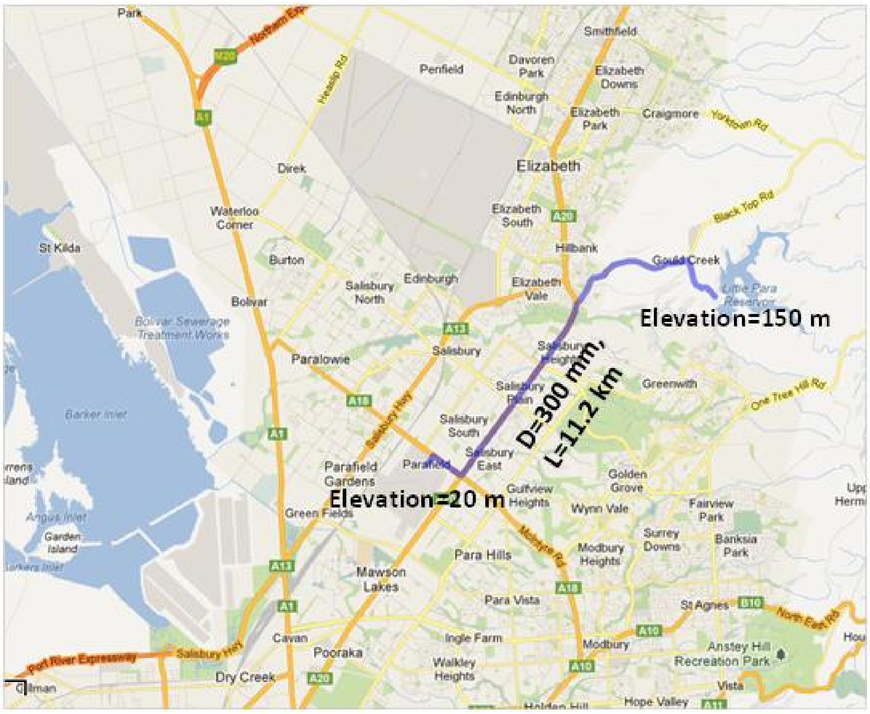


Figure G.12: Location of pipeline route for options 10 to 12

Figure G.13, Table G.16 and Table G.17show the layout of the option and its associated costs.

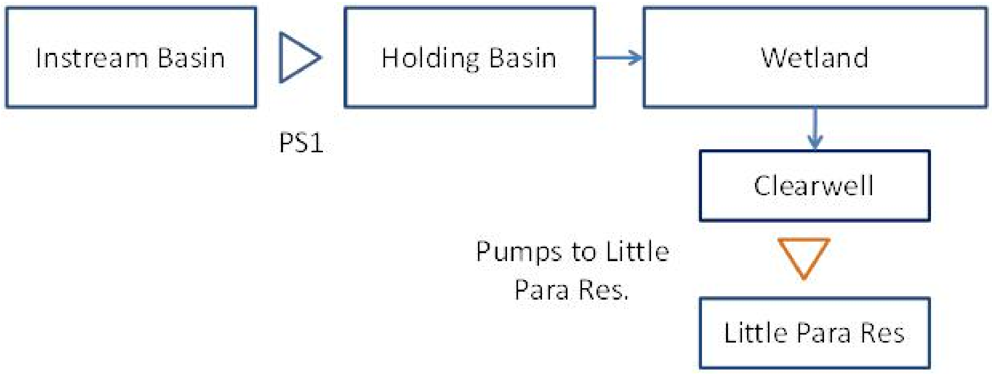


Figure G.13: Layout of option 10.

Table G.16: Summary of New Facilities for Option 10

Average annual supply	New Facilities
1.034 GL/year	Pipe (11.2 km X 300 mm dia.)
	Pumps for transfer to Little Para res. (188 kW)

Table G.17: The summary of cost analysis (Present Values) for Option 10 assuming a 25 year economic life

Item			**Present Value Costs ($m)**
Capital Cost ($m)	Water Transfer to Little Para	Pipe	3.73
		Pumps for Little Para Res.	1.10
Operating and Maintenance Costs ($m)	Water injection and extraction Costs	Pump station 1	0.74
		Clearwell storage	0.25
	Water Transfer to Little Para	Pipe (2% of capital cost p.a.)	0.95
		Pumps	2.90
	Treatment*	Operating cost of treatment for Little Para treatment plant (assuming $0.20/kL treatment costs)	2.63
Other Costs ($m)		Pumps (replacement)	0.06
Risk management costs ($0.22/kL)			3.08
Total Present Value ($m)			15.45
Levelised cost ($/kL) (Supply = 1034 ML/year)			1.17

* It is assumed that the Little Para treatment plant is used, so the capital costs weren't considered for this case.

G.3.3 Option 11: Stormwater harvesting, ASR and transfer to Little Para Reservoir for potable use

The only difference between Options 10 and 11 is that storage and treatment through the aquifer system is added for Option 11, hence the yield has to take into account the aquifer recovery efficiency. Note that no log removals for pathogens have been allowed for in the aquifer storage and recovery (ASR) nor in the reservoir. Aquifer treatment does provide a protective barrier but until ASR pathogen removal capability is validated it cannot be relied on as an accredited pathogen barrier in health risk assessment (Page et al., 2013a).

For the 3 ML/day scheme, it is estimated that a 300 mm (nominal) uPVC pipe is required to transfer water from Parafield to Little Para reservoir . This allows for transfer of the annual yield by pumping for 20 hours per day for 6 months. A set of pumps providing 152 kW of power (allowing 50% standby) are also needed (see Appendix P). The cost of conventional treatment at Little Para and the levelised cost of Option 11 assume a 6% loss of the harvested water in the reservoir due to evaporation.

As will Option 10, it is assumed that no additional treatment facilities will be required at the Little Para Treatment Plant to treat the harvested stormwater.

Figure G.14, TableG.18 and Table G.19 show the layout of the option and its associated costs.

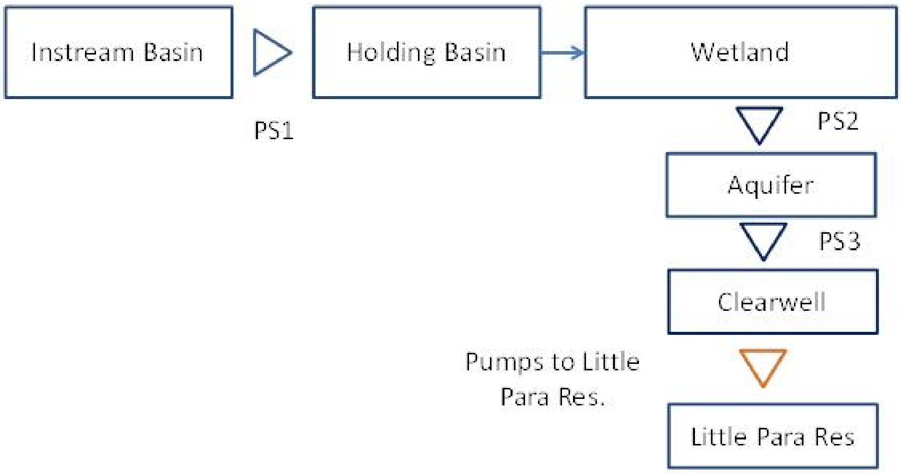


Figure G.14: Layout of option 11.

Table G.18: Summary of New Facilities for Option 11

Average annual supply	New Facilities
0.827 GL/year	Pipe (11.2 km X 300 mm dia.)
	Pumps for transfer to Little Para res. (135 kW)

Table G.19: The summary of cost analysis (Present Values) for Option 11 assuming a 25 year economic life

Item			**Present Value Costs ($m)**
Capital Cost ($m)	Water Transfer to Little Para	Pipe	3.73
		Pumps for Little Para Res.	0.89
Operating and Maintenance Costs ($m)	Water injection and extraction Costs	Pump station 1	0.74
		Pump station 2	0.57
		Pump station 3	0.84
		Clearwell storage	0.25
	Water Transfer to Little Para	Pipe (2% of capital cost p.a.)	0.95
		Pumps	2.14
	Treatment*	Operating cost of treatment for Little Para treatment plant (assuming $0.20/kL treatment costs)	2.11
Other Costs ($m)		Pumps (replacement)	0.06
Risk management costs ($0.22/kL)			2.46
Total Present Value ($m)			14.75
Levelised cost ($/kL) (Supply = 827 ML/year)			1.40

* It is assumed that the Little Para treatment plant is used, so the capital costs weren't considered for this case.

G.3.4 Option 12:Stormwater harvesting, ASR, disinfection and transfer to Little Para Reservoir for potable use

Option 12 includes a more robust treatment prior to transfer to Little Para Reservoir in the event that water quality was to decline in the Parafield catchment or if standards were to change in future. Option 12 involves treatment through a wetland and ASR followed by UV disinfection prior to being transferred into Little Para Reservoir (Figure G.15 and Figure G.16). There it mixes with other water in the reservoir and is then treated by the Little Para water treatment plant prior to being distributed to consumers. Note that no log removals have been allowed for in the aquifer storage and recovery (ASR) nor in the reservoir. As with Options 10 and 11, it is assumed that no additional treatment facilities are required at Little Para water treatment plant to treat the harvested stormwater.

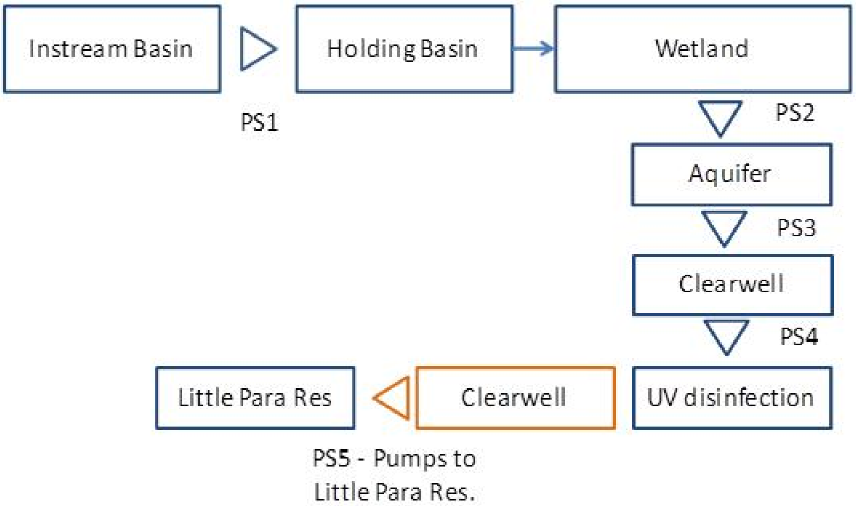


Figure G.15:Layout of option 12.

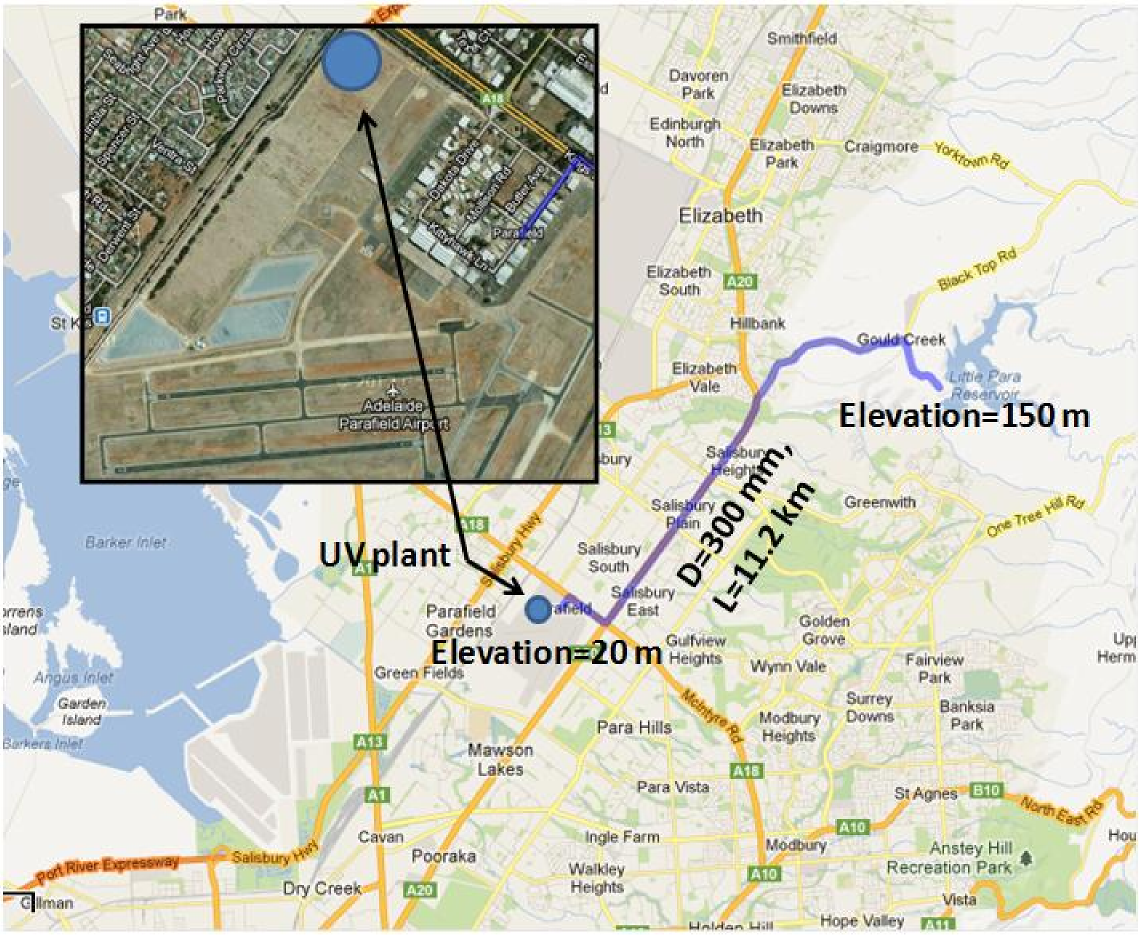


Figure G.16: Location of pipeline route and UV plant for option 12

It is estimated that a 300 mm (nominal) uPVC pipe and a set of pumps providing 152 kW of power (50% standby) are required for the transfer to Little Para Reservoir. This option has two storages, one after the aquifer and one after the UV disinfection. Each storage is sized to hold 4 hours of the peak flow rate. It is assumed that the existing two tanks of 0.3 ML can be used, therefore only an additional 0.2 ML has been costed for the first tank.

The capital cost of a UV disinfection facility is estimated to be $200,000. The new infrastructure required for this project is given in Table G.20 and the cost analysis is given in Table G.21. Note that the risk management costs are $0.22/kL (Declan Page, CSIRO, Pers. Comm., May 12, 2013).

Table G.20: Summary of New Facilities for Option 12

Average annual supply	New Facilities
0.827 GL/year	Pipe (11.2 km X 300 mm dia.)
	Pumps for transfer to Little Para res. (135 kW)
	New 0.8 ML storage after disinfection
	UV disinfection facility

Table G.21: The summary of cost analysis (Present Values) for Option12 assuming a 25 year economic life

Item			**Present Value Costs ($m)**
Capital Cost ($m)	Water Transfer to Little Para	Pipe	3.73
		Pumps for Little Para Res.	0.89
		Water storage after disinfection	0.43
	Treatment	UV disinfection	0.20
Operating and Maintenance Costs ($m)	Water injection and extraction Costs	Pump station 1	0.74
		Pump station 2	0.57
		Pump station 3	0.84
		Clearwell storage	0.25
		Pump station 4 for UV disinfection	0.96
	Water Transfer to Little Para	Pipe (2% of capital cost p.a.)	0.95
		Pumps	2.14
		Water Storage after disinfection (5% p.a.)	0.27
	Treatment*	Operating cost of treatment for Little Para treatment plant (assuming $0.20/kL treatment costs)	2.11
		UV disinfection	1.12
Other Costs ($m)		Pumps (replacement)	0.06
Risk management costs ($0.22/kL)			2.46
Total Present Value ($m)			17.73
Levelised cost ($/kL) (Supply = 827 ML/year)			1.68

* It is assumed that the Little Para treatment plant is used, so the capital costs weren't considered for this case.

A summary of the average annual supply, present value of costs and levelised costs of all options is given in Table G.22.

Table G.22: Summary of the average annual supply, present value of costs and levelised costs of the various options

Option	Average annual supply (ML/year)	Present Value of Cost ($m)	Levelised Cost ($/kL)
1	370	2.13	0.45
2	880	4.71	0.42
3	880	5.08	0.45
4	2100	17.06	0.64
5 (Greenfield)	370	12.11	2.56
5 (Brownfield)	370	20.25	4.28
6 (Greenfield)	880	24.57	2.18
6 (Brownfield	880	43.93	3.91
7 (Greenfield)	1000	27.30	2.14
7 (Brownfield)	1000	49.30	3.86
8(Greenfield)	2100	55.54	2.08
8 (Brownfield)	2100	101.43	3.80
9	880	22.19	1.97
10	1034	15.45	1.17
11	880	14.75	1.40
12	880	17.73	1.68

Appendix H: Estimation of the Economic Benefits when Demand Changes in Response to Price

In a number of circumstances, harvested stormwater will be offered to customers at a reduced price compared to potable supply. For example, this applies to third pipe systems if the non-potable supply is offered at a lower price than the potable supply.

The situation is illustrated in Figure H.1 which shows the supply and demand curves for outdoor water use for a single household. Supply curve #1 represents the situation when water for outdoor use is supplied via a non-potable third pipe network at a price P_1. The annual household demand is q_1kL/year. Supply curve #2 is when water for outdoor use is supplied via potable mains supply at a price P_2. In this case the annual household demand is q_2kL/year.

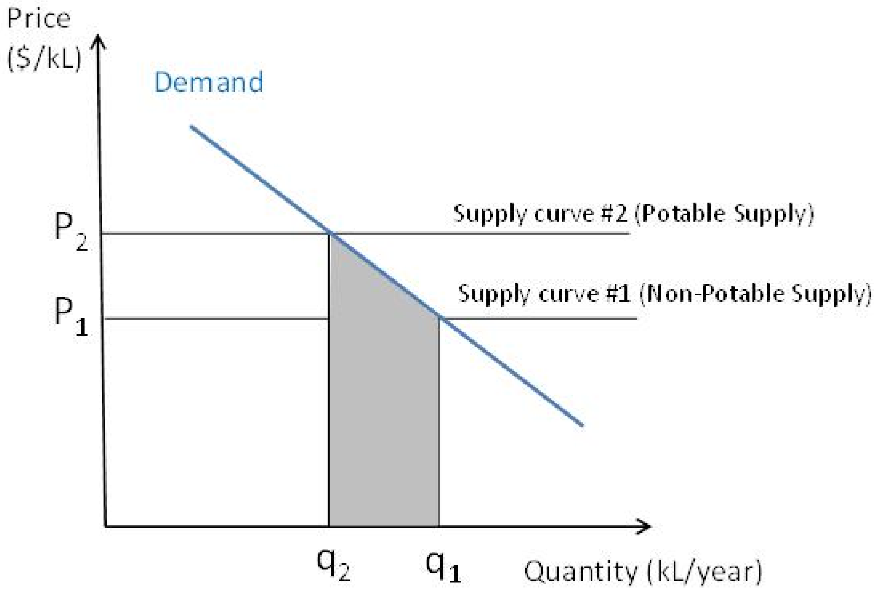


Figure H.1:Demand and supply curves for a single household for outdoor water use.

The additional gross benefit to the household of consuming the water at the lower price is given by the change in willingness-to-pay, which is the shaded area in Figure H.1. Assuming that the demand curve is approximately linear in this range, the gross benefit is given by:

$$\Delta WTP_i = (q_1 - q_2) \cdot \left(\frac{P_1+P_2}{2}\right) \qquad \$/\text{year} \qquad \text{(H.1)}$$

Where ΔWTP_i = additional willingness-to-pay of household*i*

If there are *n* households with similar demand curves the total additional willingness-to-pay (*WTP)* is given by:

$$WTP = n(q_1 - q_2) \cdot \left(\frac{P_1+P_2}{2}\right) \qquad \$/\text{year} \qquad \text{(H.2)}$$

$$WTP = (Q_1 - Q_2) \cdot \left(\frac{P_1+P_2}{2}\right) \quad \text{(H.3)}$$

where Q_j = total outdoor water consumption of all households when the price is P_j.

The net benefits will need to take into account the difference in supply cost of the two sources, hence:

$$NAB = (Q_1 - Q_2) \cdot \left(\frac{P_1+P_2}{2}\right) - (C_N(Q_1) - C_P(Q_2)) \quad \text{(H.4)}$$

With *NAB*= Net annual benefits ($/year), $C_i(Q_j)$ = the cost of supplying quantity Q_j using the supply source *i* (*i* = *N* indicates non potable supply; *i* = *P* indicates potable supply).

Equation H.4 can be rewritten as:

$$NAB = (Q_1 - Q_2) \cdot \left(\frac{P_1+P_2}{2}\right) + C_P(Q_2) - C_N(Q_1) \quad \text{(H.5)}$$

where the first term in Equation H.5 is the gross annual benefits to consumers, the second term is the savings in supply costs from the potable system and the third term is the costs of supply using the non-potable system.

Note if there is no change in consumption, Q_1=Q_2 and

$$NAB = C_P(Q_1) - C_N(Q_1) \quad \text{(H.6)}$$

In this special case the net benefits equal the difference in supply costs of the two sources.

Q_1 and Q_2 are related through the price elasticity of demand ε using the following equation:

$$\varepsilon = \left(\frac{Q_1-Q_2}{Q_1}\right) \cdot \frac{P_1}{(P_1-P_2)} \quad \text{(H.7)}$$

Hence $Q_2 = Q_1\left(1 - \frac{\varepsilon(P_1-P_2)}{P_1}\right)$ (H.8)

Example: Water use for toilet flushing at outdoor water use at Mawson Lakes in Adelaide.

Estimates of the price elasticity of demand for outdoor water use vary considerably. Xayavong et al (2008) using panel data at a suburb level for Perth estimated a value in the range -1.30 to -1.45. A study for South Africa cited in van Zyl et al (2003) estimated values in the range -0.39 to -0.79. Dandy et al (1997) estimated values for summer water consumption in Adelaide to be between -0.69 and -0.86 using panel data from 400 houses. Given the range of variability and the fact that the demand for toilet flushing is likely to be less price elastic than outdoor use, a value of -1.0 for the price elasticity of outdoor plus toilet flushing demand appears to be reasonable. Other values in 2012/13 are:

P_1 = $2.59/kL

P_2 = $3.45/kL

Therefore, applying Equation H.8:

Q_2=0.67Q_1

i.e outdoor and toilet flushing consumption would be expected to be around 33% lower at Mawson Lakes if all water were supplied from the mains supply and charged at the tier 2potable price.

Appendix I: Energy and Gross Greenhouse Gas Emissions

In this Appendix the energy and gross greenhouse gas emission evaluation process including capital and operating energy and emissions (outlined in Appendix B) is applied to this project.

As noted in Section 4.3.5, net emissions can be determined by deducting an allowance for the purchase of carbon offsets or green energy by the water utility or other authority. This should be assessed in accordance with the National Carbon Offset Standard Carbon Neutral Program Guidelines (Australian Government Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education, 2013).

It is assumed that, of the volume of water supplied by harvested stormwater, 80% will replace River Murray water and 20% desalinated water (as discussed in Section 4.3.3). These percentages were used to estimate the savings in energy and greenhouse gases by using harvested stormwater. An energy factor of 0.3 MWh/ML is assumed for treatment of water from the Mount Lofty Ranges (Kenway, 2008). Pumping and treatment of water from the River Murray is estimated to require an average of 1.9 MWh/ML (ATSE, 2012). The energy requirement for water from Adelaide's desalination plant including pumping this water up to Happy Valley is estimated to be 5 MWh/ML (ATSE, 2012).

An emission factor of 0.79 kg CO_2 –e/ kwh is used to convert energy into greenhouse gas emissions (Section 4.3.5). This figure is based on the average mix of all sources of electricity used in South Australia and considers the full cycle of emissions (Scope 2 plus Scope 3 emissions). It is understood that SA Water purchases 100% green energy for its desalination plant and so is entitled to fully offset its greenhouse gas emissions from this source.

Therefore, using an emission factor of 0.79 kg CO2/kWh the gross emissions associated with supplying water from the River Murray equals 1.50 tonnes/ML and supplying water from the desalination plant has gross emissions of 3.95 tonnes of CO_2-e/ML. Hence the supply of 0.88 GL/year of water from the River Murray involves the production of 1,321 tonnes of CO_2-e per year. Supply of this volume of water from the desalination plant would produce gross greenhouse gas emission of 3,476 tonnes of CO_2-e per year.

For all sources, the embodied energy is converted into an annual energy consumption by dividing by the life of the project (assumed to be 25-years). Similarly, the gross capital greenhouse gas emissions are converted into gross annual greenhouse gas emissions by dividing by the life of the project. This assumes no discounting of energy or greenhouse gas emissions.

The embodied energy values for pipes have been obtained from Ambrose et al., (2002). They proposed embodied energy coefficients of 540.2 and 74.9MJ/kg for DICL and PVC-U pipes, respectively. The operating GHG emissions for pumps are determined based on the required pump power (Appendix P).

The operating and capital GHG emission for disinfection and UV treatment are calculated using the curves from Newman, (2012) (Appendix O). As a comparison with the operating GHG emissions, the capital GHG emission for treatment plants is small and can be ignored.

The embodied energy and gross GHGs of the existing infrastructure (wetland and wells in Parafield, pipelines for the distribution in Parafield, Bolivar-Greenfield-Mawson Lakes system and existing tanks is estimated in Section I.1.

The incremental energy and gross GHGs associated with the 12 stormwater options are estimated in Sections I.2 to I.4 below.

I.1 Embodied energy and gross greenhouse gas emissions for the existing infrastructure

A number of assumptions are required in order to estimate the embodied energy and gross greenhouse gas emissions for the existing infrastructure.

Note that the embodied energy for the Parafield stormwater harvesting scheme is different for options with or without ASR, as the former includes the energy used to excavate the well and to produce the well casing. The embodied energy in the existing tanks is also different for the various options as, for example, Option 1 does not use the existing storage at Greenfields, Option 5 does not use the existing tank at Parafield and Option 4 uses both storages.

The embodied energy for the holding and in-stream basins, reedbed and well excavation are computed considering a soil density equal to 1600 kg/m^3 (the 2 wells are 200 m deep, with an assumed diameter equal to 0.25 m). The well casing is 160 m deep and it is assumed to be made from a PVC-U 200/12 S1 (836.6 MJ/m). GHGs emitted for the extraction and the construction of clearwater tank storages is computed assuming an emission factor for diesel equal to 69.2 kgCO_2-e/GJ. Capital GHGs of pipes are computed considering an emission factor equal to 0.79 kgCO_2-e/kWh.

Table I.1 gives a summary of the embodied energy and gross greenhouse gas emissions for the existing infrastructure. Table I.2 provides a summary of the calculations and assumptions involved in calculating these results.

Table I.1: Embodied energy and gross GHGs of existing infrastructure

Option	Embodied energy of stormwater harvesting scheme (MWh)	Embodied energy of pipelines for distribution (MWh)	Embodied energy for Bolivar-Greenfield pipeline (MWh)	Embodied energy for tanks (MWh)	Total embodied energy (MWh)	Total gross GHGs (tCO_2-e)
1	3,993	2,783	0	83	6,859	3.199
2	4,058	2,783	0	83	6,934	3,258
3	4,068	2,783	0	83	6,934	3,258
4	4,068	2,783	4,151	419	11,421	6,561
5	3,993	2,783	0	336	7,112	3,217
6	4,068	2,783	0	419	7,270	3,281
7	3,993	2,783	4,151	336	11,263	6,496
8	4,068	2,783	4,151	419	11,421	6,561
9	4,068	0	0	83	4,151	1,059
10	3,993	0	0	83	4,076	1,000
11	4,068	0	0	83	4,151	1,059
12	4,068	0	0	83	4,151	1,059

Table I.2: Summary of calculations and assumptions to compute the embodied energy (EE) and GHGs of existing infrastructure

Component	Properties[a]	Equation	TOTAL
Instream basin (IB) Holding basin (HB) Cleansing reedbed(CR)	***Volume:***47 ML (IB); 48 ML (HB); 20 ML (CR) [2 ha x 1 m depth] ρ_{soil}= 1250 kg/m^3 energy for excavation: 0.1 MJ/kg emissions for diesel: 69.2 kgCO$_2$-e/GJ	Embodied energy (MJ)=Volume*ρ_{soil} * energy used for excavation Capital GHGs (kgCO$_2$-e)= Embodied energy (MJ)* emissions for diesel	EE=3,993 MWh GHG=995 tCO$_2$-e
ASR wells	No. wells: 2 Well depth: 200 m Well diameter: 0.25 m ρ_{soil}= 1600 kg/m^3 energy for excavation: 0.1 MJ/kg emissions for diesel: 69.2 kgCO$_2$-e/GJ Well casing depth: 160m Well casing: PVC-U 200/12 S1: 836.6 MJ/m Full cycle emission factor for electricity; 0.79 kgCO$_2$-e/kWh	Excavation EE (MJ): No. wells* Well depth*π*(well dia)^2/4*ρ_{soil}* energy for excavation Excavation GHG (kgCO$_2$-e) = Embodied energy * emissions for diesel Casing EE (MJ): No. wells* Casing depth* embodied energy (MJ/m) Casing GHG (kgCo$_2$-e) = Embodied energy (kWh)*Full cycle emission factor for electricity (kgCo$_2$-e/kWh)	EE excavation:0.9MWh GHG excavation: 0.2 tCO$_2$-e EE casing: 74.4 MWh GHG casing: 59 tCO$_2$-e
Pipelines for distribution	Pipe to Mawson Lakes: D=225mm; L=3 km; embodied energy of PVC-U 250/12 S1 = 1298 MJ/m Pipe to Mitchell: D=300mm; L=3 km; embodied energy of PVC-U 300/12 S2 = 2041 MJ/m Pipe Bolivar-Greenfields D=280mm; L=9 km; embodied energy of PVC-U 300/12 S1= 1660.5 MJ/m Full cycle emission factor for electricity; 0.79 kgCO$_2$-e/kWh	Embodied energy (MJ)=Length (m)* embodied energy (MJ/m) Capital GHGs (kgCo$_2$-e)= Embodied energy (kWh)*Full cycle emission factor for electricity (kgCo$_2$-e/kWh)	EE=1,082 MWh GHG=855 tCO$_2$-e for pipe to Mitchell EE=1,701 MWh GHG=1,344 tCO$_2$-e for pipe to Mawson Lakes EE=4,151 MWh GHG=3,279 tCO$_2$-e for pipe Bolivar-Greenfields
Tanks	***Volume:*** Clearwell after reedbed: 0.6 ML; Tank at Greenfields: 2.6 ML Emissions for diesel: 69.2 kgCO$_2$-e/GJ [c]	Embodied energy (GJ) = 0.4551*Volume (kL) +26.717[b] Capital GHGs (kgCO$_2$-e)= Embodied energy (MJ)* emissions factor	EE: 83 MWh GHG; 21 tCO$_2$-e For tank after reedbed EE: 336 MWh GHG: 84 tCO$_2$-e For tank at Greenfields

[a]Soil density and pipe type have been assumed. [b]based on data provided by Pullen (1999). [c]this emission factor is assumed because the emission factor for electricity would overestimate the embodied energy.

I.2 Options 1-4: Open space irrigation

As stated earlier Options 1-4 involve harvesting of urban stormwater through a stormwater harvesting system and a number of other activities, e.g. treatment through a wetland (Options1-4), treatment through aquifer (Options 2-4), disinfection (Options 3-4). The energy and greenhouse gas analyses for Options 1-4 are provided in TableI.3 – Table I.5.

I.2.1 Option 1: Stormwater harvesting without ASR followed by open space irrigation

The required energy for this option is estimated based on the pumping activity for water transfer between storages and the wetland. As the Parafield facilities are currently used for this option, the total embodied energy is assumed to be zero. The energy and greenhouse gas emissions are given in TableI.3.

Table I.3: Summary of energy and GHG emissions for Option 1

Item			**Transfer average annual supply: 0.37 GL /year**	
			Required energy (MWh/year)	**GHG emissions (tCO_2/year)**
Operating and Maintenance GHGs	Parafield	Pump Station PS1	24.7	19.5
		Pump Station PS4	76.9	60.8
Total			**101.7**	**80.3**

I.2.2 Option 2 Stormwater harvesting with ASR and open space irrigation

The required activities for this option are urban stormwater harvesting through a stormwater harvesting system and treatment through a wetland and aquifer. Compared to the previous option (Option 1), the required energy has been increased option to allow for water injection into and extraction from the aquifer. The energy and greenhouse gas emissions are given in TableI.4.

Table I.4: Summary of energy and GHG emissions for Option 2

Item			**Transfer average annual supply: 0.88 GL/year**	
			Required energy (MWh/year)	GHG emissions (tCO2/year)
Operating and Maintenance GHGs	Parafield	Pump Station PS1	81.6	64.5
		Pump station PS2	111.6	88.2
		Pump station PS3	178.6	141.1
		Pump Station PS4	182.2	143.9
Total			**554.0**	**437.6**

I.2.3 Option 3 Stormwater harvesting with ASR, chlorination and open space irrigation

The required activities for this option are the same as option 2, a part from the addition of the chlorination treatment. Option 3 has the same energy and greenhouse gas emissions as option 2 as the energy and emissions due to this treatment are small and have been neglected for all options.

I.2.4 Option 4 Stormwater harvesting with ASR, blending with treated wastewater and open space irrigation

The required activities for this option are urban stormwater harvesting through a stormwater harvesting system and treatment through a wetland and aquifer followed by chlorination and blending with tertiary treated wastewater, and exposure control. The energy and greenhouse gas emissions are given in Table I.5.

Table I.5: Summary of energy and GHG emissions for Option 4

Item			**Transfer average annual supply: 0.88 GL/year**	
			Required energy (MWh/year)	GHG emissions (tCO_2/year)
Embodied energy and capital GHGs	Greenfield	Storage tank upgrade	6.4	1.6
Operating and Maintenance GHGs	Parafield	Pump Station PS1	81.6	64.5
		Pump station PS2	111.6	88.2
		Pump station PS3	178.6	141.1
		Pump Station PS4	182.2	143.9
		Pumping Bolivar to Greenfield	299.6	236.7
		Pump station PS5	708.7	559.8
		DAFF treatment at Bolivar	286.5	226.3
Total			**1855.1**	**1462.1**

I.3Options 5-8: Third pipe system – external and internal uses

As stated earlier Options 5-8 involve harvesting of urban stormwater through a stormwater harvesting system and additional activities, e.g., treatment through a wetland (Options 5-8), treatment through aquifer (Options 6 and 8), disinfection (Options 5-8). For Options 7 and 8, the harvested stormwater is blended with treated wastewater and disinfection. For these options, the embodied energy of the third pipe network required to distribute the non-potable water has to be evaluated. In the computations, an average consumption equal to 100 kL/house/year has been assumed (this accounts for non-potable water only) and that, on average, 15 m of pipes are required to connect each house.

The pipe size required changes depending on the distance from the source, but, for simplicity, an average pipe size of about 150 mm has been considered. The PE100 180/12.5 (internal diameter = 151.8 mm) assumed in the computations has an embodied energy equal to 536.2 MJ/m (Ambrose et al. 2002). The total embodied energy can be calculated by multiplying the embodied energy of the pipe (536.2 MJ/m) by the number of houses connected (i.e. the total yield of the Option divided the average non-potable consumption per house) and by the connection distance (15 m). By converting this value in kWh and dividing it by 25 years, the annual energy requirement can be determined. Note that the discount factor assumed for greenhouse gas emissions and embodied energy is equal to zero. The greenhouse gas emissions are computed using the emission factor (0.79 $kgCO_2$-e/KWh).

I.3.1 Option 5 Stormwater harvesting, chlorination and supply to households via a third pipe network

The current pumping and water transfer facilities at Parafield, Greenfield and Mawson Lake have enough capacity for the case of 3 ML/day. The energy and greenhouse gas emissions are given in Table I.6.

Table I.6: A summary of energy and GHG emissions for Option 5

Item			**Transfer average annual supply: 0.37 GL/year**	
			Required energy (MWh/year)	**GHG emissions (tCO2/year)**
Embodied energy and Capital GHGs	Mawson Lakes	Third Pipe System	330.7	261.2
Operating and Maintenance GHGs	Parafield	Pump Station PS1	24.7	19.5
		Pump Station PS4	76.9	60.8
		Pump station PS5	125.7	99.3
Total			**558.0**	**440.9**

I.3.2 Option 6 Stormwater harvesting, ASR, chlorination and supply to households via a third pipe network

The treatment and activities are similar to option 5, but aquifer storage and recovery are considered for this option. The energy and GHG analysis for the other facilities is the same as for Option 5. The energy and greenhouse gas emissions are given in Table I.7.

Table I.7: A summary of energy and GHG emissions for Option 6

Item			**Transfer average annual supply: 0.88 GL/year**	
			Required energy (MWh/year)	**GHG emissions (tCO2/year)**
Embodied energy and Capital GHGs	Mawson Lakes	Third Pipe System	782.9	618.5
Operating and Maintenance GHGs	Parafield	Pump station PS1	81.6	64.5
		Pump station PS2	111.6	88.2
		Pump station PS3	178.6	141.1
		Pump Station PS4	182.2	143.9
		Pump station PS5	297.6	235.1
Total			**1634.5**	**1291.2**

I.3.3 Option 7 Stormwater harvesting, blending with treated wastewater, chlorination and supply to households via a third pipe network

This option includes harvesting of urban stormwater through a harvesting system and treatment through a wetland followed blending with treated wastewater and disinfection. The energy and greenhouse gas emissions are given in Table I.8.

Table I.8: A summary of energy and GHG emissions for Option 7

Item			**Transfer average annual supply: 1.00 GL/year**	
			Required energy (MWh/year)	**GHG emissions (tCO_2/year)**
Embodied energy and Capital GHGs	Mawson Lakes	Third Pipe System	893.7	706.0
Operating and Maintenance GHGs	Parafield	Pump station PS1	24.7	19.5
		Pump Station PS4	76.9	60.8
		Pumping Bolivar to Greenfield	166.2	131.3
		Pump station PS5	339.8	268.4
		DAFF treatment at Bolivar	149.2	117.9
Total			**1650.5**	**1303.9**

I.3.4 Option 8 Stormwater harvesting, ASR, blending with treated wastewater, chlorination and supply to households via a third pipe network

The treatment and activities are similar to option 7, but aquifer storage and recovery are considered for this option. As a result the total energy and GHG emission increase in comparison with Option 7. The energy and greenhouse gas emissions are given in Table I.9.

Table I.9: A summary of energy and GHG emissions for Option 8

Item			**Transfer average annual supply: 2.10 GL/year**	
			Required energy (MWh/year)	**GHG emissions (tCO_2/year)**
Embodied energy and Capital GHGs	Mawson Lakes	Third Pipe System	1863.9	1472.5
	Greenfield	Storage tank upgrade	6.4	1.6
Operating and Maintenance GHGs	Parafield	Pump station PS1	81.6	64.5
		Pump station PS2	111.6	88.2
		Pump station PS3	178.6	141.1
		Pump Station PS4	182.2	143.9
		Pumping Bolivar to Greenfield	299.6	236.7
		Pump station PS5	708.7	559.8
		DAFF treatment at Bolivar	286.5	226.3
Total			**3719.1**	**2934.6**

I.4Options 9-12:

As discussed in Section 4.1, this set of options involve treatment to Drinking Water Standard and injection directly into the potable water supply mains (Option 9) or treatment and transfer into the Little Para Reservoir for potable Use (Options 10, 11 and 12). The results for energy and GHG emissions for different options are presented in the following tables.

I.4.1Option 9: Stormwater harvesting, ASR, treatment to drinking water quality and direct injection into the potable water supply mains

This option involves stormwater capture, aquifer storage and recovery followed by micro-filtration, and disinfection and then injection into the mains close to the site. The GHG emission for this option is provided in Table I.10. As a new option, the GHG emissions are estimated for the microfiltration plant.

Table I.10: A summary of GHG emissions for Option 9

Item			**Transfer average annual supply: 0.88 GL/year**	
			Required energy (MWh/year)	**GHG emissions (tCO_2/year)**
Embodied energy and Capital GHG		1 km pipe	12.0	9.5
		Storage after disinfection	8.4	2.1
Operating and Maintenance GHGs	Parafield	Pump station PS1	81.6	64.5
		Pump station PS2	111.6	88.2
		Pump station PS3	178.6	141.1
		Pump Station PS4	182.2	143.9
		Pump station PS5	297.6	235.1
		Microfiltration	175.2	138.4
		UV & Disinfection	175.2	138.4
Total			**1222.4**	**961.2**

I.4.2 Option 10: Stormwater harvesting and transfer to Little Para Reservoir for potable use

Option 10 involves harvesting the stormwater and transferring it to Little Para reservoir, without aquifer storage and recovery. Harvested stormwater is then mixed with other water in the reservoir and treated by the Little Para water treatment plant prior to being distributed to consumers. Table I.11 gives the energy and greenhouse gas emissions associated with this Option.

Table I.11:Summary of energy and GHG emissions for Option 10

Item			**Transfer average annual supply: 1.10 GL/year**	
			Required energy (MWh/year)	**GHG emissions (tCO_2/year)**
Capital GHG		11 km pipe	161.7	127.7
Operating and Maintenance GHGs	Parafield	Pump station PS1	81.6	64.5
		Pump station PS5 for Little Para Reservoir	685.5	541.6
		Treatment at Little Para Reservoir	308.8	243.9
Total			**1237.6**	**977.7**

I.4.3 Option 11: Stormwater harvesting, ASR and transfer to Little Para Reservoir for potable use

Option 11 is similar to option 10, but water is stored in the aquifer before being pumped to the Little Para Reservoir. Water is then mixed with other water in the reservoir and treated by the Little Para water treatment plant prior to being distributed to consumers. Table I.12 gives the energy and greenhouse gas emissions associated with this Option.

Table I.12: Summary of energy and GHG emissions for Option 11

Item			**Transfer average annual supply: 0.88 GL/year**	
			Required energy (MWh/year)	**GHG emissions (tCO_2/year)**
Capital GHG		11 km pipe	161.7	127.7
Operating and Maintenance GHGs	Parafield	Pump station PS1	81.6	64.5
		Pump station PS2	116.2	88.2
		Pump station PS3	178.6	141.1
		Pump station PS5 for Little Para Reservoir	491.2	388.1
		Treatment at Little Para Reservoir	247.0	195.2
Total			**1271.7**	**1004.7**

I.4.4 Option 12: Stormwater harvesting, ASR, disinfection and transfer to Little Para Reservoir for potable use

Option 12 involves treatment through a wetland and ASR followed by UV disinfection prior to being transferred into Little Para Reservoir (Figure 4.1). The treated water is then mixed with other water in the reservoir and treated by the Little Para water treatment plant prior to being distributed to consumers. Table I.13 gives the energy and greenhouse gas emissions associated with this Option.

Table I.13: Summary of energy and GHG emissions for Option 12

Item			**Transfer average annual supply: 0.88 GL/year**	
			Required energy (MWh/year)	**GHG emissions (tCO_2/year)**
Embodied energy and Capital GHG		11 km pipe	161.7	127.7
		New storage after UV and disinfection	4.3	1.1
Operating and Maintenance GHGs	Parafield	Pump station PS1	81.6	64.5
		Pump station PS2	116.2	88.2
		Pump station PS3	178.6	141.1
		Pump Station PS4	182.2	143.9
		Pump station PS5 for Little Para Reservoir	491.2	388.1
		UV & Disinfection	175.2	138.4
		Treatment at Little Para Reservoir	247.0	195.2
Total			**1633.4**	**1288.1**

I.5 Summary

The energy and gross greenhouse gas emissions for each option (including the existing infrastructure) are summarised in Table I.14 and Table I.15. Note that the embodied energy and capital greenhouse gas emissions associated with existing infrastructure given in Table I.14have been converted into annual values by dividing by the life of the project (25 years in this case).

The emissions are compared with those produced by an equivalent volume of water from the River Murray (80%) and from desalination (20%). The levelised benefit of using harvested stormwater has been computed based on the assumption that 80% of the harvested water replaces River Murray water and 20% replaces desalinated water. Also note that SA Water purchases green energy for their desalination plant and this offsets most of their greenhouse gas emissions from this source.

Table I.14: A summary of energy consumption per year for all options (including the embodied energy of existing infrastructure for the Parafield scheme and the Bolivar-Greenfield infrastructure)

Option	Volume of Water Supplied (GL/year)	Incremental Energy consumption (MWh/year)	Embodied energy of existing infrastructure (MWh/year)	Energy consumption of equivalent volume of water supplied from the River Murray and the desalination plant (MWh/year)	Reduction in energy consumption (MWh/year)	Levelised reduction in energy consumption (MWh/ML)
1	0.37	102	274	932	556	1.50
2	0.88	554	277	2218	1387	1.58
3	0.88	554	277	2218	1387	1.58
4	2.10	1855	457	5292	2980	1.42
5	0.37	558	284	621*	-221	-0.60
6	0.88	1635	291	1479*	-447	-0.51
7	1.00	1651	451	1680*	-422	-0.42
8	2.10	3719	457	3528*	-648	-0.31
9	0.88	1222	166	2218	830	0.94
-10	1.034	1238	163	2772**	1371	1.33
11	0.827	1272	166	2218**	780	0.94
12	0.827	1633	166	2218**	419	0.51

*Based on supply of 67% of non-potable demand from conventional sources due to the higher price of water to the consumer
**Allows for 6% evaporation loss in the Little Para Reservoir

Table I.15: A summary of gross GHG emissions for all options (including the existing infrastructure for the Parafield scheme and the Bolivar-Greenfield –Mawson Lakes infrastructure)

Option	**Volume of Water Supplied (GL/year)**	**Gross GHG emissions (Tonnes CO_2 -e per year)**	**GHGs due to embodied energy of existing infrastructure (Tonnes CO_2 -e per year)**	**Gross GHG emissions of equivalent volume of water supplied from the River Murray and the desalination plant (Tonnes CO_2 -e per year)**	**Reduction in Gross GHG emissions (Tonnes CO_2 -e per year)**	**Levelised reduction in Gross GHG emissions (kg CO_2 –e/kL)**
1	0.37	80	128	737	529	1.43
2	0.88	438	130	1752	1184	1.35
3	0.88	438	130	1752	1184	1.35
4	2.10	1462	262	4181	2457	1.17
5	0.37	441	129	491*	-79	-0.21
6	0.88	1291	131	1168*	-254	-0.29
7	1.00	1304	260	1327*	-237	-0.24
8	2.10	2935	262	2787*	-410	-0.20
9	0.88	961	42	1752	749	0.85
10	1.034	978	40	2190**	1172	1.13
11	0.827	1005	42	1752**	705	0.85
12	0.827	1288	42	1752**	422	0.51

*Based on supply of 67% of non-potable demand from conventional sources due to the higher price of water to the consumer

**Allows for 6% evaporation loss in the Little Para Reservoir

Appendix J: Amenity Services – River Murray

River Murray Water for the Adelaide metropolitan area comes from the Adelaide Mt. Lofty Ranges, the River Murray and the Port Stanvac desalination plant. The amount of water coming from the River Murray varies from about 40 per cent in a normal rainfall year to as much as 90 per cent in a dry year. At the height of the Millennium drought, Adelaide received in the order of 206GL from the River Murray in one year and after the drought, it is projected that 70GL per year will be required. SA Water currently has a non-tradeable license of 130GL of water and use of this entitlement is subject to a rolling five-year total of 650 GL for metropolitan Adelaide.

The Coorong is the key ecological feature downstream of Adelaide that would benefit from substituting some River Murray water with harvested stormwater for urban water supply purposes. Calculating a potential benefit to the Coorong is complicated by the evolving property rights to water, actual river management operations and the non-linear, discontinuous ecological response of the Coorong to quantities of water and flow regimes. Under the Murray-Darling Basin Plan, 2850GL of water will be returned to the environment to improve riverine health. For the calculation of any benefit, the amount of water reaching the Coorong will be determined by the implementation of the Murray-Darling Water Sharing Plan and the evolving water and dam sharing agreements among States.

Under current water sharing arrangements, based on the calculated requirements of irrigators, the environment and urban areas, daily releases of water are scheduled for the major storages in the Murray-Darling basin. If the stormwater harvested and stored by Salisbury Council (say 1 GL) is excluded from the daily release requirements for SA Water operations, then the 1 GL water would sit in the dam. If the stormwater harvested by Salisbury Council is not included in the daily release calculations and not required by SA Water then under current arrangements, the water will flow down to the Coorong-Lower Lakes and Murray Mouth.

Under the new arrangements in SA, volumetric entitlements will be an access entitlement system based on shares. As a result of Basin state negotiations, there will be new carry-over provisions for private irrigators in SA -currently SA does not have as secure a carry-over provision as do Victoria and New South Wales. Essentially SA entitlements are described as horizontal storage while NSW and Victoria have vertical storage. Essentially, SA entitlements spill first. These changes will change the amount of water flowing down the river to the Coorong.

The ecological benefit to the Coorong depend on the flow regime and whether the 1 GL could be added to a middle to large flood event. Under very low flow conditions, 1 GL of water in 2009 at the end of the drought would have had limited ecological impact due to hypersalinity. Under high flows, 1 GL may have its best impact if the water helps to flush the system and reduce salinity levels from unhealthy hypersaline states to a healthy saline ecosystem state which supports a variety of migratory water birds and fish.

Hatton MacDonald et al (2011) estimated the national willingness to pay to restore the Coorong and Lower Lakes to good quality habitat for migratory birds as $900m each year for ten years. These values are given in Table J.1. The estimates are in 2009 $ based on simplified biophysical representations of the Coorong using accessible information at the time the valuation survey was initially prepared. Since that time, more ecological information has become accessible as a result of the extensive biophysical modelling of significant assets across the Murray-Darling Basin in 2009-10 (Lester and Fairweather 2009; 2011).

Table J.1: Estimates of the Value to Australians of an Improved Coorong (adapted from Hatton MacDonald et al,2011).

	NSW	ACT	Victoria	South Australia	Rest of Australia	TOTAL
	5% Discount Rate - extrapolation based on response rate					
Improve Coorong	$1,578m	$125m	$1,174m	$547m	$2,353m	$5,776
	5% Discount Rate - 30% of non-respondents having similar preferences					
Improve Coorong	$2,086m	$153m	$1,470m	$641m	$2,950m	$7,300m
	28% Discount Rate - 30% of non-respondents having similar preferences					
Improve Coorong from	$1,077m	$79m	$759m	$331m	$1,522m	$3,768m

Environmental water requirements, based on complex modelling for the Coorong and Lower Lakes, suggest that a series of states can result from different flow regimes. Across the Coorong, these include estuarine-marine, marine and hypersaline states ranging from degraded to a healthy ecological condition.

Table J.2:Relevant targets from MDBA and SA

MBDA		**Without development**	**baseline**	**3000 GL**
	5100 GL/y long term average	✓	✗	
	2000 GL/y rolling average over 3 years in 95% of years	✓	✗	
	1000 GL/y rolling average over 3 years	✓	✗	✗
	3200GL/y ten-year rolling average for salt export	✓	✗	✗
SA government targets				
	Absolute minimum of 650 GL 95% of years	✓	✗	✓
	4000 GL – previous year in 95% of years	✓	✗	✗
	6000 GL – previous 2 years (adjusted) in 95% of years	✓	✗	✗
	2000 GL – previous year in 100% of years	✓	✗	✗
	3000 GL – previous 2 years (adjusted) in 100% of years	✓	✗	✗
	SA minimum flow (max of three previous targets) in 100% of years	✓	✗	✗
	6000 GL/y 1-in-3 year frequency	✓	✗	✓
	10,000 GL/y 1-in-7 year frequency	✓	✗	✓

✓' indicates the target was met.

✗' indicates where the target was not met.

Source: Pollino et al 2011

Table J.2 provides a number of different environmental water requirements. While the final proposal of 2850GL has not been examined in terms of the potential to meet environmental water requirements, Pollino et al (2011) and CSIRO (2012) examined a number of additional scenarios against a baseline and without development scenarios that may be relevant. Under the new basin-wide water sharing arrangements, a 1.1 and 3.65 GL addition to the long-term environmental flow over the barrages, may have a better ecological impact terms of ecological benefits compared with flows in the last ten years. Ultimately realising the benefit to the Coorong will depend on rainfall and the actual flow regime implemented. If drought conditions return or rainfall patterns shift and run-off to the Basin is quite low, restoring the Coorong as a good habitat area may be infeasible. Only under favourable rainfall conditions, a particular flow regime and specific institutional rules will harvested stormwater being substituted for River Murray result in positive environmental benefit to the Coorong.

Using the last row of figures from Table J.1, the present value of willingness-to-pay benefits for an improved Coorong is $3768m. If this benefit can be provided by a flow of 5100 GL per year and the benefit is assumed to be proportional to flow, the present value of the benefits due to an additional 1GL is estimated to be $0.739m. The 3 ML/day scheme provides 1.1 GL/year which becomes 0.88 GL/year after ASR. If 80% of this replaces River Murray water, the benefit of the additional flow in the Murray would be $0.52m (in present value terms). In the absence of ASR, the benefit is $0.22m (in present value terms) due to the reduction in harvested stormwater. These values translate to $0.046/kL for both schemes.

Appendix K: Amenity Services – Recreational Parklands

One method for estimating the value of the use of water on open public spaces is to use markets to infer the value of different environmental qualities. In economic theory, this technique is known as a hedonic pricing model where individuals derive utility from the properties or the characteristics of the goods. Hedonic pricing models are based on the relationship between the attributes of a good and its final selling price. To describe the modelling intuition, consider a class of similar market products. If this class has sufficient members with different combinations of characteristics, it is possible to estimate a statistical relationship (called the hedonic price function) that relates the market price of any member in the class as a function of the quantities of its various characteristics. This modelling approach is especially ideal for real estate products that can potentially bundle environmental and facility-related attributes. To build models requires information on the actual arms-length sales prices of the properties and information on their associated environmental features, locational or neighbourhood characteristics and structural features (e.g. housing characteristics). Regression techniques can be used to estimate the importance of each of these characteristics as an explanatory variable of the market price. The coefficients associated with any characteristic can be used to develop the implicit price of that characteristic.

Any member or product mi contained in C can be described by a vector of its characteristics. Let X = q1…qj…qk represent the vector of characteristics. Thus, for member mi, mi=f(qi1,….qij,…qik) where qij is the quantity of the jth characteristic provided by i. More formally, for mi

$$P_{mi} = p_m\left(q_{i1},\ldots q_{ij},\ldots q_{ik}\right) \tag{K.1}$$

Where P_{mi} is the price of mi observed in some free market transaction. If the hedonic price function pm(.) can be estimated from observations of the prices and characteristics of different members of C, the price of any member within PC can be calculated from information about its characteristics. The partial derivative of pm(.) with respect to any of its arguments (q) yields the implicit marginal price of that characteristic. This price is the additional amount that must be paid by a buyer to move to another product in C with a higher level of that chosen characteristic. This interpretation is convenient as marginal implicit price can be considered a measure of a buyer's marginal willingness to pay for higher quantities of that characteristic.

For this application to net benefits, we employ a first stage approach in examining the value of public and private green space areas across Adelaide SA. We assume that buyers and sellers are maximising utility and that the market clears as a result of consumer tastes and seller costs. Therefore, the final selling price is determined by the buyer's appraisal of the value of the characteristics of the property. In the estimation of pm(.) we select a set of explanatory variables that relate to the location of the properties, the structural characteristics of any buildings located on them and environmental features that we believe buyers and sellers are cognisant of. The dependent variable in this modelling approach involves the final selling price of the property. These features of our estimation are important in identifying the marginal implicit prices associated with the independent variables we include in the estimation of pm(.).

Mahmoudi et al (2013) developed a complete first stage hedonic model for metropolitan Adelaide for 2005-2008 for two types of open space (small reserves and sports parks). Using only statistical significant coefficients, we can summarise the marginal implicit prices as follows:

Small reserves

$$\frac{\partial P}{\partial distancetosmallreserve} = \left(Bi\frac{P*areaofsmallreserve}{distancetosmallreserve}\right) \qquad \text{(K.2)}$$

Bi=-0.000046

Sport Parks

$$\frac{\partial P}{\partial distancetosportpark} = P\left(Bj\frac{1}{distancetosp} + Bk\ \frac{tougherwaterrestriction}{distancetosp}\right) \text{(K.3)}$$

B_j= -0.002565
B_k= -0.003663
Mean price in Salisbury council = $249,000,
Area of small reserve = 5493 m^2

These values can be used to consider how expanding the area of a pocket park or the impact of watering sport parks impacts on surrounding houses. As Salisbury Council uses harvested stormwater for its parks, nearby homeowners benefit from the green areas especially during water restrictions. For instance across the Salisbury council area, an individual property within 50 m of a watered sporting field would increase in value by $31during severe water restrictions. Within a 1km radius, the sum of increased property value is $11,424. Figure K.1 provides an overview of the values that accrue to surrounding properties as a result of watered sporting fields.

Converting the capitalized benefits in the 1 km zone of influence into an annual value and assuming that sports turf irrigation standards were used in applying recycled water to the area, the benefit is calculated to be $0.021 per kL (A$2008). It is assumed the benefit is the result of the application of water.

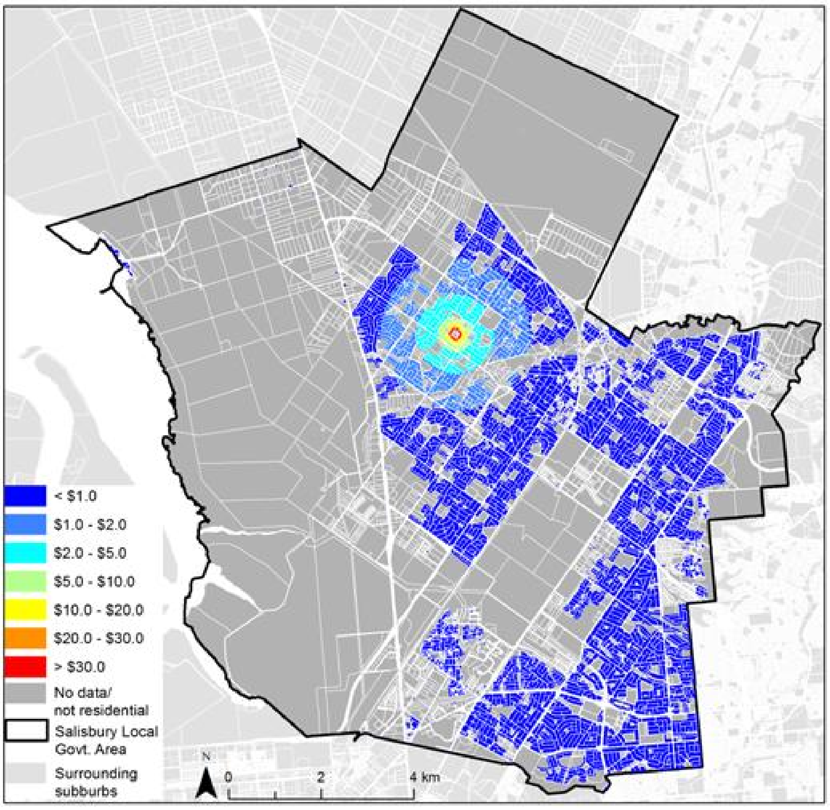


Figure K.1:Increase in Property Values as a Result of Watering Sports Fields

This analysis could be improved by updating the real estate data to the present, the use of estimating models that incorporate sub-markets, and the inclusion of spatial layers for areas which are watered using recycled rainwater and more detailed information about facilities within parks. It would also be of interest to examine the relationship between wetlands and man-made lakes and property values. In this study it was not possible to determine this effect because wetlands, dams and reservoirs were all considered as one entity. Boyer and Polasky(2004) showed that Hedonic studies of the value of wetlands that included rural entities such as swamps and dams had a mixed response because of the decrease in agricultural production often associated with the wetland

The metropolitan Adelaide hedonic pricing model produces an average over space. On a sub-market level, these relationships can be estimated using a more refined set of spatial metrics.

Appendix L: Amenity Services – Urban Wetlands

If stormwater is harvested generally wetlands are required to detain and treat stormwater prior to storage in aquifers. One option is to develop wetlands as part of urban developments. This is often the most effective form of flood mitigation for new developments. It has also been a significant selling point for developers at the point of house sales. To date no studies have been undertaken to determine the effect of urban wetlands on property values in the Adelaide region, however one such study has been undertaken in northern Perth (WA). Tapsuwan *et al* (2009) used *Hedonic* pricing to investigate the value of urban wetlands.

The Hedonic pricing technique was introduced by RAMSAR to value environmental amenities that are not sold in the market and do not have direct market value. The hedonic pricing method is based on the idea that properties are not homogenous; they differ in respect to a variety of characteristics such as number of bedrooms, bathrooms, lot size, proximity to parks and schools. Property prices can be affected by all these location-specific environmental, structural and neighbourhood characteristics (Tapsuwan *et al* ,2009). The method relies on observable market transactions, for instance, property sales data, to place values upon the various characteristics that make up a heterogeneous product (Boxall *et al.,* 2005). The hedonic approach can be used to value wetlands as prices of properties near wetlands contain a capitalized amenity value for wetland proximity, so that when the properties are sold, the new buyers have to pay for this amenity value in the form of higher house prices (Loomis and Feldman 2003).

The hedonic property price approach is based on real market transactions that have occurred in a real market setting and therefore could overcome hypothetical bias. Nonetheless, urban wetlands have both public and private use and the hedonic method may not fully capture the public service component of wetlands as this value presumably cannot be fully reflected through property market prices which tend to capturing private (rather than public) values.

Three studies have applied the hedonic method to estimate the value of wetlands to nearby property owners in urban areas (Mahan et al. 2000, Lupi et al. 1991, Doss and Taff, 1996). All three studies find a positive impact from wetlands on property values. Mahan *et al.* (2000) used data on over 14,000 home sales in the Portland, Oregon metropolitan area, along with detailed information about housing characteristics, GIS information on location of wetlands, lakes, rivers, streams, and other environmental amenities, as well as the location of industrial, commercial sites and other neighbourhood characteristics. They found that closer proximity to a wetland increased property value. Decreasing the distance to the nearest wetland by 300 meters from an initial distance of 1.6 kilometres resulted in an estimated $436 increase in property value. They also found only a very modest ($24) increase in house value with an increase in the size of the nearest wetland by 0.4ha.

Lupi *et al.* (1991) used data from Ramsey County, Minnesota, near where St. Paul is located. They estimated that an increase in wetlands acreage in the survey section where the house was located increased housing value by $19 per hectare of increased wetlands (1989 dollars). The increase in value for wetland area tended to be greater in areas where there were few nearby wetlands. Doss and Taff (1996) also found a positive value from nearby wetlands using data from Ramsey County, Minnesota. They found a preference for open-water wetlands and scrub-shrub wetland types over emergent-vegetation and forested wetlands.

An area studied in Perth by Tapsuwan et al (2009) is located near lakes Herdsman and Monger, and is not dissimilar to urban areas of Adelaide that could accommodate (or already have) urban wetlands: the area is flat with the coast to the west and hills to the east; it has a river running through it and has a range of suburbs ranging from affluent beach areas to inner urban suburbs and less affluent areas in the north, further from the city centre. There is a mixture of land uses including residential, light industrial and commercial, and a large parkland/nature reserve, named Bold Park, which represents the neighbourhood ‘green space’. There is also a major freeway that passes through the study area, running approximately from the city centre to just east of the chain of wetlands on the northern boundary of the study area. Finally, in and around the study area, there are other amenities such as golf courses, large shopping centres and places of tertiary education and numerous small parks and reserves.

The major difference between Adelaide and Peth are the mean house prices in the study areas. The mean house price in the Perth study was $795,000, while the mean house price in a similar Adelaide location (Salisbury) is $310,000. This is a significant difference in price. The size of properties is smaller in Salisbury than for the Perth study area, so that the real estate cost per hectare is similar.

By applying the Hedonic Property Price approach, Tapsuwan *et al* (2009) found that both the distance to the nearest wetland and the number of wetlands within close proximity significantly influence house sales price. Wetland distance influences sales price within a premium zone extending from the edge of a wetland (Figure L.1). The price diminished to median price for properties that are 943 m away. Similarly, the existence of an additional wetland within close proximity of the property will increase the sales price by $7,000 (these results took into account total land area; number of: bedrooms, bathrooms, studies, parking spaces in garage or carport, dining rooms, games rooms; age of the house in years; tiled roofing, distance to: beach, GPO, freeway entrance and property elevation). These results are similar to those reported by Lupi et al. (1991), Doss and Taff (1996) and Mahan et al. (2000), who also showed a significant relationship between distance to urban wetlands and sales price.

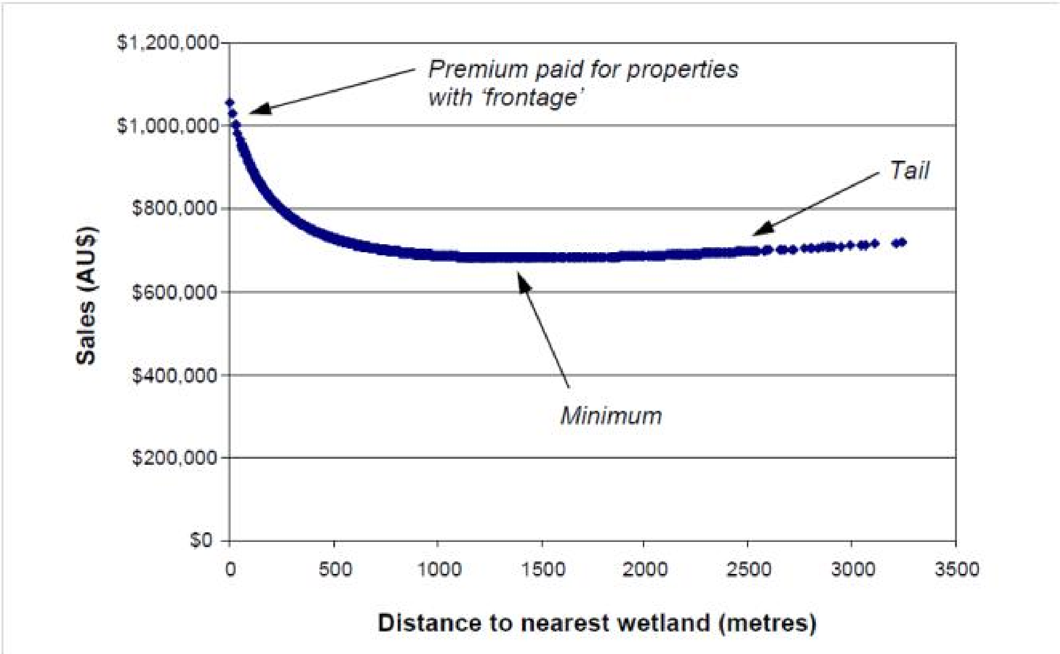


Figure L.1:The effect of distance to the nearest wetland on the estimated sales price, holding all other variable constant at their average values for the study area (from Tapsuwan *et al* 2009).

By scaling Perth results based on the mean price of real estate per hectare and the effect of the distance to the wetland, as it is possible to estimate the magnitude of the impact of the proximity to a wetland for other regions.

Tapsuwan *et al* (2009) showed that even small wetlands contribute a large premium to the neighbourhood. Based on an average density of 5.3 properties per hectare, the total premium in sales price for a 20 ha wetland, which is approximately the mean size of wetlands in the Perth study area, is approximately AU$140 million, or between AU$40 million and AU$230 million (the 95 per cent CI).

Figure L.2, (derived from Tapsuwan *et al,* 2009), shows the effect on land values as the distance from the wetland increases. The wetland is approximated as being circular, with a radius r_1, and land value premium is assumed to decline from h_1 ($/ha) with increasing radius as a piece-wise linear function, with a change in slope at radius, r_2, to a radius r_3, beyond which the wetland is considered not to affect land value.

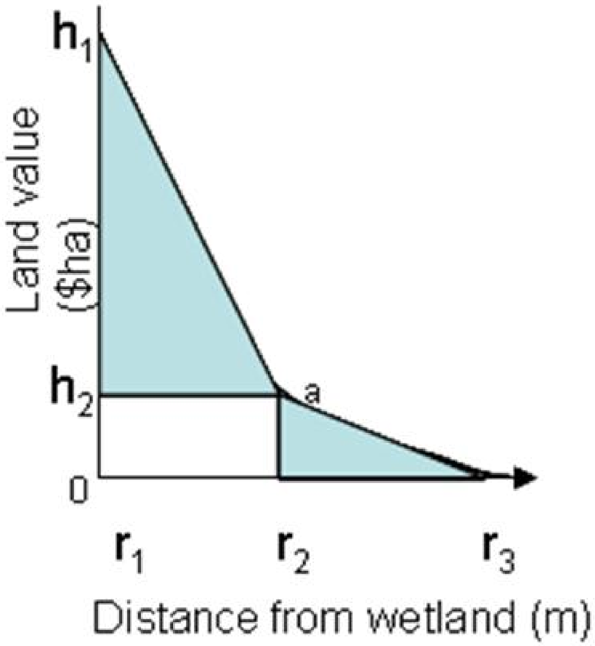


Figure L.2:The effect of distance to the nearest wetland on the estimated sales price per hectare.

The toroidal volume of the triangle h_1, h_2, a; the rectangle h_2, a, r_2, r_1; and the triangle a,r_3,r_2 revolved around the axis r=0, gives the total increase in land value due to the wetland. Equation L.1 below gives the calculation for the first triangle (h_1, h_2, a) (and by substitution allows the second triangle to be calculated). Equation L.2 is the formula for a rectangular component.

$$v = \frac{\pi(h_1 - h_2)}{3(r_2 - r_1)}(r_2^{\ 3} - 3r_2 r_1^{\ 2} + 2r_1^{\ 3}) \qquad \text{(L.1)}$$

$$v = \pi h_2 (r_2^{\ 2} - r_1^{\ 2}) \qquad \text{(L.2)}$$

As indicated by Tapsuwan *et al* (2009), the number of houses affected by distance to the wetland is a function of wetland size; the larger the wetland area the greater the number of houses that can be close to the wetland. It is therefore necessary to include the radius of the wetland and the surrounding housing density to estimate the impact of distance to wetland on house values for other study areas, as presented in the equations L.1 and L.2. Table L.1 shows the increase in land value associated with wetland proximity for different sized wetlands in the study areas of Perth (WA) and Salisbury (SA). In this table the values of radii r_2 and r_3 for the 20 ha. wetland are based on values obtained by Tapsuwan *et al* (2009). The values of r_2 and r_3 for the smaller wetlands are scaled from the 20 ha. values in proportion to the radius of the wetland.

TableL.1: Increase in land value associated with wetland proximity for different sized wetlands in the study areas of Perth (WA) and Salisbury (SA).

Wetland area	**20 ha.**	**2 ha.**	**0.2ha.**
Effective radius, r_1 (m)	250	80	25
% value increase at r_1	50	50	50
Radius, r_2 (m)	450	143	45
% value increase at r_2	11	11	11
Radius of influence, r_3 (m)	750	238	75
Perth base land value, ($\$/m^2$)	371	371	371
Land value increase ($M)	55	5.5	0.6
Salisbury base land value, ($\$/m^2$)$^+$	310	310	310
Land value increase ($M)	70	7.0	0.7

$^+$Based on 1) Research4 (2009) Adelaide housing density of 450m2, and allowing 150m^2 for roads/verge, 2) Gov SA housing, property and land (2012) for Salisbury, mean house price of $284,000.

A number of new housing developments have created artificial wetlands to add extra environmental appeal to their properties. In the case of Perth, Western Australia, urbanizing around existing wetlands not only will improve surround property prices, but could also help raise the water level in wetlands from increased run-off and groundwater recharge.

These results from suggests that the value to sales premium to properties surrounding a 2 ha wetland in Salisbury (SA) could be as high as $7 million.

Appendix M: Stormwater Harvesting Impacts on Coastal Water Quality

M.1. Introduction

This Appendix was prepared to identify potential benefits to coastal water quality and flow-on effects of stormwater harvesting from catchments in the Adelaide metropolitan area.

In November 2007 the Adelaide Coastal Waters Survey (ACWS) was completed (Fox *et al,* 2007). The report had three focal points: water quality, seagrass loss, and sediment stability. Other ecosystem components such as reefs, mangroves, and fish were outside the terms of reference for this study, as were considerations of impacts on human health and on recreational and aesthetic values. No attempt was made to attribute economic values associated with the findings of the report.

This Appendix firstly considers the findings of the ACWS, with a particular focus on the impact of water quality on seagrass loss. It then examines the market and non-market economic values associated with stormwater and wastewater impacts on coastal waters and seagrasses. It draws on local studies wherever possible, however where no local study has been undertaken it draws on relevant studies from other regions. The market and non-market economic values examined include:

- Water treatment- nitrogen
- Fish production;
- Sea grass loss;
- Beach access/existence;
- Beach restoration, and
- Aesthetic values.

M.2. Coastal Water Quality

M.2.1 Nutrients

The results from the ACWS showed that in 2003, approximately 2450 tonnes of Nitrogen were being discharged into the sea. Of this 90% was derived from wastewater treatment plants (WWTP's) and Penrice Soda. The contribution by Stormwater was only 6% (151 tonnes) (Table M.1).

Table M.1: Summary contribution of stormwater and wastewater loads to total nitrogen and particulate levels in the ACWS area, 2001-2003. (Source: Fox et al, 2007).

Source	Volume water discharged (GL/yr)	Nitrogen discharged (T/yr)	Suspended solids discharged (T/yr)
Stormwater 2003	114	151	6849
Wastewater 2003	62	1204	1579
Other 2003	215	1098	1909
Total 2003	391	2453	10,337

Evidence from the ACWS pointed towards the key role of nitrogen loads in causing nutrient enrichment of coastal waters, growth of epiphytes, and (possibly) direct effects on seagrasses. There is no evidence from this study to show that toxicants or other chemical stressors play a key role in the ecosystem dynamics, which is consistent with the findings of other studies of sheltered coastal waters in Australia (Deans and Townsend, 2003).The study suggests that the primary causative agent of seagrass loss is most likely high nutrients (nitrogen); with turbidity a minor contributor. The study recommended a discharge level reduction target of 75% for Nitrogen and 50% for sediment load from 2003 levels.

M.2.2 Turbidity

The report does not present figures for turbidity *per se*, but does present figures for particulates in water, which in turn affects water turbidity. Stormwater is shown to contribute 67% (6849 tonnes) of particulates, with WWTP's contributing only 15% (1579 tonnes) (Table M.1). These figures suggest that the source primarily responsible for water turbidity is stormwater. The study recommended a discharge level reduction target of 50% for sediment load from 2003 levels.

M.2.3 Seagrass loss

Seagrass meadows are an integral part of the morphology and ecology of the coast and beaches of Adelaide. However a loss of over 4,100 ha of seagrass (*Posidonia*, *Amphibolis*, *Zostera*, *Heterozostera*and *Halophila*) occurred between 1949 and 1996, from the Aldinga to Largs Bay area. This equates to 32% of the 1949 total seagrass area. The average rate of loss has been approximately 87 hectares per year, and the loss is continuing (EPA, 1998).Seagrass loss can in turn result in loss of fish habitat and cause destabilisation of sea beds resulting in sand loss from beaches.

The ACWS (2007) concluded that the primary causative agent of seagrass loss is most likely high levels of nutrients (nitrogen); with turbidity being a minor contributor. This conclusion is supported by earlier work undertaken by (Deans and Townsend 2003) who state that seagrass loss is generally attributed to elevated nutrient levels from sewage and stormwater discharges. However, water quality not only effects seagrass loss, but can have significant impacts on the recreational and aesthetic values of the coastal areas affected.

M.3. The market and non-market economic values associated with stormwater and wastewater on coastal waters and sea grasses.

M.3.1 Nitrogen

The cost to the environment of the nitrogen discharge is the loss of sea grasses. The cost to remove this nitrogen from the discharge water is estimated to be $800 per kg (CSIRO, 1999). This figure is based on the cost imposed on developers in Melbourne by Melbourne Water to provide regional water quality treatment (construction and operating costs) to protect receiving waterways. Thus the total cost to the community of removal of 2453 tonnes of nitrogen from WWTP and stormwater (Table M.1) is approximately $1,084 Million. Assuming a treatment plant life of 25 years and a discount rate of 6% the cost to the community per year is $85 Million.

Table M.1 shows that 151 tonnes of nitrogen comes from stormwater, and thus at a cost of $800 per kg, the costs associated with stormwater nitrogen impact are $5.22 Million per year.

M.3.2 Fish production

It is evident from the literature (e.g. Bell and Pollard, 1989; Edgar et al., 1993; Connolly, 1994; Jenkins et al., 1996; Butler and Jernakoff, 1999; Robertson, 1977; and others) that there is an important link between seagrass habitats and fishery production and thus the loss of seagrass beds adversely affects coastal fish species and commercial fisheries production. Evidence suggests that damage to seagrass will change the abundance and variety of fish species, and possibly reduce stocks of some of the most important commercial and recreational fish, mollusc and crustaceans.

McArthur and Boland (2006) undertook a comprehensive study into the impact on the fishing industry of the loss of seagrass habitat on the SA fishing industry. They estimated the value of seagrass habitats in terms of the contribution to secondary production of some important South Australian fish species in a broad scale domain. Their approach considered the relationship between primary production estimates for seagrass habitats in temperate and subtropical coastal waters and estimates of commercial, recreational and discarded catch figures. The paper briefly describes models which link expected harvest of different species to seagrass area and the consequent expected reduction in catch given seagrass decline. Their results showed that the economic contribution of seagrass habitats to secondary production in the gulf waters of South Australia is of the order of $114 million per year, $133.23/ha/yr) ($131 Million $153.93/ha/yr in 2012 dollars)

It is estimated that seagrasses covers 5000 km^2 of the sheltered coastal waters of Gulf St Vincent (EPA, 2009), with approximately 12,800 ha in the study area – Largs bay to Aldinga.

A total of 40.8 km^2 (4086 hectares) of seagrass has been lost in the study area since 1949. This equates to 32% of 1949 total seagrass area (EPA 1998)4,086 ha loss x $159.93/ha/yr = $653,500 per year.

These figures suggest that to date, the value of the lost seagrass meadows (32%) to the fishing industry in SA is in the order of $0.65 million per year.

M.3.3 Seagrass loss

While the ACWS (2007) suggests that the primary causative agent of seagrass loss is most likely high nutrient levels (principally nitrogen); with turbidity a minor contributor, it does not hazard a guess at what proportion of the damage is done by what, and how 'minor' the minor damage is. This makes allocation of responsibility for seagrass loss between the major pollution sources (wastewater and stormwater) very difficult.

It is therefore necessary to assume a range of responsibility between nitrogen and turbidity for seagrass losses in order to determine stormwater related costs to the fishing industry. For the purposes of this work it is assumed that turbidity is responsible for between 0 and 15 percent of seagrass (and related fisheries) loss, and that the remainder of the loss is attributable to nitrogen (eg: if turbidity caused 10% of the loss, nitrogen causes the other 90%).

Furthermore, we know that stormwater contributes 6 percent of the nitrogen load while wastewater contributes 49 percent (Table M.1). Thus if total fish losses due to seagrass loss are $0.65 million per year and if 100 percent of this loss is caused by nitrogen, and if 6% of this nitrogen comes from stormwater, then the loss from nitrogen in stormwater per year is $0.65 million x 100% x 6% = $39,210.

The report does not present figures for turbidity per se, but does present figures for particulates in water, which in turn affects water turbidity. Stormwater is shown to contribute 67% (6849 tonnes) of particulates, with WWTP's contributing only 15% (1579 tonnes). These figures suggest that stormwater is primarily responsible for water turbidity.

Table M.2 presents the range of fishery losses that can be attributed to stormwater impacts on seagrasses. Given the assumptions described above, this data suggests that it is reasonable to assume that stormwater impacts are costing $63,000 per year in the study area.

Table M.2: The range of fishery losses that can be attributed to stormwater impacts on seagrasses.

Particulatesin stormwater contribution to fishery losses	Nitrogen in stormwater contribution to fishery losses	Fisheries losses associated with stormwater
0	100	39,210
3	97	51,169
6	94	63,128
9	91	75,087
12	88	87,046
15	85	99,000

This stormwater impact is based on a total stormwater volume of 114 GL/year flowing into the Gulf. Assuming a linear relationship with volume of stormwater harvested, the expected benefit of reducing stormwater inflow to the Gulf is $552/GL. In present worth terms this is $7,050 per GL/year of stormwater harvesting.

M.3.4 Beach access/existence

Burgan (2003) examined the question: how much value do Adelaide residents place on having access to adequate beaches. The context of the study was the need to maintain the adequacy of beaches currently maintained by a sand management (i.e. beach replenishment) program.

Burgan did not look at the costs of replenishment associated with the program, but examined the value that the community puts on access to beaches. The implication is that without continued replenishment program, or an alternative, the quality of beaches will be significantly decreased, and the assessed value will be essentially lost or greatly reduced.

Burgan (2003) employed three methodologies in his work:

- An econometric study to ascertain the impacts of beach proximity on the site or land value of a property – and isolate the extent to which direct access to a beach, or being in walking distance of a beach, and having water views affects the value. The first two are presumed to be directly related to the quality of the beach (access to the beach was interpreted as being related to the value of sand i.e. a sandy beach rather than a sea-walled foreshore. The presumption was that if there were no sand on a beach there would be no or limited value to beach access). Water views are presumed to be unrelated to sand quality.

- For other metropolitan residents (i.e. those not residing within beach proximity) the value of access to a beach was based on an assumed intrinsic value of between $2 and $3.60 per visit (i.e. the value in use of a public good). The modelling was based on metropolitan residents (excluding those residing in proximity to the beach) visiting the beach an average 5.73 times in summer.

- The impacts of beach quality on property values (as above) that flow through into Council rates.

On the basis of these assumptions, the conclusions as to annual value associated with beach access and use in 2003 are presented in Table M.3 (Results have been converted to 2012 values).

Table M.3: Value of access to Adelaide beaches.

Impact on Property value due to:	**Annual Value ($M)**	**Annual Value ($M)**	**Capitalised ($M)**	**Capitalised ($M)**
	2003 dollars	2012 dollars	2003 dollars	2012 dollars
Beach access value	5	6.3	71.7	91.75
Walking distance value	16	20.1	227.9	291.62
Total	**21**	**26.4**	**299.6**	**383.37**
Other value				
Day visits	22.8	28.7	325.9	417.02
Public finance	1.8	2.3	25.7	32.89
Total	**45.6**	**57.4**	**651.1**	**833.28**

The public sector return is primarily the impact of higher property values on rates and taxes. This impact or value is additional to the house value effect calculated above in that this is netted out by the owner of the house in their view of the “value” of the house. The total value of useable beaches to Adelaide residents is estimated as $57 million per year. However it is suggested that even this evaluation remains conservative. The estimate of value excludes impact or benefits such as:

- Returns from tourism
- Producer surplus from business operations along the beach
- Impacts of crowding or congestion on remaining beaches (e.g. south coast) if Adelaide residents forced to these alternative uses

How much of this loss can be attributed to stormwater?

The total value of useable beaches to Adelaide residents has been shown to be worth $46 million per year.

Once again given that beach access/existence is related to the loss of seagrass meadows, the methodology developed to allocate losses to stormwater has again been employed.

Table M.4 presents the range of beach access/existence that can be attributed to stormwater impacts on seagrasses. This data suggests that it is reasonable to assume stormwater impacts are costing $4.4 million per year. However, there is a question regarding how much of this is reversible for reductions in stormwater inputs into the Gulf.

Table M.4: The range of beach access/existence values that can be attributed to stormwater impacts on seagrasses.

Particulates In stormwater assumed contribution to loss of beach values	Nitrogen in stormwater assumed contribution to loss of beach values	Beach access/existence losses associated with stormwater
0	100	2,700,000
3	97	3,523,500
6	94	4,347,000
9	91	5,170,500
12	88	5,994,000
15	85	6,817,500

M.3.5 Beach restoration

The northward drift of sand along the Adelaide coast was historically at a much lower rate than it is today. The single biggest influence increasing sediment transport rates along the coast has been the large-scale loss of seagrass (Deans *et al* 2003). Once there are gaps in the seagrass meadows, the sand below the meadow edge can be eroded by waves. This is thought to have increased the rate of seagrass loss and made it difficult for plants to recolonise the seafloor, even though water quality has been improved.

The loss of seagrass has affected the coastal processes in a number of ways. As a result of the loss of sand from the seabed, the level of the seabed has steadily become up to one metre deeper and the wave energy reaching our beaches has increased. This causes a larger quantity of sand to drift north along the coast (ACWS 2007). Net alongshore transport rates were estimated (from accumulations at breakwaters and by numerical modelling) to be between 30,000 and 50,000 m^3/yr in the early 1980s. The present-day rates are currently estimated to be approximately 50,000 to 80,000 m^3/yr. On-shore movement of sand released from under former seagrass meadows has been observed. Analysis of the recent build-up of sand has shown that it is considerably finer and higher in calcareous material than the native beach sand on beaches to the south. This finer sand is unsuitable for replenishment in its own right because it tends to remain in the underwater part of the beach and is moved too quickly by waves. Large volumes of this finer sand have come onshore on Adelaide's northern beaches (in Largs Bay) and mixed with the coarser beach sand that has arrived via the littoral system. This mixed sand is also unsuitable for replenishment of beaches further south(Deans *et al*, 2003).

The beach replenishment program commenced in Adelaide in the 1970's in response to Adelaide being subject to increasing levels of storm damage along the coast. This resulted from, and in, reduced dune and beach buffers between development and the sea, particularly and initially in the southern suburbs that were progressively eroded by the ongoing northward drift. The protection of the coastal development replenishment program has continued from that time with Deans *et al* (2003) estimating that five-year average total beach replenishment rates increased from less than 500,000 $m^3$to over 900,000 m^3, in the period 1997/98 to 2001/02. Most of the beach replenishment in the last 15 years has been by dredging and pumping. Since sand-carting commenced in 1973, the Board, in conjunction with local government, has redistributed 2.5 million cubic metres of sand along Adelaide's beaches and brought in 1.4 million cubic metres of new sand, in addition to maintaining about 14 km of seawalls as a 'last-line-of-defence' against storm erosion.

Deans *et al*. (2003) stated that the protection of coastal development via annual beach replenishment over thirty years has, on average, cost Adelaide $1 million /year ($1.25 million in 2012 dollars). Total other coastal protection costs over 30 years have been approximately $1 million for seawalls, around $0.5 million for drift fencing and approximately $1.5 million to repair general foreshore damage (a total of $192,000 per year in 2012 dollars). In addition to these costs, Deans and Townsend (2003) have identified costs associated with the removal of seagrass wrack of $488,000 per year.Thus the protection of costal development via sand replenishment is costing the Adelaide community $1.9 million per year.

How much of this loss can be attributed to stormwater?

Given that the loss of sand is related to the loss of seagrass meadows, the methodology developed to allocate fishery losses to stormwater has again been employed. Table M.5 presents the range of beach restoration costs that can be attributed to stormwater impacts on seagrasses. This data suggests that it is reasonable to assume stormwater impacts are in the order of $173,000 per year. As with the value of beach access/existence, there is a question of whether reductions in stormwater inflows into the Gulf will produce a proportionate reduction in beach restoration costs.

Table M.5:The range of beach restoration losses that can be attributed to stormwater impacts on seagrasses.

Particulates in stormwater assumed contribution to beach restoration costs	Nitrogen in stormwater assumed contribution to beach restoration costs	Sand replenishment losses associated with stormwater
0	100	108,000
3	97	140,940
6	94	173,880
9	91	206,820
12	88	239,760
15	85	272,700

M.3.6 Aesthetic values

No specific studies have been undertaken into the aesthetic value placed on water quality by the Adelaide population, however a study relevant to this work was undertaken in Auckland (NZ) by Batstone *et al* (2010). Auckland has a large number of coastal beaches facing the same stormwater disposal issues as Adelaide. Both cities have a similar population (1.5 million, Auckland and 1.2 million, Adelaide) with a wide coastal zone providing the public with a choice of beaches.

The aim of the Batstone *et al* (2010) study was to determine what value the Auckland public placed on aspects of coastal use impacted by the constituents of stormwater. An unlabelled choice experiment was developed at three broad coastal categories – coastal, middle and upper harbour. Only the results from the coastal regions are relevant for this study, however it is recognised that as the study included all three categories some participants would have chosen to allocate their funds to the two other categories and hence the coastal values may be lower than if the study been limited to coastal regions alone. Respondents had a strong preference for improved environmental quality at outer coastal beach locations over middle and upper harbour locations.

The environmental qualities impacted by stormwater and considered in the Batstone et al. (2010) study are:

- ecological health, determined by showing participants pictures of species diversity, and species numbers;
- water clarity, determined by showing participants photo depictions of coloured water in bottles, and
- underfoot conditions determined by showing participants photo depictions of sea floor conditions.

The payment vehicle was motivated by local governments' capacity in New Zealand to levy additional property rates for environmental management, for example storm water remediation costs, with flow-on effects for both owners and those who rent homes. The levels of the payment vehicle were obtained in preparatory focus groups: $0, $25, $50, $75 and $150.

A sample of respondents was selected to be representative of the adult Auckland population in terms of proportions defined by residential location and census demographics: age, gender, ethnic affiliation. Participants were offered an incentive of $50 to attend data collection meetings. The exact nature of the meeting subject was not disclosed, although participants were informed that the subject was Auckland's coast. Data were collected in three rounds of three meetings, with each meeting attended by 30–40 participants. Data collection took place at five locations and participants could choose to attend any locations.

The results from their work are presented in the first column of Table M.6, and indicate that respondents valued water quality more highly than underfoot conditions or ecological health. When these results are extended to Adelaide beaches (using Adelaide population figures) it can be seen that improvements in water quality gained by improvements in stormwater management would be worth over $100 million per year.

While the study found that age, gender, and coastal use avidity interactions with environmental quality attributes were not statistically significant, income level and residential location (related to income level for two suburbs) did have an effect. Respondents with greater levels of income (over $100,000) were willing to pay more for outer zone (beach) water quality, while residents with lower income levels were willing to pay less. Thus if improvements in stormwater management resulted in improvements in coastal water quality, the value to the whole of the Adelaide metropolitan area would be over $100 million per year. The limitations of transferring results from Auckland to Adelaide need to be borne in mind. For this reason, this value has not been included in the case study in this report.

Table M.6: Annual household willingness to pay for coastal ecological health, water quality and conditions underfoot (adapted from Batstone *et al*, 2010).

Attribute	Auckland household WTP to change quality NZ $/yr	Auckland household WTP to change from medium to high quality (2-1) NZ $/yr	Assumed Adelaide household WTP to change from medium to high quality (2-1) Au $/yr	Total Adelaide population WTP to change from medium to high quality (2-1) Au M $/yr *+
Outer Ecological health Medium	135.64[1]			
Outer Ecological health High	181.45[2]	45.81	45.81	24.99
Outer water quality medium	189.45[1]			
Outer water quality High	274.96[2]	85.51	85.51	46.64
Outer underfoot conditions Medium	116.05[1]			
Outer underfoot conditions High	168.94[2]	52.89	52.89	28.85
Total estimate of benefits		184.21	184.21	100.48

*Assuming 2.2 persons per household and Adelaide population of 1.2 million

+ Assuming similar income levels in Auckland and New Zealand would provide similar willingness to pay results. In 2006, for people aged 15 years and over, the median income in Auckland Region is NZ$26,800 (Statistics NZ, 2006 census), while the same measure for Adelaide was A$23, 200 (ABS 2006 Census QuickStats).

Table M.7:Attributes relevant to recreational value of beaches in Auckland and Adelaide

Relevant Characteristics	Auckland	Adelaide
Population (million)	1.5	1.2
Mean annual income in 2006	NZ$26,800	A$23,200
Mean avg annual temperature ºC	18.9	22.3
Mean Feb max temp ºC	23.7	29.5
Number of months > 20 ºC mean	5	7
Sunshine hours	2007	2370
Mean annual rainfall (mm)	1240	570

Appendix N: Equations for the Hydraulic Design of Pipes and Pumps

The pipes and pumps used in this study were designed using the following equations.

Power Provided to a Pump

$$P = \frac{\rho g Q H}{\eta} \qquad \text{(N1)}$$

Where, P = Pump power (watts)
ρ = Fluid density (kg/m^3)
g = Acceleration due to gravity (m/s^2)
Q = Pump discharge (m^3/s)
H = Head provided by the pump (m)
η = Pump efficiency

Head Provided by a Pump (Darcy Weisbach Equation for head loss in a pipe)

$$H = \frac{flv^2}{d(2g)} + H_s \qquad \text{(N2)}$$

Where f = Friction factor
l = Length of pipe (m)
v = Velocity of flow in pipe (m/s)
d = Diameter of pipe (m)
H_s = Static head (m)

Swamee-Jain Equation

$$f = \frac{0.25}{\left[\log_{10}\left(\frac{\varepsilon}{3.7d} + \frac{5.74}{(Re)^{0.9}}\right)\right]^2} \qquad \text{(N3)}$$

Where ε = Roughness height (m)
Re = Reynold's number of the flow $\left(Re = \frac{dv}{\nu}\right)$
ν = Kinematic viscosity of the fluid (m^2/s)

Constants used in this Study

ρ = 1000 kg/m^3
g = 9.81 m^3/s
η = 0.80
ε = 0.0025 m
ν = 1.14x10^{-6} m^2/s

Appendix O: Cost Estimates

O.1 Pipes

Pipe costs are estimated according to the following table (Table O.1):

Table O.1: PVC pipe costs as a function of diameter.

Diameter (mm)	**Cost ($/m)**
250	283
300	333
375	408
450	656
500	792

These are based on figures provided by Alana Duncker (Optimatics Pty Ltd, pers. comm., February 23, 2012)

O.2 Pumps

The following formula was developed from indicative data for the capital cost of pumping stations:

$$\text{Cost (\$m)} = \frac{47.37 * \text{Power}^{0.6299}}{10^3} \tag{O1}$$

where, Power = pump power in kW. However, based on comments by Josh Cantone (Wallbridge&Gilbert, pers. comm., April 22, 2013) that these costs were rather high, Equation N1 was modified to the following equation:

$$\text{Cost (\$m)} = \frac{31.58 * \text{Power}^{0.6299}}{10^3} \tag{O2}$$

Annual maintenance costs have been computed as a fixed percentage (5%) of the capital costs. Operational costs have been computed by multiplying the energy consumed by the pump (assuming 80% efficiency) by the energy price.

Pump replacement costs for new pumping station facilities have been computed using the following formula from McGivney and Kawamura (2008),

$$\text{Cost (\$)} = 3214.7 * \text{Q} + 60716 \tag{O3}$$

where Q = peak flow (ML/day)

O.3 Clearwell water storage

Capital costs for water storage tanks are estimated using data from McGivney and Kawamura (2008), where cost and volume of the tank can be related according to the following formula:

$$\text{Cost (\$)} = 199620 * \text{V} + 268901 \quad \text{(O4)}$$

where V = tank volume (ML).

Maintenance costs are assumed to be equal to 5% of the capital cost of the clearwell water tank.

O.4 Chlorination plant

Josh Cantone (Wallbridge&Gilbert, pers. comm., April 22, 2013) suggested that an indicative capital cost for a chlorination plant able to treat about 4.8 ML/day would be around $200,000. This cost has been therefore included in Options 5, 6, 9 and 12. For the Options where a larger size of chlorination plant is needed, capital costs have been assumed to be proportional to the capacity of the plant.

Operational costs have been computed considering the chlorine costs and labour costs (assumed to be equal to the chlorine costs). Note that it is assumed that energy costs can be neglected as the energy requirements of chlorination plants are small.

The cost of disinfectant is estimated using the following equation by Friedler and Hadari, (2006):

$$\text{C}_{\text{dis}} = \frac{8760\ \text{(Chlorine dose).Q.Unit cost}}{\text{X}.\rho} \quad \text{(O5)}$$

where C_{dis} is the annual cost of chlorine solution (A$/year); Chlorine dose is expressed in kg/m^3,Q is the flow (m^3/h); X the fraction of chlorine in the chlorine solution ($kg_{chlorine}/kgs_{olution}$) (the solution contains 11% chlorine, thus X = 0.11); ρ is the chlorine solution density (kg/L) (approximately 1kg/L) with the unit cost being A$0.17/L.

O.5 Microfiltration, UV, disinfection, pH adjustment and fluoridation plant

The capital cost for a treatment plant that includes microfiltration, UV, chlorination, pH adjustment and fluoridation has been estimated by Josh Cantone (Wallbridge & Gilbert, pers. comm., April 22, 2013 and November 8, 2013) to be in the order of $6m for a plant able to deliver 4.8 ML/day. This value has been used in the economic analysis. The annual operating and maintenance cost is expected to be $325,000 per year or a present value of $4.16m. Energy requirements of UV disinfection are assumed to be 0.2 kWh/kL. This value agrees with data from Newman (2012) and Josh Cantone (Wallbridge & Gilbert, pers. comm., April 22, 2013).

Newman, (2012) developed some relationships that estimate the capital costs and embodied energy and the operating costs and energy expenditure of UV and chlorination treatment plant. His relationships are developed based on the peak daily capacity of the plant and the overall pathogen log-reduction that the plant achieves. He calibrated the relationships based on manufacturers' data specified in Holt and James (2006) and some treatment information from NRMMC (2006). His relationships are given in Figure O.1.

Energy requirements for microfiltration are also assumed to be 0.2 kWh/kL as reported by the Dutch Foundation for Applied Water Research (STOWA, 2006). http://www.stowa-selectedtechnologies.nl/Sheets/Sheets/Microfiltration.html

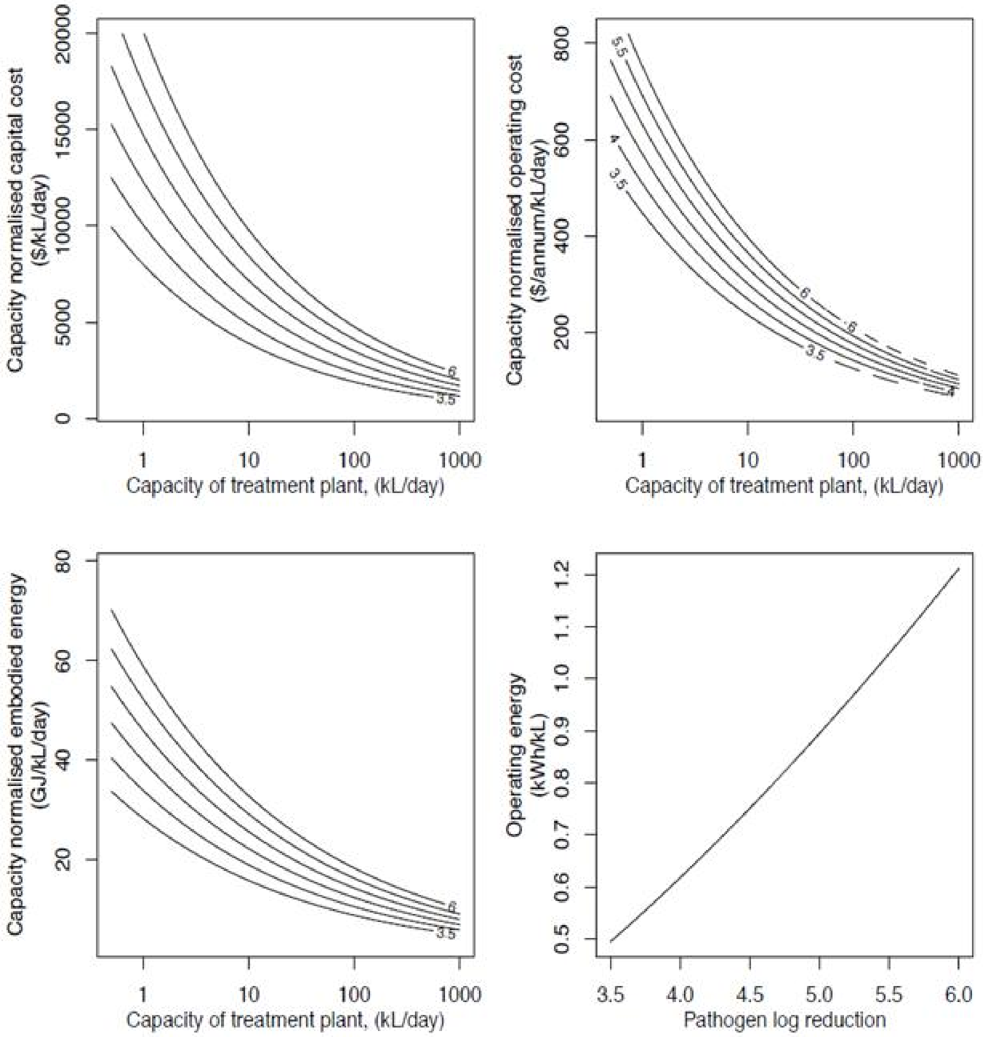


Figure O.1: Cost and Energy Curves for UV and Chlorine Disinfection (Newman, 2012)

Appendix P: Pump Characteristics

To compute the pump power, the following values have been assumed: water density = 997.5 kg/m^3, acceleration of gravity g=9.81 m/s^2, pump efficiency = 80%.

P.1 Option 1: Open space irrigation

P.1.1 PS1: Pumping from instream basin to holding basin.

This is an existing pumping station. Note that the values indicated by * are from Marks et al. (2005).

Characteristic	Value	Units
Pump head	18.2	m
Pump flow	50*	ML/day
Power	155*	kW
Hours of operation per year	160	hours
Total energy consumed	24.7	MWh/year

P.1.2 PS4: Pumping station from wetland to distribution.

This is an existing pumping station that is currently used to pump from the tanks after the aquifer to the distribution system. The pumping station is able to deliver 10 ML/day at 600 kPa (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013). It is assumed that the pumps of this pumping station can be used to pump from the wetland to the distribution system for this option.

As the pumps have the capacity to move 10 ML/day, the pumps need to operate 740 hour in a year to deliver 370 ML/year.

Characteristic	**Value**	**Units**
Pump head	61.2	m
Pump flow	10	ML/day
Power	104	kW
Hours of operation per year	740	hours
Total energy consumed	76.9	MWh/year

P.2 Option 2: Open space irrigation with ASR

P.2.1 PS1: Pumping from instream basin to holding basin.

This is an existing pumping station.

Characteristic	**Value**	**Units**
Pump head	18.2	m
Pump flow	50*	ML/day
Power	155*	kW
Hours of operation per year	528	hours
Total energy consumed	81.6	MWh/year

* Marks et al. (2005)

P.2.2 PS2: Injection into aquifer.

This is an existing pumping station able to deliver 8 ML/day (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013). To pump about 1.1 GL/year, the pumps have to operate 2738 hours per year.

Characteristic	**Value**	**Units**
Pump head	30	m
Pump flow	8	ML/day
Power	41	kW
Hours of operation per year	2738**	hours
Total energy consumed	111.6	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.2.3 PS3: Extraction from aquifer.

This is an existing pumping station able to pump 6 ML/day (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013). However, on average, only 4.8 ML/day can be extracted, as the aquifer recovery efficiency is 80%. The total flow extracted from the aquifer is 0.876 GL/year (=4.8 ML/day * 365/2). The pump head is estimated to be about 60 m as Bruce Naumann (City of Salisbury, Pers. Comm. May 19, 2013) reported that the average pump head for extraction is slightly lower than the pump head of the pumping station PS4.

Characteristic	**Value**	**Units**
Pump head	60	m
Pump flow	6	ML/day
Power	61	kW
Hours of operation per year	2920**	hours
Total energy consumed	178.6	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.2.4 PS4: Pumping station from the tanks after the aquifer to the distribution system.

This is an existing pumping station able to deliver 10 ML/day at 600 kPa (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013).

Characteristic	**Value**	**Units**
Pump head	61.2	m
Pump flow	10	ML/day
Power	104	kW
Hours of operation per year	1752**	hours
Total energy consumed	182.2	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.3 Option 3: Open space irrigation with ASR and chlorination

P.3.1 PS1: Pumping from instream basin to holding basin.

This is an existing pumping station.

Characteristic	Value	Units
Pump head	18.2	m
Pump flow	50*	ML/day
Power	155*	kW
Hours of operation per year	528	hours
Total energy consumed	81.6	MWh/year

* Marks et al. (2005)

P.3.2 PS2: Injection into aquifer.

This is an existing pumping station able to deliver 8 ML/day (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013). To pump about 1.1 GL/year, the pumps have to operate 2738 hours per year.

Characteristic	Value	Units
Pump head	30	m
Pump flow	8	ML/day
Power	41	kW
Hours of operation per year	2738**	hours
Total energy consumed	111.6	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.3.3 PS3: Extraction from aquifer.

This is an existing pumping station able to pump 6 ML/day (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013). However, on average, only 4.8 ML/day can be extracted, as the aquifer recovery efficiency is 80%. The total flow extracted from the aquifer is 0.876 GL/year (=4.8 ML/day * 365/2). The pump head is estimated to be about 60 m as Bruce Naumann (City of Salisbury, Pers. Comm. May 19, 2013) reported that the average pump head for extraction is slightly lower than the pump head of the pumping station PS4.

Characteristic	Value	Units
Pump head	60	m
Pump flow	6	ML/day
Power	61	kW
Hours of operation per year	2920**	hours
Total energy consumed	178.6	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.3.4 PS4: Pumping station from the tanks after the aquifer to the distribution system.

This is an existing pumping station able to deliver 10 ML/day at 600 kPa (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013).

Characteristic	Value	Units
Pump head	61.2	m
Pump flow	10	ML/day
Power	104	kW
Hours of operation per year	1752**	hours
Total energy consumed	182.2	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.4 Option 4: Open space irrigation with ASR and blending with recycled wastewater

P.4.1 PS1: Pumping from instream basin to holding basin.

This is an existing pumping station.

Characteristic	Value	Units
Pump head	18.2	m
Pump flow	50*	ML/day
Power	155*	kW
Hours of operation per year	528	hours
Total energy consumed	81.6	MWh/year

*Marks et al. (2005)

P.4.2 PS2: Injection into aquifer.

This is an existing pumping station able to deliver 8 ML/day (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013)

Characteristic	Value	Units
Pump head	30	m
Pump flow	8	ML/day
Power	41	kW
Hours of operation per year	2738*	hours
Total energy consumed	111.6	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.4.3 PS3: Extraction from aquifer.

This is an existing pumping station. The pumping station is able to provide 6 ML/day (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013).

Characteristic	Value	Units
Pump head	60	m
Pump flow	6	ML/day
Power	61	kW
Hours of operation per year	2920**	hours
Total energy consumed	178.6	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.4.4 PS4: Pumping station from the tanks after the aquifer to Greenfield.

This is an existing pumping station able to deliver 10 ML/day at 600 kPa (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013)

Characteristic	**Value**	**Units**
Pump head	61.2	m
Pump flow	10	ML/day
Power	104	kW
Hours of operation per year	1752**	hours
Total energy consumed	182.2	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.4.5 Pumping from Bolivar to Greenfield.

This is an existing pumping station able to deliver a maximum of 95 L/s (XJ Wang, SA Water, Pers. Comm., March 28, 2013), equivalent to 6.8 ML/day if only 20 hours/day of pumping are considered. Note that, because of the salinity requirements, only 6.6 ML/day of recycled wastewater can be mixed with the recovered stormwater.

Characteristic	**Value**	**Units**
Pump head	72.9	m
Pump flow	6.6	ML/day
Power	82 (max Power=90)***	kW
Hours of operation per year	3650*	hours
Total energy consumed	299.6	MWh/year

*** the maximum power corresponds to a flow equal to 95 L/s and a pressure head equal to 77.7 m.

P.4.6 PS5: Pumping from Greenfield to distribution in Mawson Lakes.

There is an existing pumping station at Greenfield that distributes the mixed water (recycled wastewater + recovered stormwater) to Mawson Lakes. The existing pumping station can deliver 4 ML/day (XJ Wang, SA Water, March 28, 2013).

Existing pumping station:

Characteristic	**Value**	**Units**
Pump head	100	m
Pump flow	4	ML/day
Power	68	kW
Hours of operation per year	3650*	hours
Total energy consumed	248.0	MWh/year

To deliver a peak flow of 11.4 ML/day (recycled wastewater + recovered stormwater) it is necessary to upgrade the existing pumping station, so that it is able to provide the additional flow. The pumping head has been assumed equal to 100 m as in the previous table.

New pumping station (to be added to the existing one):

Characteristic	Value	Units
Pump head	100	m
Pump flow	7.4	ML/day
Power	126	kW
Hours of operation per year	3650*	hours
Total energy consumed	460.6	MWh/year

P.5 Option 5: 3rd pipe: wetland and treatment

P.5.1 PS1: Pumping from instream basin to holding basin.

This is an existing pumping station.

Characteristic	Value	Units
Pump head	18.2	m
Pump flow	50*	ML/day
Power	155*	kW
Hours of operation per year	160	hours
Total energy consumed	24.7	MWh/year

* Marks et al. (2005)

P.5.2 PS4: Pumping station from the wetland to treatment.

Currently there is an existing pumping station able to deliver 10 ML/day at 600 kPa (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013). This pumping station is used to pump the water extracted from the aquifer to the distribution system. However, it is assumed that the pumps could be moved to pump the water directly from the instream to the water distribution system.

Characteristic	Value	Units
Pump head	61.2	m
Pump flow	10	ML/day
Power	104	kW
Hours of operation per year	740	hours
Total energy consumed	76.9	MWh/year

P.5.3 PS5: Pumping station from treatment to the distribution system.

It is supposed that the treatment is located in Greenfield and that the actual pumping station that pumps the water from Greenfield to Mawson Lakes can be used. The existing pumping station can deliver 4 ML/day (XJ Wang, SA Water, March 28, 2013).

Existing pumping station:

Characteristic	Value	Units
Pump head	100	m
Pump flow	4	ML/day
Power	68	kW
Hours of operation per year	1233	hours
Total energy consumed	83.8	MWh/year

To deliver a peak flow of 6 ML/day, it is necessary to upgrade the existing pumping station. The pumping head has been assumed equal to 100 m as in the previous table.

New pumping station (to be added to the existing one):

Characteristic	Value	Units
Pump head	100	m
Pump flow	2	ML/day
Power	34	kW
Hours of operation per year	1233	hours
Total energy consumed	41.9	MWh/year

P.6 Option 6: 3rd pipe: wetland, aquifer and treatment

P.6.1 PS1: Pumping from instream basin to holding basin.

This is an existing pumping station.

Characteristic	Value	Units
Pump head	18.2	m
Pump flow	50*	ML/day
Power	155*	kW
Hours of operation per year	528	hours
Total energy consumed	81.6	MWh/year

* Marks et al. (2005)

P.6.2 PS2: Injection into aquifer.

This is an existing pumping station able to deliver 8 ML/day (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013)

Characteristic	Value	Units
Pump head	30	m
Pump flow	8	ML/day
Power	41	kW
Hours of operation per year	2738*	hours
Total energy consumed	111.6	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.6.3 PS3: Extraction from aquifer.

This is an existing pumping station. The pumping station is able to provide 6 ML/day (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013).

Characteristic	Value	Units
Pump head	60	m
Pump flow	6	ML/day
Power	61	kW
Hours of operation per year	2920**	hours
Total energy consumed	178.6	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.6.4 PS4: Pumping station from the tanks after the aquifer to Greenfield.

This is an existing pumping station able to deliver 10 ML/day at 600 kPa (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013)

Characteristic	Value	Units
Pump head	61.2	m
Pump flow	10	ML/day
Power	104	kW
Hours of operation per year	1752**	hours
Total energy consumed	182.2	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.6.5 PS5: Pumping station from treatment in Greenfield to the distribution system.

It is assumed that the treatment is located in Greenfield and that the actual pumping station that pumps the water from Greenfield to Mawson Lakes can be used. The existing pumping station can deliver 4 ML/day (XJ Wang, SA Water, March 28, 2013).

Existing pumping station:

Characteristic	Value	Units
Pump head	100	m
Pump flow	4	ML/day
Power	68	kW
Hours of operation per year	3650**	hours
Total energy consumed	248.0	MWh/year

**pumps are assumed to be operating half of the year for 20 hours in a day.

To deliver a peak flow of 4.8 ML/day, it is necessary to upgrade the existing pumping station. The pumping head has been assumed equal to 100 m as in the previous table.

New pumping station (to be added to the existing one):

Characteristic	Value	Units
Pump head	100	m
Pump flow	0.8	ML/day
Power	14	kW
Hours of operation per year	3650**	hours
Total energy consumed	49.6	MWh/year

**pumps are assumed to be operating half of the year for 20 hours in a day.

P.7 Option 7: 3rd pipe: no aquifer and blending with recycled water

P.7.1 PS1: Pumping from instream basin to holding basin.

This is an existing pumping station.

Characteristic	Value	Units
Pump head	18.2	m
Pump flow	50*	ML/day
Power	155*	kW
Hours of operation per year	160	hours
Total energy consumed	24.7	MWh/year

* Marks et al. (2005)

P.7.2 PS4: Pumping station from the wetland to Greenfield.

Currently there is an existing pumping station able to deliver 10 ML/day at 600 kPa (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013). This pumping station is used to pump the water extracted from the aquifer to the distribution system. However, it is assumed that the pumps could be moved to pump the water directly from the wetland to the water distribution system.

Characteristic	Value	Units
Pump head	61.2	m
Pump flow	10	ML/day
Power	104	kW
Hours of operation per year	740	hours
Total energy consumed	76.9	MWh/year

P.7.3 Pumping from Bolivar to Greenfield.

This is an existing pumping station able to deliver a maximum of 95 L/s (XJ Wang, SA Water, Pers. Comm., March 28, 2013), equivalent to 6.8 ML/day if only 20 hours/day of pumping are considered. The salinity requirements allow 1.73 ML/day of recycled wastewater to be mixed with stormwater on average. Therefore it is possible to deliver the required recycled stormwater also considering a peaking factor equal to 2 without updating the plant.

Characteristic	Value	Units
Pump head	77.7	m
Pump flow	6.8	ML/day
Power	90	kW
Hours of operation per year	1842	hours
Total energy consumed	166.2	MWh/year

P.7.4 PS5: Pumping from Greenfield to distribution in Mawson Lakes.

There is an existing pumping station at Greenfield that distributes the mixed water (recycled wastewater + recovered stormwater) to Mawson Lakes. The existing pumping station can deliver 4 ML/day (XJ Wang, SA Water, March 28, 2013).

Existing pumping station:

Characteristic	Value	Units
Pump head	100	m
Pump flow	4	ML/day
Power	68	kW
Hours of operation per year	3650	hours
Total energy consumed	248	MWh/year

To deliver a peak flow of 5.48 ML/day (recycled wastewater + recovered stormwater) it is necessary to upgrade the existing pumping station, so that it is able to provide the additional flow. The pumping head has been assumed equal to 100 m as in the previous table.

New pumping station (to be added to the existing one):

Characteristic	Value	Units
Pump head	100	m
Pump flow	1.5	ML/day
Power	25	kW
Hours of operation per year	3650	hours
Total energy consumed	91.7	MWh/year

P.8 Option 8: 3rd pipe: via aquifer and blending with recycled water

P.8.1 PS1: Pumping from instream basin to holding basin.

This is an existing pumping station.

Characteristic	Value	Units
Pump head	18.2	m
Pump flow	50*	ML/day
Power	155*	kW
Hours of operation per year	528	hours
Total energy consumed	81.6	MWh/year

* Marks et al. (2005)

P.8.2 PS2: Injection into aquifer.

This is an existing pumping station able to deliver 8 ML/day (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013)

Characteristic	Value	Units
Pump head	30	m
Pump flow	8	ML/day
Power	41	kW
Hours of operation per year	2738*	hours
Total energy consumed	111.6	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.8.3 PS3: Extraction from aquifer.

This is an existing pumping station. The pumping station is able to provide 6 ML/day (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013).

Characteristic	Value	Units
Pump head	60	m
Pump flow	6	ML/day
Power	61	kW
Hours of operation per year	2920**	hours
Total energy consumed	178.6	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.8.4 PS4: Pumping station from the wetland to Greenfield.

Currently there is an existing pumping station able to deliver 10 ML/day at 600 kPa (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013).

Characteristic	**Value**	**Units**
Pump head	61.2	m
Pump flow	10	ML/day
Power	104	kW
Hours of operation per year	1752**	hours
Total energy consumed	182.2	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.8.5 Pumping from Bolivar to Greenfield.

This is an existing pumping station able to deliver a maximum of 95 L/s (XJ Wang, SA Water, Pers. Comm., March 28, 2013), equivalent to 6.8 ML/day if only 20 hours/day of pumping are considered. The salinity requirements allow only a peak flow of 6.6 ML/day of recycled wastewater to be mixed with stormwater.

Characteristic	**Value**	**Units**
Pump head	72.9	m
Pump flow	6.6	ML/day
Power	82 (max power = 90)***	kW
Hours of operation per year	3650**	hours
Total energy consumed	299.6	MWh/year

**pumps are assumed to operate a maximum of 20 hours in a day.

*** the maximum power is based on a pump flow equal to 95 L/s and a pump head equal to 77.7 m.

P.8.6 PS5: Pumping from Greenfield to distribution in Mawson Lakes.

There is an existing pumping station at Greenfield that distributes the mixed water (recycled wastewater + recovered stormwater) to Mawson Lakes. The existing pumping station can deliver 4 ML/day (XJ Wang, SA Water, March 28, 2013).

Existing pumping station:

Characteristic	**Value**	**Units**
Pump head	100	m
Pump flow	4	ML/day
Power	68	kW
Hours of operation per year	3650**	hours
Total energy consumed	248.0	MWh/year

**pumps are assumed to operate a maximum of 20 hours in a day.

To deliver a peak flow of 11.4 ML/day (recycled wastewater + recovered stormwater) it is necessary to upgrade the existing pumping station, so that it is able to provide the additional flow. The pumping head has been assumed equal to 100 m as in the previous table.

New pumping station (to be added to the existing one):

Characteristic	**Value**	**Units**
Pump head	100	m
Pump flow	7.4	ML/day

Power	126	kW
Hours of operation per year	3650**	hours
Total energy consumed	460.6	MWh/year

**pumps are assumed to be operating half of the year for 20 hours in a day.

P.9 Option 9: treat to Drinking standards and Inject Directly into the Potable Water Supply Mains

P.9.1 PS1: Pumping from instream basin to holding basin.

This is an existing pumping station.

Characteristic	Value	Units
Pump head	18.2	m
Pump flow	50*	ML/day
Power	155*	kW
Hours of operation per year	528	hours
Total energy consumed	81.6	MWh/year

* Marks et al. (2005)

P.9.2 PS2: Injection into aquifer.

This is an existing pumping station able to deliver 8 ML/day (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013)

Characteristic	Value	Units
Pump head	30	m
Pump flow	8	ML/day
Power	41	kW
Hours of operation per year	2738*	hours
Total energy consumed	111.6	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.9.3 PS3: Extraction from aquifer.

This is an existing pumping station. The pumping station is able to provide 6 ML/day (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013).

Characteristic	Value	Units
Pump head	60	m
Pump flow	6	ML/day
Power	61	kW
Hours of operation per year	2920**	hours
Total energy consumed	178.6	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.9.4 PS4: Pumping station from the tanks after the aquifer to the treatment.

Currently there is an existing pumping station able to deliver 10 ML/day at 600 kPa (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013).

Characteristic	Value	Units
Pump head	61.2	m
Pump flow	10	ML/day
Power	104	kW
Hours of operation per year	1752**	hours
Total energy consumed	182.2	MWh/year

**pumps are assumed to be for a maximum of 20 hours in a day.

P.9.5 PS5: Pumping from the treatment to the water supply mains.

Is it assumed that a new pumping station has to be built so as to inject 4.8 ML/day into the water supply mains. It is assumed that the pumps have to be able to provide a pressure head equal to 100 m.

Characteristic	Value	Units
Pump head	100	m
Pump flow	4.8	ML/day
Power	82	kW
Hours of operation per year	3650**	hours
Total energy consumed	297.6	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.10 Option 10: via Little Para Reservoir

P.10.1 PS1: Pumping from instream basin to holding basin.

This is an existing pumping station.

Characteristic	Value	Units
Pump head	18.2	m
Pump flow	50*	ML/day
Power	155*	kW
Hours of operation per year	528	hours
Total energy consumed	81.6	MWh/year

* Marks et al. (2005)

P.10.2 PS5: Pumping from the treatment to the Little Para Reservoir.

Is it assumed that a new pumping station has to be built so as to pump 4.8 ML/day to the Little Para Reservoir. Pumps have to be able to provide a pressure head equal to 165 m.

Characteristic	Value	Units
Pump head	184	m
Pump flow	6	ML/day
Power	188	kW
Hours of operation per year	3650**	hours
Total energy consumed	685.5	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.11 Option 11: via Little Para Reservoir after aquifer storage

P.11.1 PS1: Pumping from instream basin to holding basin.

This is an existing pumping station.

Characteristic	Value	Units
Pump head	18.2	m
Pump flow	50*	ML/day
Power	155*	kW
Hours of operation per year	528	hours
Total energy consumed	81.6	MWh/year

* Marks et al. (2005)

P.11.2 PS2: Injection into aquifer.

This is an existing pumping station able to deliver 8 ML/day (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013)

Characteristic	Value	Units
Pump head	30	m
Pump flow	8	ML/day
Power	41	kW
Hours of operation per year	2738*	hours
Total energy consumed	111.6	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.11.3 PS3: Extraction from aquifer.

This is an existing pumping station. The pumping station is able to provide 6 ML/day (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013).

Characteristic	Value	Units
Pump head	60	m
Pump flow	6	ML/day
Power	61	kW
Hours of operation per year	2920**	hours
Total energy consumed	178.6	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.11.4 PS5: Pumping from the treatment to the Little Para Reservoir.

Is it assumed that a new pumping station has to be built so as to pump 4.8 ML/day to the Little Para Reservoir. Pumps have to be able to provide a pressure head equal to 165 m.

Characteristic	Value	Units
Pump head	165	m
Pump flow	4.8	ML/day
Power	135	kW
Hours of operation per year	3650**	hours
Total energy consumed	491.2	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.12 Option 12: via Little Para Reservoir after aquifer storage and supplementary treatment

P.12.1 PS1: Pumping from instream basin to holding basin.

This is an existing pumping station.

Characteristic	Value	Units
Pump head	18.2	m
Pump flow	50*	ML/day
Power	155*	kW
Hours of operation per year	528	hours
Total energy consumed	81.6	MWh/year

* Marks et al. (2005)

P.12.2 PS2: Injection into aquifer.

This is an existing pumping station able to deliver 8 ML/day (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013)

Characteristic	Value	Units
Pump head	30	m
Pump flow	8	ML/day
Power	41	kW
Hours of operation per year	2738*	hours
Total energy consumed	111.6	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.12.3 PS3: Extraction from aquifer.

This is an existing pumping station. The pumping station is able to provide 6 ML/day (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013).

Characteristic	Value	Units
Pump head	60	m
Pump flow	6	ML/day
Power	61	kW
Hours of operation per year	2920**	hours
Total energy consumed	178.6	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.12.4 PS4: Pumping station from the tanks after the aquifer to the treatment.

Currently there is an existing pumping station able to deliver 10 ML/day at 600 kPa (Bruce Naumann, Salisbury Water, pers. comm., April 17, 2013).

Characteristic	Value	Units
Pump head	61.2	m
Pump flow	10	ML/day
Power	104	kW
Hours of operation per year	1752**	hours
Total energy consumed	182.2	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

P.12.5 PS5: Pumping from the treatment to the Little Para Reservoir.

Is it assumed that a new pumping station has to be built so as to pump 4.8 ML/day to the Little Para Reservoir. Pumps have to be able to provide a pressure head equal to 165 m.

Characteristic	**Value**	**Units**
Pump head	165	m
Pump flow	4.8	ML/day
Power	135	kW
Hours of operation per year	3650**	hours
Total energy consumed	491.2	MWh/year

**pumps are assumed to operate for a maximum of 20 hours in a day.

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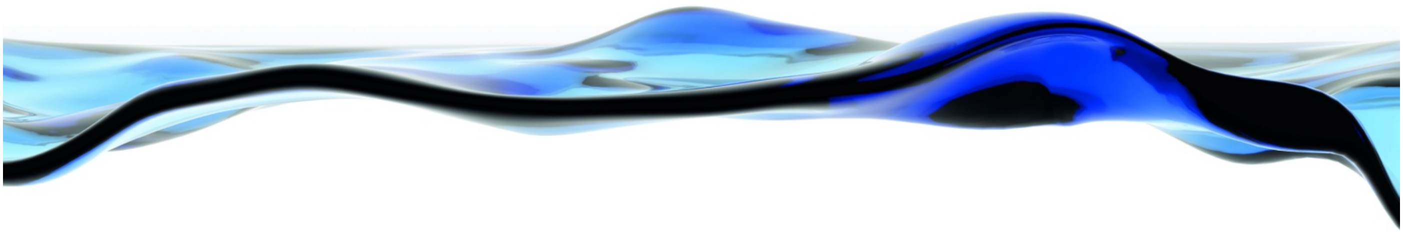

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