

Review of Stormwater Harvesting Practices

Michelle Philp¹, Joseph McMahon¹, Sonja Heyenga¹,
Oswald Marinoni¹, Graham Jenkins¹, Shiroma Maheepala¹,
Margaret Greenway²

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The Urban Water Security Research Alliance (UWSRA) is a \$50 million partnership over five years between the Queensland Government, CSIRO's Water for a Healthy Country Flagship, Griffith University and The University of Queensland. The Alliance has been formed to address South-East Queensland's emerging urban water issues with a focus on water security and recycling. The program will bring new research capacity to South-East Queensland tailored to tackling existing and anticipated future issues to inform the implementation of the Water Strategy.

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The University of Queensland - visit <http://www.uq.edu.au/>
Griffith University - visit <http://www.griffith.edu.au/>

Enquiries should be addressed to:

The Urban Water Security Research Alliance
PO Box 15087
CITY EAST QLD 4002

Ph: 07-3247 3005; Fax: 07-3405 3556
Email: Sharon.Wakem@qwc.qld.gov.au

Authors : 1 – CSIRO ; 2 - Griffith University

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FOREWORD

Water is fundamental to our quality of life, to economic growth and to the environment. With its booming economy and growing population, Australia's South-East Queensland (SEQ) region faces increasing pressure on its water resources. These pressures are compounded by the impact of climate variability and accelerating climate change.

The Urban Water Security Research Alliance, through targeted, multidisciplinary research initiatives, has been formed to address the region's emerging urban water issues.

As the largest regionally focused urban water research program in Australia, the Alliance is focused on water security and recycling, but will align research where appropriate with other water research programs such as those of other SEQ water agencies, CSIRO's Water for a Healthy Country National Research Flagship, Water Quality Research Australia, e-Water CRC and the Water Services Association of Australia (WSAA).

The Alliance is a partnership between the Queensland Government, CSIRO's Water for a Healthy Country National Research Flagship, The University of Queensland and Griffith University. It brings new research capacity to SEQ, tailored to tackling existing and anticipated future risks, assumptions and uncertainties facing water supply strategy. It is a \$50 million partnership over five years.

Alliance research is examining fundamental issues necessary to deliver the region's water needs, including:

- ensuring the reliability and safety of recycled water systems.
- advising on infrastructure and technology for the recycling of wastewater and stormwater.
- building scientific knowledge into the management of health and safety risks in the water supply system.
- increasing community confidence in the future of water supply.

This report is part of a series summarising the output from the Urban Water Security Research Alliance. All reports and additional information about the Alliance can be found at <http://www.urbanwateralliance.org.au/about.html>.



Chris Davis

Chair, Urban Water Security Research Alliance

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1. INTRODUCTION

Issues relating to water supply have come to the forefront of the political agenda in Australia due to the recent severe drought and the continent's natural climatic regime, which categorises it as the driest inhabited continent (Bureau of Meteorology 2008). It has become evident that demand for water resources in many urban centres is approaching supply capacity and, in some instances, exceeding sustainable limits (Hatt *et al.* 2004; Mitchell *et al.* 2003). The traditional approach to urban water systems has seen the use of a parallel series of systems for potable water, sewerage and stormwater drainage. The unsustainable nature of this traditional approach is highlighted by the environmental issues apparent in the urban environment including degraded and highly modified riparian ecosystems due to severe changes in the hydrology of catchments and quality of runoff. Urbanisation also causes changes to catchment behaviour due to an increase in the impervious area and the reduction in catchment storages as waterways become channelled and piped.

Increasing runoff and pollutant loads and pressure on existing systems due to the spread of urbanisation, especially in areas such as South East Queensland, also results in a significant economic cost required to augment the existing systems. Alternative approaches are required to develop a sustainable approach to water systems in the urban environment. Achieving sustainable urban water systems and protecting the quality and quantity of freshwater resources are identified as key components of ecologically sustainable development as defined by the United Nations Agenda 21 (United Nations 1992).

Integrated Urban Water Management (IUWM) is one such approach which views water supply, drainage and sanitation as components of an integrated physical system situated within an organisational and natural landscape (Mitchell 2006; Mitchell *et al.* 2007b). This integrated system seeks to minimise system inputs and outputs in order to decrease the inefficiencies in water resource use that are associated with traditional practices of urbanisation (Hardy *et al.* 2005). Although integration and diversification of urban water systems increases complexity, it reveals more opportunities to attain sustainable urban systems and, analogous to natural systems, increases system resilience (Mitchell and Diaper 2005; Mitchell *et al.* 2007b).

The capture and use of urban stormwater can form a key component of IUWM. Stormwater is defined as the runoff from pervious and impervious surfaces in predominantly urban environments. Impervious surfaces include roofs, driveways, pavements, footpaths, and roads. Stormwater runoff from Australian capital cities has been found to be comparable to the amount of potable water consumed (Dowsett *et al.* 1995; Environment Australia 2002). The harnessing of this resource has the benefits of:

- Providing an alternative water supply;
- Preventing the need to prioritise the supply to various end uses;
- Improving the water quality of runoff entering receiving waters;
- Returning the catchment hydrology to a situation more similar to pre-development hydrology;
- Reducing pressure on existing water supply systems; and
- Creating multi-functional waterways which commonly results in higher property values.

There is considerable scope for a proportion of urban water currently consumed to be replaced by lower quality water, as it has been estimated that between 50-80% of water used in urban areas does not require potable quality (DEC 2006; Dowsett *et al.* 1995; Mitchell *et al.* 2002). In 1995 it was estimated that the cost to treat this water to potable standard ranged from \$100 to \$150 million per year (Dowsett *et al.* 1995). However, utilising stormwater has inherent difficulties due to spatial and temporal variability and interaction of collection surface; atmospheric conditions; population density; land use; percentage impervious area; waste disposal and sanitation practices; soil type; climate and amount of

construction activity (Mitchell *et al.* 2002). All of these factors influence the physical, chemical and biological characteristics of stormwater quality (Mitchell *et al.* 2002).

There has been substantial research into collection and use of runoff from roofs, however knowledge on use of general runoff has until relatively recently been limited (Hatt *et al.* 2004). Stormwater use schemes however have greater potential and flexibility to meet ecological objectives due to several reasons (Mitchell *et al.* 2005b). First, rainwater harvesting leaves runoff from impervious surfaces other than roofs untreated, while a stormwater harvesting system can be designed to treat runoff from all impervious surfaces and therefore increases the potential yield and supply reliability. Secondly operation of rainwater tanks involves decentralised management reliant on individual tank owners operating them in appropriate ways to meet local flow targets. Stormwater use schemes are generally managed by a centralised authority. Thirdly a stormwater use system can be designed to meet water quantity and quality targets necessary for ecological health by adjusting the size of detention storages and outlets.

Currently stormwater use is limited in Australia, occurring mainly as rainwater harvesting or stormwater harvesting for groundwater recharge (Hatt *et al.* 2004). Although stormwater harvesting and installation of rainwater tanks can have roughly similar benefits in terms of reduction in pollutant loads, downstream stormwater flows and demand for mains water, there are distinct difference in terms of costs, stakeholders, maintenance and health risks (DEC 2006). A comparison between stormwater harvesting and rainwater tanks is shown in Table 1.1. This review does not consider rainwater harvesting from individual households, and focuses on centrally managed schemes of general stormwater runoff (defined by DEC (2006) as runoff that has entered drains or creeks).

CSIRO (2005) has shown that 8% of rainwater is harvested for use while 14% of wastewater is used. Thomas *et al.* (1997) suggest that this trend is due to the lack of stormwater treatment infrastructure compared to wastewater treatment systems. However, with the increasing adoption of Water Sensitive Urban Design (WSUD) across Australian cities, stormwater treatment infrastructure is becoming commonplace (Hatt *et al.* 2004). The increased stormwater quality resulting from WSUD, and the fact that many such features don't differ substantially when designed for treatment or use, increases the viability of stormwater use schemes (Hatt *et al.* 2004; Mitchell *et al.* 2002). Given the widespread implementation of WSUD, achieving integrated treatment and use systems will accomplish multiple objectives and ensure substantial environmental and economic benefits in the future (Hatt *et al.* 2004; Mitchell *et al.* 2006a).

Table 1.1 Comparison of the advantages and disadvantages of stormwater harvesting and rainwater tanks (DEC 2006)

Aspect	Stormwater Harvesting	Rainwater tanks
Application	Centralised community household or industrial uses	Domestic non-potable uses
Capital costs	Higher, but paid by central authority or industry owner	Lower, but paid by individual homeowner (rebates may be available)
Costs per kL of water used	Likely to be higher than rainwater tanks	Likely to be lower than stormwater harvesting
Distribution costs	Distribution costs may be significant, depending on the location of the storage relative to the use	Storage located near use, with negligible distribution costs
Flow attenuation benefits	Use schemes can reduce stormwater flows from a catchment	Rainwater tanks only reduce flows from roofs
Health risks – drowning	Potential public safety risks with open storages	No safety risks due to tanks
Health risks – pathogens	Higher pathogen levels in raw stormwater than rainwater	Pathogen levels in rainwater relatively low
Health risks – viruses	Potential for mosquito breeding in storages with associated diseases	Limited potential for mosquito breeding in tanks
Landtake	Above-ground storage can occupy a relatively large area of a catchment	Rainwater tanks can be readily incorporated on most residential blocks
Maintenance	Maintained by a single organisation (e.g. council), hence likely to be reasonable	Maintained by householder likely to be highly variable
Statutory approvals	Approvals needed	Normally exempt from requiring approval (standard requirements need to be met)
Suitability for application in existing urban areas	Potentially suitable	Land availability on existing blocks likely to impair uptake
Water quality benefits	Potentially significant reduction in pollution loads as runoff from roads and other paved areas is collected	Limited reduction in pollution loads, as relatively clean roof runoff is collected

A survey of current stormwater use systems completed by Hatt *et al.* (2004) revealed that:

- The majority were smaller scale sites;
- Reclaimed stormwater was mainly supplied for uses with low human contact;
- Collection was generally achieved through traditional techniques such as gutter, channel, pipe systems;
- Treatment was generally based on WSUD techniques unless higher health risks were involved;
- Conventional storage methods were used such as water tanks; and
- Frequently used techniques did not necessarily reflect optimal suitability but rather were a consequence of the limited awareness of the range of applicable techniques.

Overall there are general principles associated with stormwater use. These include that the use of stormwater must not result in any form of pollution of the environment, the quality and quantity must be suitable for the purpose and use for potable purposes is not acceptable unless approved by a local authority (Hatt *et al.* 2004).

In addition to problems of spatially and temporally variable quantity and quality, integrating stormwater resources into a viable alternative water source for urban areas faces several obstacles, including lack of regulation and design criteria, clear design guidelines and methods to adequately assess costs and benefits of use systems against conventional water supply options.

Stormwater harvesting has become an important option for many Australian cities, and in South East Queensland it has the potential to deliver great quantities of water for urban and agricultural use.

1.1. South East Queensland

South East Queensland (SEQ) covers 22,420 square kilometres, stretching 240km from Noosa in the north to Cooloongatta in the south, and 140km west to Toowoomba; it is governed by 11 city and regional councils. SEQ's population is heavily urbanised and is generally concentrated along the coast between Noosa and Cooloongatta as indicated by the intensive land use shown in Figure 1.1 (Figure 1.1 is based on data from *Land, Vegetation and Water 2006* provided by the Queensland Department of Natural Resources and Water). SEQ is located in the sub-tropics, and as such experiences warm summers and mild winters. Rainfall is highly variable, occurring mainly in conjunction with summer storms. SEQ is one of the most diverse, species-rich regions in Australia and the world, and the topographic features of the region include mountain ranges, pastoral lands, rainforests, beaches and islands. The diverse industries in the region include agriculture, aquaculture, manufacturing, mining, commercial and tourism enterprises, generating 62% of Queensland's gross state product and 68% of the state's employment (QWC, 2008).

SEQ is Australia's fastest growing region. By 2026, its population is expected to grow by more than one million to around four million people. The region's growth will generate demand for 575,000 new dwellings and 425,000 new jobs, as well as supporting infrastructure and services (Dept Infrastructure and Planning, 2008). It will impose significant social, economic and environmental pressures on the region. SEQ is also experiencing the worst drought in recorded history – the Millennium drought – which has been running for over eight years. Historically, the SEQ community has relied on rainfall over dam catchments and the recharging of groundwater aquifers to meet water needs (QWC, 2008). However, the growing pressures on water resources and the effects of the drought have highlighted the need to diversify the water resources and practices used in SEQ.

In response to this the Queensland Water Commission has developed *Water for today, Water for tomorrow - South East Queensland Water Strategy* [draft] (2008). This document outlines a 50-year strategy for securing water supply for South East Queensland in an integrated and sustainable manner. Stormwater harvesting practices in SEQ to date were identified to provide a boutique solution requiring more research to identify opportunities within the region. Up until now, dialogue about stormwater harvesting has, by-and-large, been high level, lacking the in-depth investigation required to conclusively determine its strengths and weakness and its niche within the growing toolbox of sustainable urban drainage and integrated urban water management tools available to planners and engineers (Mitchell *et al.* 2007b).

The aim of this project is to address the key challenges associated with stormwater harvesting in the SEQ region. An important step in the process of developing this project is to review the current information and practices regarding stormwater capture and recovery in order to build on current knowledge of stormwater and harvesting potential in the region. This study looks at the current practices and technologies used locally, nationally and internationally in the field of urban stormwater capture and recovery with the intent to identify opportunities for SEQ. Whilst augmenting water supply in the region is of primary concern for the study, the objectives of stormwater management in the industry today have broadened from single objective, flood protection systems and now achieve multiple objectives taking into account the social, environmental and economic implications and the policy and legislative frameworks that guide water management.

Chapter 2 provides an overview of the issues affecting the water balance within urban areas, and provides a typical comparison between traditional urban water supply requirements and stormwater runoff volumes.

The various components within stormwater use systems are discussed in Chapter 3.

Chapter 4 provides an overview of both national and SEQ regulations and legislation relating to stormwater use.

The social, environmental and economic issues affecting stormwater harvesting are described in Chapter 5. The overview also identifies the need for the use of a multi criteria analysis in assessing different stormwater harvesting options.

Chapter 6 presents a description of international, national and SEQ examples of stormwater harvesting.

A brief outline of future research directions is provided in Chapter 7.

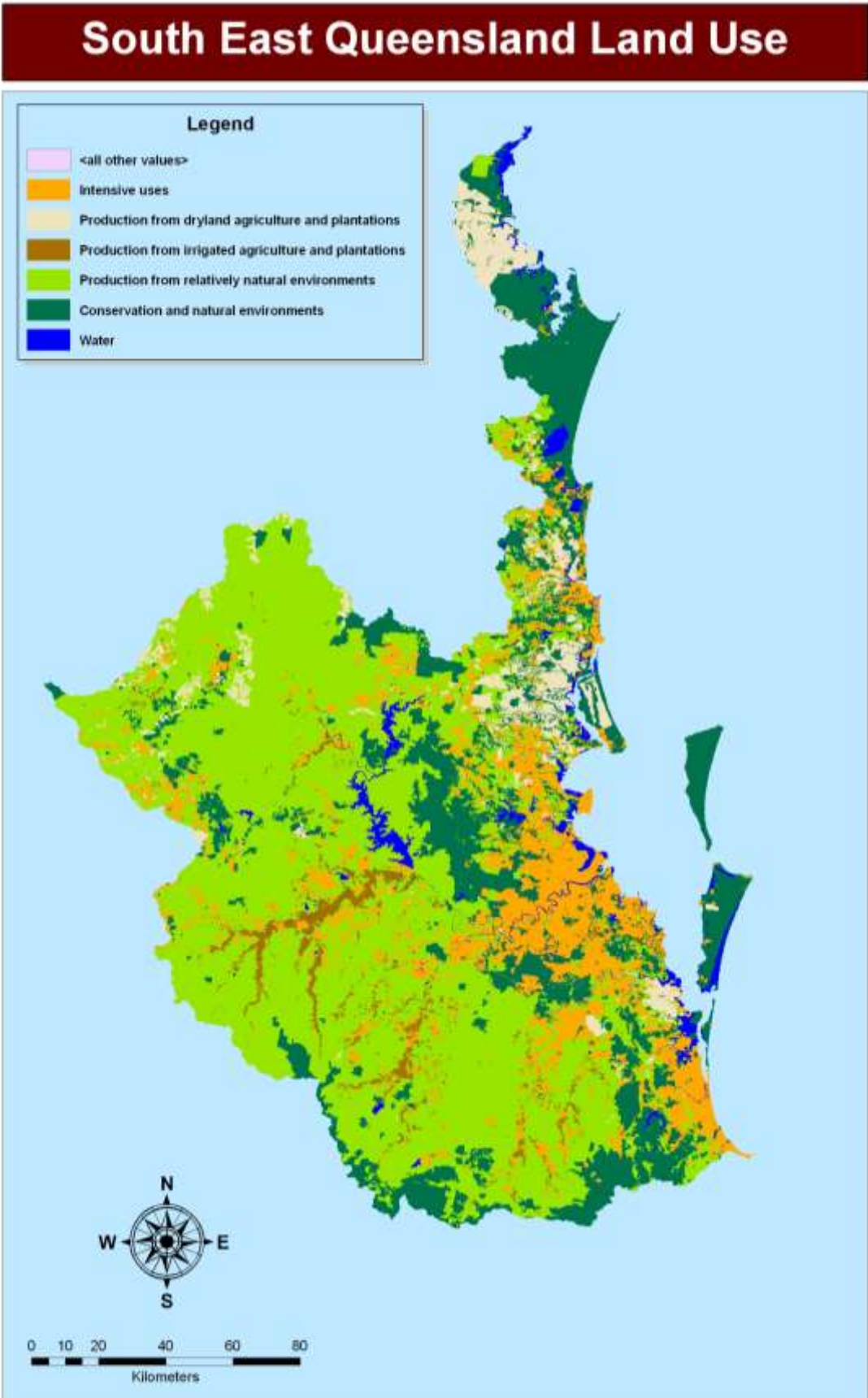


Figure 1.1 UWSRA Stormwater Capture and Recovery Project Extent

2. URBAN WATER BALANCE

Mass balances are founded on the principles of conservation of mass and/or energy over time. These principles state that mass cannot disappear, but will be either recycled or become waste which dissipates into other systems (Meadows *et al.* 1992). They provide insight into the complex processes that occur in natural systems through relatively simple simulations that allow cross-checking with either modelled or estimated fluxes (Eyre 1995). As Nixon *et al.* (1995) succinctly state, mass balances represent a “final unequivocal constraint against which the combined forces of ignorance, error and omission must come to rest and be reconciled or, at the very least, be recognised”.

Water mass balances are used in urban water management to establish a baseline of resource availability, use and potential sources within an urban boundary. The water mass balance can quantify changes in the urban water system over time with respect to factors such as climate, urban planning, water supply and demand choices or consumer behaviour. Urbanisation impacts the local water balance not only through changes in domestic water demand, but also by augmenting runoff generation from the urbanised area with respect to the pre-urbanised surface (van Rooijen *et al* 2005).

Previous studies have employed a range of methods to estimate the water balance of a region, ranging from basic accounting of the inputs and outputs of the system, through to complex modelling looking at the internal processes operating within the hydrological system.

Aston (1977) applied a simple accounting approach to the water resources of Hong Kong (Figure 2.1) using reference data from 1971, following severe water restrictions to provide an indication on the future water needs to sustain future populations in the region. Significant quantities of sea water were used in Hong Kong at the time for toilet flushing and industrial cooling, adding a unique source of water to the traditional water balance. Studies that employ this simple accounting approach allow a snapshot look at a water system at a particular time in the past, but do not identify the underlying processes.

Using a more complex modelling approach, Kenway *et al.* (in prep) compiled a water mass balance for the South East Queensland region for the 2004-2005 period using the urban water mass balance formula in Equation 1.

$$\Delta S = (C + D + P) - (W + R_s + G + ET) \quad (1)$$

Where ΔS is change in water stored within the boundary, C is centralised or imported water, D is decentralised water, P is precipitation, W is wastewater discharged, R_s is stormwater runoff, G is flow to groundwater and ET is actual evapotranspiration.

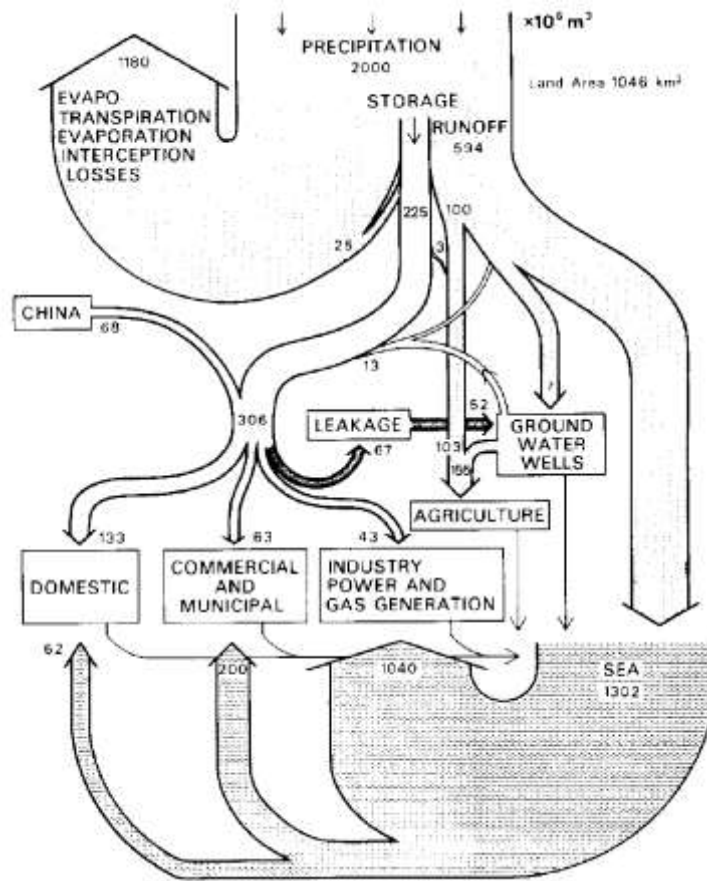


Figure 2.1 Urban water balance of Hong Kong in 1971 (Aston, 1977)

As discussed by Grimmond and Oke (1986), direct comparison of urban water balances from various studies is not a simple task for many reasons including the geographic differences between cities (e.g. climate, physiography, vegetation, soils, urban form, and urban function), the definition of the area represented (e.g. whole or part of a city), the emphasis of the original study, and the techniques used to estimate or measure the terms in the balance. In the following paragraphs, the work of Kenway *et al.* (2008) is compared to various studies with respect to the parameter selection of the water balance equation.

Grimmond *et al.* (1986) developed an urban water balance model to allow the investigation of the daily, monthly, seasonal, and annual patterns of water exchange in an environment where human modification to hydrologic and climatological processes, amongst others is pronounced. The model was described by the unifying equation (equation 2):

$$p + I = r + E + \Delta S \quad (2)$$

Where p is precipitation, I is the piped in water supply, r is the net runoff, E is evapotranspiration, and ΔS is net water storage change. The model considered the water balance in terms of external and internal systems. The external system was described by the parameters in Equation 2, which are influenced by the internal processes (Figure 2.2).

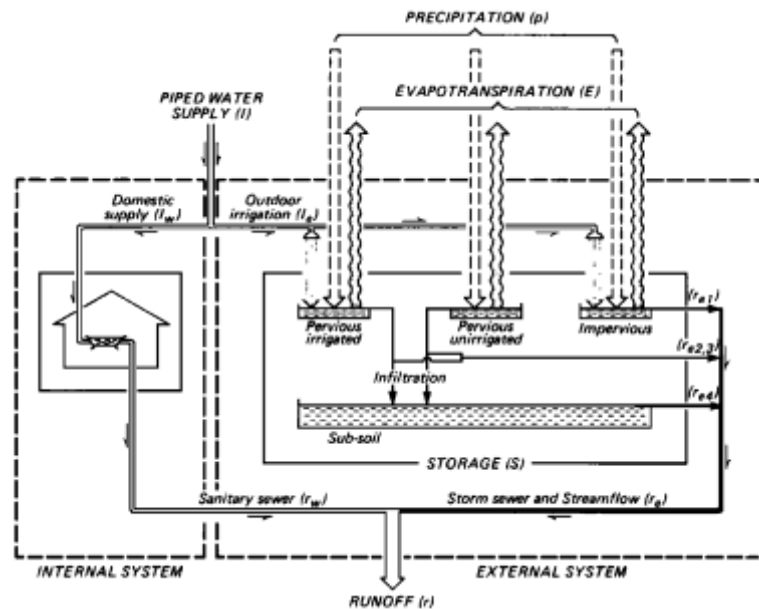


Figure 2.2 External and internal systems of the urban water balance (Grimmond et al 1986)

Limitations of this model with respect to Kenway *et al.* (in prep) is the lack of descriptors with respect to wastewater and groundwater in the external system, important factors for consideration in integrated water management. There is also no consideration given to decentralised water supplies, an important component in the SEQ region where systems such as rainwater tanks are common.

Mitchell *et al.* (2003) developed a continuous daily model to quantify the components of the total water balance of the Curtin catchment in Canberra. The study was undertaken to illustrate the impact of urbanisation on the hydrological cycles, evaluate the influence of seasonality and inter-annual climate variability on the catchment water balance, and gain insight into the opportunities for stormwater and wastewater utilisation (Mitchell *et al* 2003). This study used Equation 3 to describe the urban water balance

$$\Delta S = (P + I) - (E_a + R_s + R_w) \quad (3)$$

Where ΔS is the change in catchment storage (which includes storage on the soil profile and groundwater aquifers as well as natural and constructed above ground surface water storages), P is precipitation, I is imported water, E_a is actual evapotranspiration, R_s is stormwater runoff, and R_w is wastewater discharge. The parameters selected in this model provide an improvement to the basic components of the Grimmond *et al.* (1986) model by considering wastewater discharge, however the impact of decentralised water systems is still not considered.

Another water balance model was recently developed for the SEQ region by KBR (2006). This model was used to assess various water security scenarios and to analyse future water supply options. Due to the nature of the KBR (2006) model, it does not consider all aspects of the hydrological cycle necessary for the current study and cannot be directly compared to the Kenway *et al* (in prep) model.

The parameters selected by Kenway *et al.* (in prep) show an integrated approach to understanding the urban water system with respect to the other approaches discussed above. The alternative water balance models tend to neglect aspects such as groundwater flow, or in turn do not provide enough of a component breakdown, for example, of centralised and decentralised water systems. The level of detail provided by the Kenway *et al.* (in prep) model is suitable for application in the current study.

Table 2.1 shows the results of the Kenway *et al.* (in prep) water balance for the SEQ region.

Table 2.1 Water mass balance for South East Queensland in 2004-2005. All units in GL unless otherwise stated (modified from Kenway et al. (in prep))

Area / System Boundary (km ²) ¹	Population (' 000) ²	Water inputs				Use Water ⁵	Water outputs				Store Change in stored water (conceptual only)
		Centralised or Imported water ³	Decentralised water (groundwater)	Decentralised water (rainwater tanks) ⁴	Rainfall on urban area ¹		Wastewater collected ³	Urban stormwater discharges ⁶	Groundwater seepage	Evapo-transpiration ¹	
1,281	2,667	480	0	1	1,309	16	230	500	ND	1,044	17

Note: ND – not determined; ¹(Barratt 2007); ²(OUM 2005); ³(AWA 2005); ⁴(Grant and Kenway in prep); ⁵(WSAA 2005); ⁶(Bureau of Meteorology; Barratt 2007; GCCC 2006; Weber 2007).

Estimating stormwater is one of the most difficult aspects of performing a water mass balance on urban areas. Kenway *et al.* (in prep) assessed urban stormwater discharge (R_s) by comparing three estimates determined from different modelling and calculation methods. Modelling estimates were determined through use of EMSS (Environmental Management Support System) (Weber 2007); and the Bureau of Rural Sciences Water 2010 model (Barratt 2007). Calculations were based on 2004-2005 rainfall sourced from the Bureau of Meteorology, the urban area as defined by Water 2010 and an annual volumetric runoff coefficient for urban areas in Brisbane (GCCC 2006). The values presented in Table 2.1 were taken as the average of the three estimates described above and rounded to the nearest 50 GL due to the limitations imposed by assumptions and spatial variation of the parameters across the SEQ region.

Temporal variation of the water balance is not reflected by the work presented by Kenway *et al.* (in prep). Seasonality and longer term trends such as drought and climate change are generally not reflected in urban water mass balances. Work by Niemczynowicz (1990) shows the temporal variation of an urban water balance in Lund, Sweden by comparing the annual water balance with the water balance on a day with heavy rainfall for combined and separate sewer systems (Figure 2.3). As the diagram shows, weighting of components can vary considerably depending on the selected temporal point of analysis.

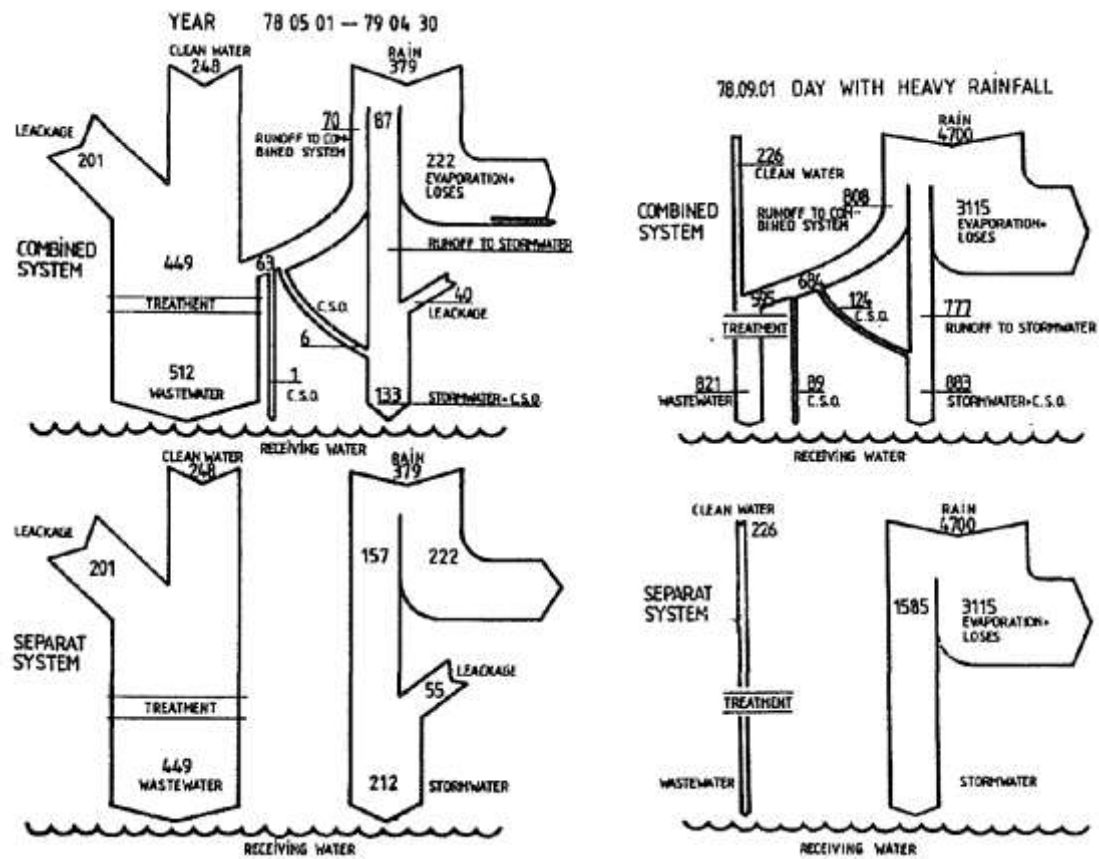


Figure 2.3 Quantitative water budgets for the city of Lund on a yearly basis and, as an example for a day with heavy rainfall. (Niemczynowicz 1990)

The Grimmond and Oke (1986) water balance for a catchment in Vancouver, Canada (Table 2.2) also highlights the effect of seasonality on the components of the water balance (see Equation 2 for component descriptions). The studies demonstrate that temporal aspects of the urban water balance must be considered when determining stormwater capture and use.

Table 2.2 Water balance for Vancouver, Canada 1982-83 (Grimmond and Oke 1986)

Period	Units	p	I_e	E	ΔS	r_e
Summer	%	50.1	49.9	81.3	-3.0	21.7
Winter	%	99.4	0.6	10.3	2.3	87.4
Annual	%	80.1	19.9	38.1	0.2	61.7

The Kenway *et al.* (in prep) water balance presented in Table 2.1 demonstrates that the volume of stormwater is comparable to the volume of centralised water supplied to the region. Clearly there is considerable potential for stormwater to augment the region's traditional urban water supply network, however the spatial and temporal variation of the water balance of the whole SEQ region is not captured in these results. Further work is required to specify the water balance at a more detailed level to better assess and consider the hydrological cycle and opportunities for stormwater capture and use. This also includes a need to research the components of the water balance required as environmental flows necessary to maintain or improve the ecological health of urban waterways.

3. STORMWATER USE SYSTEM COMPONENTS

3.1. Overview

Stormwater capture and use systems can be considered using their five core components: End Use; Collection; Treatment; Storage; and Distribution. Figure 3.1 indicates the relationships between these components and how their position in the system can vary depending on the purpose and design of individual systems.

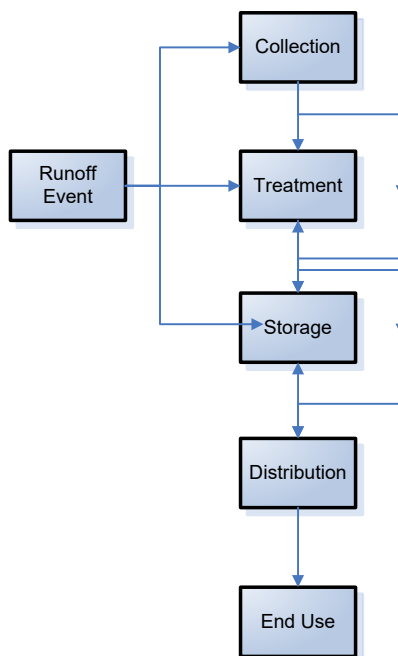


Figure 3.1 Stormwater use components

Stormwater capture and recovery has traditionally been undertaken with purpose built infrastructure or utilising existing natural features. With the advent and adoption of Water Sensitive Urban Design (WSUD) techniques, whilst primarily developed for water quality purposes, certain WSUD techniques lend themselves to being extended and refined to allow effective harvesting of treated stormwater and the development of integrated water management systems. Using WSUD approaches in stormwater harvesting systems has the added payback of achieving multiple benefits such as improved water quality, hydrology, and aesthetics compared to conventional stormwater harvesting infrastructure.

The following sections further detail the components of stormwater harvesting systems, considering a combination of conventional and WSUD techniques.

3.2. End Use

The *Australian Drinking Water Guidelines* (NHMRC 2004) recommend that drinking water should always be derived from the best available source water. However, in Queensland due to long term drought, these natural water sources will not be adequate either to support planned growth beyond a threshold population, or in more extreme cases, to meet the water needs of current population levels. In these cases, highly treated recycled water may actually become the best available source of water (EPA 2005).

Stormwater use systems should be designed and specified to match the end use in mind for the project, as this will determine the appropriate system components. Water quality should meet, but not necessarily exceed end use requirements i.e. the quality of the water should be fit for its intended purpose.

Hatt *et al.* (2004) conducted an inventory of Australian practices in relation to stormwater harvesting which found stormwater was being used for a range of non-potable urban water uses, including: toilet flushing, garden watering, car washing, industrial uses, open space irrigation, ornamental water features, fire fighting, environmental flow provision and groundwater recharge. Given appropriate treatment, stormwater can also provide a supplementary potable water supply; however, the potable use of stormwater is not commonly practised in Australia or overseas.

3.3. Collection

Collection systems divert stormwater from either an urban creek, stormwater drain (including WSUD components) or general urban runoff into a storage for harvesting. The specific characteristics of a collection system will vary depending on the type of receiving storage. For example a storage online with a waterway it harvests from will have a different collection system to one offline from a waterway receiving stormwater through pumping (see section 3.5 for a comparison of online and offline storages). Innovative methods for collecting stormwater are employed in harvesting systems around Australia, such as pumping out of service pits (see Barry Brothers case study in Appendix A). However these systems typically operate on a scale smaller than that considered in this review.

Online storages receive stormwater flows directly from a waterway or drain. This stormwater can be collected through either the traditional urban drainage system of gutters, pipes and channels; or through WSUD stormwater conduits designed for improving stormwater quality. Traditional drainage collection systems are generally sized to be sufficient to accommodate at least two year ARI flows, although sizing can range between one and 10 year ARI flows (Mitchell *et al.* 2006a). Consequently there are substantial volumes available for harvesting, although the traditional conveyance system does not provide any treatment. Traditional systems can maximise the water harvested due to minimal infiltration and evaporation losses. However some minor losses will occur due to cracks in the conveyance system, which increase with the age of the infrastructure.

WSUD features are designed to treat the majority of total urban annual runoff volume and generally convey stormwater through vegetated swale drains, filter drains or biofilters (DEC 2006; Mitchell *et al.* 2006a). Losses will occur through WSUD features due to local climate characteristics, such as potential evapotranspiration, and exfiltration into the surrounding soil. Mitchell *et al.* (2006a) quantified the relative magnitude of the losses associated with WSUD collection systems through modelling and determined that evapotranspiration losses were almost negligible. Exfiltration losses were found to vary depending on soil type, climate conditions and surface area of the WSUD conveyance system. Mitchell *et al.* (2006a) conducted modelling focusing on swales that covered 0.5-5% of a catchment and determined that for stormwater harvesting applications swales built on clay or sandy clay would not need to be lined, but those built on loam and sandy soils should be lined due to their higher hydraulic conductivities. When designing collection systems a balance should be sought between reducing exfiltration rates to maximise collection and conveyance to storages and increasing exfiltration to counteract the negative effects of traditional urban drainage on hydrology such as reduced groundwater recharge and waterway base-flows (Mitchell *et al.* 2006a).

Offline storages require an additional collection system to harvest from an urban waterway once stormwater has been collected through either the traditional urban drainage system or WSUD design features. This can be achieved through either a diversion weir which diverts low flows into the harvesting scheme and bypasses high flows, or pumping (DEC 2006; EPHC *et al.* 2008). Diversion weir design is dependent on the reliability of supply required by an end use. Generally the weir should aim to divert low ARI storm events as they produce the majority of annual yield from urban catchments (DEC 2006). For example Wong *et al.* (2000) found that 90-97% of mean annual runoff from Australian urban catchments is produced by rainfall events with a lower than three month ARI.

Prior to installation, the effect of a diversion weir on upstream flood levels; riparian vegetation; bank stability and erosion; and the passage of aquatic fauna and sediment should be assessed (EPHC *et al.* 2008). For larger waterways, lakes or ponds, stormwater can also be harvested using a well and submersible pump with an associated rising main. When using a pump to extract stormwater, measures should be taken to avoid erosion and the intake of aquatic fauna (EPHC *et al.* 2008). Sizing of both diversion weir and pump should be designed to harvest from only three month ARI events as design capacities larger than this are likely to be less cost-effective and may lead to over-extraction of water needed for stream health (DEC 2006).

Out of the stormwater projects surveyed by Hatt *et al.* (2004), collection systems using traditional urban drainage such as gutters, pipes and channels were most commonly used (approximately 70% of schemes) (see Figure 3.2). This is possibly due to infrastructure already being in place and their greater hydraulic efficiency (Hatt *et al.* 2004). Natural drainage was used only for catchments with areas greater than 5ha, while channels were used for collection for catchments with areas less than 200ha (see Figure 3.3) (Hatt *et al.* 2004).

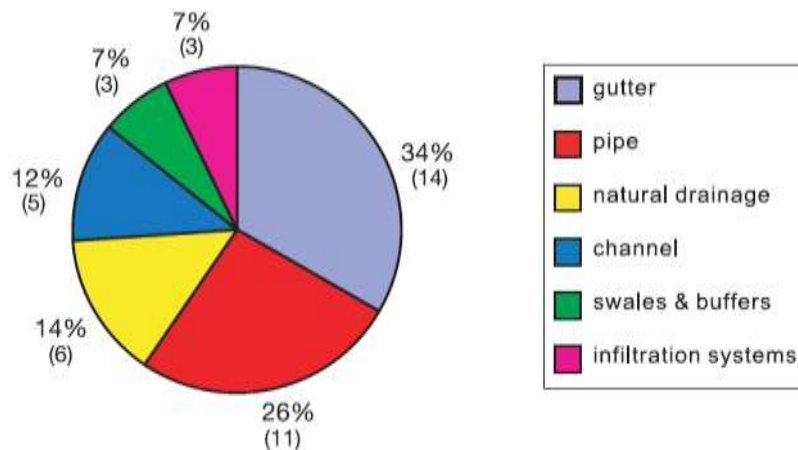


Figure 3.2 Frequency of collection components in Australia (Hatt et al. 2004)

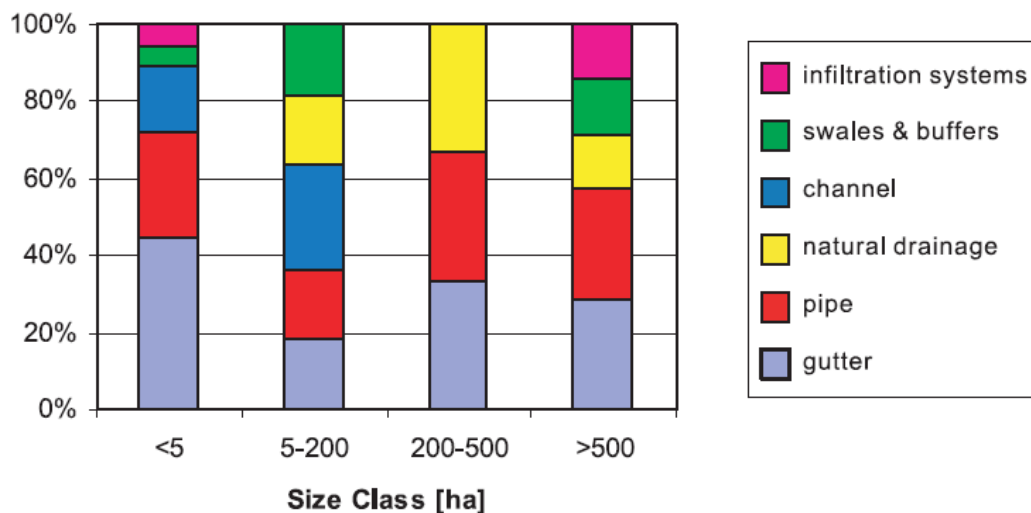


Figure 3.3 Frequency of collection components in relation to catchment size (Hatt et al. 2004)

3.4. Treatment

At present, a significant obstacle to widespread implementation of stormwater use is a lack of reliable and affordable treatment techniques (Hatt *et al.* 2007). Where stormwater is being treated for use, public health and safety considerations impose a higher level of uniformity and certainty in treated water quality with respect to treatment of water intended for water quality improvement. The level of treatment required is largely determined by both the catchment properties (which influence the type and level of pollutants) and the intended end use (Mitchell *et al.* 2006a).

The concept of a “treatment train” approach is important in considering treatment techniques for application in stormwater use. Treatment trains use a variety of complementary processes to treat the water to the level required by the end use. Table 3.1 lists possible treatment system combinations to achieve the water quality required for various recycling applications. Treatment trains are not restricted to using methods from any one particular category of treatment technique. A WSUD treatment upstream of an advanced treatment process could be important for the effective functioning of the process.

Table 3.1 Possible treatment systems to achieve water quality required for various recycling applications (WBM 1999)

Recycling Application	Suggested Treatment (*optional)
Urban Recycling	Screening* – Filtration – Disinfection
Restricted access area irrigation	Filtration – Disinfection
Agricultural recycling – food crops not commercially processed <i>Surface irrigation of orchards and vineyards</i>	Screening* – Filtration – Disinfection
Agricultural recycling non food crops	Screening* – Filtration – Disinfection
Recreational impoundments	Screening* – Filtration – Disinfection
Landscape impoundments	Filtration – Disinfection
Construction uses	Filtration – Disinfection
Industrial recycling <i>Once through cooling</i>	Screening – Disinfection
Industrial recycling <i>Recirculating cooling towers</i>	Filtration – Disinfection
Other industrial uses	Screening* – Filtration – Disinfection OR Screening* – Filtration – Carbon Adsorption – Disinfection OR Screening* – Filtration – Disinfection – Ion Exchange OR Screening* – Filtration – Disinfection – Membrane Process
Environmental recycling	Screening – Disinfection
Groundwater Recharge <i>By spreading or injection into non potable aquifers</i>	Screening* – Filtration – Disinfection OR Screening* – Coagulation – Filtration – Disinfection
Indirect potable recycling <i>By spreading or injection into non potable aquifers</i>	Screening* – Filtration – Carbon Adsorption – Disinfection OR Screening* – Coagulation - Filtration – Carbon Adsorption – Disinfection
Indirect potable recycling <i>Augmentation of surface supplies</i>	Screening* – Filtration – Carbon Adsorption – Disinfection OR Screening* – Coagulation - Filtration – Carbon Adsorption – Disinfection

3.4.1. WSUD Treatment Techniques

In the past WSUD has focused on water quality improvements for the protection of receiving waters (Mitchell *et al.* 2007, Walsh *et al.* 2005). In these situations temporary exceedence of guideline values for pollutants is acceptable as the consequences of occasional incidences of elevated pollutant concentration may not be significant to the ecological health of the water body. However, treating stormwater for use in the public domain requires a higher level of uniformity in treated water quality due to public health and safety considerations.

Mitchell *et al.* (2006b) undertook a modelling exercise to determine whether a treatment device designed for aquatic ecosystem protection could satisfy use targets, or whether extensive modifications would be required. For example, where a wetland is the only treatment in place prior to utilisation of stormwater, it may need to be built substantially larger than would normally be the case for WSUD, with intensive planting of macrophytes, to ensure that pollutants are treated to the same standard during a wide range of storm events. Similarly, hydraulic loading will need to be carefully controlled (with the provision of a bypass) to minimise re-suspension of fine sediment, and attached pollutants.

The application of WSUD treatment techniques for the purposes of stormwater use are discussed in the following categories: physical processes, infiltration methods, biofilters and proprietary devices.

Physical Processes

Physical Processes is the category used here to describe WSUD treatment devices that rely on hydraulic properties for treatment. These treatment techniques include swales, buffer strips, and open water bodies (natural and constructed). It is unlikely that these processes alone will provide significant treatment to allow use of harvested water, however they may provide important preliminary treatment to reduce pollutants such as sediment loads before subsequent steps in the treatment train approach. The case studies in Appendix A also highlight some examples where these techniques are the principal treatment mechanism. In these cases stormwater is used directly on site for irrigation, primarily of golf courses where public access is restricted. These physical processes work on the principle of reducing flow velocities to allow sediments to settle out of the water column. The open water bodies also have the combined benefit of exposure to UV light to provide some level of disinfection.

Infiltration Methods

Infiltration treatment measures use the physical process of infiltration to provide treatment to the collected stormwater. These processes include porous and permeable pavements, infiltration basins and trenches, sand filters and biologically engineered soils. Infiltration devices can also be combined with vegetation to assist with the treatment of the water (refer to *Biofilters and Wetlands*).

According to a number of studies carried out in Australia (Booth *et al.* 2003, Fletcher 2003, Melbourne Water 2005, Jayasuriya 2007) if pervious pavements are correctly designed and maintained they can remove up to 80% of sediment, 60% of phosphorus, 80% of nitrogen, 70% of heavy metals and 98% of oils and greases in stormwater.

Sand filters have been shown to remove a high proportion (75-100%) of suspended solids from stormwater, although a pre-treatment for coarse sediment and litter removal is required (EPA, 1997). Birch *et al.* (2005) tested a 450m² stormwater infiltration basin with a catchment area of 2.7ha (urban residential) in a small park in metropolitan Sydney. The infiltration basin was shown to be highly efficient in removing suspended particulate matter, trace metals (copper, lead and zinc), and faecal contaminants. Phosphorus levels were moderately reduced by infiltration of stormwater through the filter bed, however the basin was ineffective in reducing total nitrogen. Some trace metal concentrations were shown to increase after treatment possibly due to leaching of clay minerals from the filter bed, however the concentrations of these elements were only moderately above recommended ANZECC guidelines for freshwater quality.

Design and maintenance of these treatment methods is highly important to ensure the treatment efficiency of the device. A field survey by Lindsey *et al.* (1992) showed that only 38% of infiltration basins were functioning as designed after four years of operation, with 31% clogged. Schuler *et al.* (1992) showed that 50% of infiltration systems were not working due to clogging.

Biofilters and Wetlands

Biofilters, including wetlands (natural and constructed), use biological and physical methods to treat stormwater. Biofilters involve a soil filter medium planted with vegetation, and containing a collection pipe to convey the filtered water to receiving waters or downstream storage facilities. There have recently been a number of promising results in the treatment effectiveness of biofilters in relation to stormwater use:

- Hatt *et al.* (2007a) conducted trials that showed biofilters could be designed to achieve the required water quality standards for stormwater use.
- Read *et al.* (2008) found that percolation of stormwater through soils with or without plants, effectively reduced concentrations of suspended solids, trace metals, and to a lesser degree phosphorus. Vegetated biofilters reduced nutrient levels relative to the soil-only control.
- Henderson *et al.* (2007) demonstrated that the best media choice for biofiltration treatment of stormwater appears to be sand or sandy-loam. Vegetation in the media was found to greatly improve the removal efficiency of nitrogen and phosphorus, and retains more nutrients during the initial flush after an inter-event dry period.

However, once again design and maintenance have a huge impact on the effectiveness of biofilters. Le Coustumer *et al.* (2007) conducted field studies that have shown that soil hydraulic conductivity of biofilters constructed around Australia varies greatly, with around 43% nominally below Australian guidelines. Hatt *et al.* (2007b) also highlighted the possible ecological consequences of using biofilters, with recent observations of elevated nitrogen concentrations during inter-event periods within urban catchments (Taylor 2006) and large nutrient pulses from ephemeral riverine and lake sediments upon re-wetting (Baldwin and Mitchell, 2000; Scholz 2002) suggesting that extended dry periods may result in an initial flush of stormwater pollutants from biofilters upon re-wetting.

Many researchers have shown that wetlands are effective at treating urban stormwater runoff (Martin and Smoot 1985; Harper *et al.* 1986; Stockdale and Horner 1987; Lakatos and McNemar 1988; Oberts and Osgood 1991; Etheridge and Olson 1992; Johengen and LaRock 1993; Smith *et al.* 1993; Carr and Rushton 1995; Reinelt and Horner 1995; Rushton *et al.* 1995; Rochfort *et al.* 1997; White and Myers 1997; Tilley and Brown 1998). Natural or constructed wetlands offer water quality improvement, landscape amenity, recreational opportunities, habitat provision and flood retention. However the stochastic nature of the hydrologic and pollutant inputs makes treatment performance prediction an inherently more difficult task than for wastewater treatment (Carleton *et al.* 2001). Wetlands require large areas of open space, however Tilley and Brown (1998) have shown that if stormwater treatment wetlands were incorporated at each scale, then some synergism between the scales would likely emerge, leading to a smaller overall demand for land area. Section 3.5 discusses the use of wetlands for storage.

Proprietary Devices

Gross pollutant, oil and grease, and sediment trap devices are available in a range of styles for a range of applications. These traps are generally used at the beginning of the treatment train to give some preliminary treatment to the stormwater before entering another treatment process. Hydrodynamic separating devices have been extensively applied especially in the USA, and have been the subject of a number of verification studies (Faram *et al.* 2000, 2005a, 2005b, 2007; Pratt 2000; Phipps *et al.* 2005). Faram (2007) considered seven hydrodynamic separators located across the United Kingdom. Proprietary interceptor devices were shown to remove fine sediments from urban runoff, preventing them from entering downstream watercourses or further treatment facilities. The optimal design or selection of stormwater sediment management systems can be aided through an understanding of individual site conditions and requirements, and related sediment physical and chemical characteristics.

3.4.2. Advanced Treatment and Disinfection

Advanced treatment processes are also important to consider in this review as this will affect the possible end use of the harvested stormwater. In order to achieve the treatment reliability required for potable and some non potable uses, advanced treatment techniques may be necessary in the treatment train. Common advanced treatment methods include: conventional media filtration (as described in Section 3.4.1), membrane filtration, reverse osmosis, membrane bioreactors, electrodialysis, biologically activated carbon filtration, ultrasound, dissolved air flotation (DAF), ion exchange, distillation, high rate clarification and biological nutrient removal.

Bernard *et al.* (1995) describe a pilot project set up to determine the effectiveness of dissolved air flotation (DAF) with respect to the treatment of urban stormwater runoff. DAF involves injecting air into water, forming very small bubbles that attach to floc particles formed by addition of chemical flocculant. Solids then float to the surface to be skimmed off. When combined with appropriate disinfection, DAF can produce high quality recycled water. The pilot project was set up at the sluice gate of the River Chelles catchment area in Seine-et Marne, France. The pilot project consists of a flotation tank, an air dissolving system, a coagulation-flocculation stage and an automatic control system for rainfall events. The results of the pilot project showed DAF to be a highly efficient stormwater treatment process as regards suspended matter, chemical oxygen demand and total hydrocarbons. Application of this process would be especially suitable for treatment of stormwater with a high total hydrocarbon content, such as runoff from car parks and airport areas. DAF would also be suitable for stormwater treatment in areas where it proved necessary to fix high purification objectives (Bernard *et al.* 1995).

While most treatment steps can lead to some reduction in pathogenic organisms, specific disinfection steps are generally required after WSUD or advanced treatment techniques to ensure that recycled water is fit for use. Where end use involves human contact, disinfection may be a necessary treatment process to ensure public safety. Common disinfection techniques include chlorination, ultra violet (UV) radiation, oxidation processes (including ozonation) and membrane filtration. Table 3.2 describes the advantages and disadvantages of the various disinfection techniques.

Table 3.2 Advantages and disadvantages of disinfection techniques (Mitchell et al. 2006a)

Method	Advantages	Disadvantages
Chlorination	Stable and continuous disinfection Well developed technology Low cost Widely available	Chlorine products are highly toxic and corrosive, and therefore require special transport, storage and handling procedures Strength of NaOCl decays during storage, CaOCl may crystallise and clog lines Tends to be ineffective against viruses and protozoa Requires mixing tanks to meet 10-25min contact time May produce toxic by-products May require post-disinfection dechlorination, depending on the end use Elevated chloride levels in irrigation water may be harmful to plants
Ultraviolet Radiation	Chemical free Small footprint Instantaneous disinfection No toxic by-products or residuals Higher virus inactivation efficiency than chlorination	Efficiency reduced by turbidity and suspended solids Power consumption No residual disinfection, potential for photo-reactivation and mutation of the microbial population Can be difficult to verify correct calibration of UV reactors in unattended locations
Oxidation (Ozonation)	Reduces colour and odour No dissolved solids production May increase dissolved oxygen concentration Reduces organic matter	Ozone is toxic, highly unstable and must be produced on-site Requires mixing tank to meet 5-15min contact time May form harmful by-products (e.g. bromates, aldehydes) Poor water quality increases the required ozone dosage High cost
Membrane Filtration	Prevents bacterial regrowth No toxic by-products Produces high water quality (suitable for industrial use, groundwater recharge, indirect potable use)	High capital cost Backwash may be significantly contaminated by microbes Requires chemicals for cleaning Moderate to high operating cost

Selection should be based on the individual case and be appropriate for the system under consideration. For example, UV systems may work well for smaller scale use systems, but are unlikely to be feasible for a large scale use project. The typical pollutant levels in untreated stormwater indicate that pre-disinfection treatment is required to remove suspended solids and reduce turbidity if chlorination, ozonation or UV radiation were the chosen disinfection method (Mitchell *et al.* 2006a). In assessing a disinfection technique the following performance objectives should be considered:

- Efficiency and reliability of reduction of micro-organisms;
- Cost effectiveness;
- Risk to human health; and
- Risk to environment.

An example of a successful treatment train including disinfection to achieve high quality stormwater use is described by Lainé *et al.* (1998). A process for the treatment of urban stormwater was designed to achieve treated effluent of a quality suitable for bathing activities. This process (Figure 3.4), which combines DAF, sand filtration and UV disinfection, was tested at the pilot plant level on the effluent of a combined system during rainy weather in the eastern suburbs of Paris, France. The pilot plant receives water from a catchment area of 284ha(28% impermeable) containing industrial and urban land uses. The combination of three treatment processes led to a very high efficiency in physiochemical and microbiological pollution removal, regardless of the variations in polluting loads entering the process.

For the treatment of urban stormwater, the global performance of the three processes demonstrated excellent purification levels. Lainé *et al.* (1998) summarised the advantages of this treatment system as:

- Maximum efficiency in the first minute of start up, which allows intermittent operation due to discontinuous rainfall frequency;
- An output concentration independent of inlet concentration variations during rainfall; and
- High efficiency with regard to both physiochemical pollution removal and microbiological disinfection, which ensures treated effluent meets bathing water quality standards.

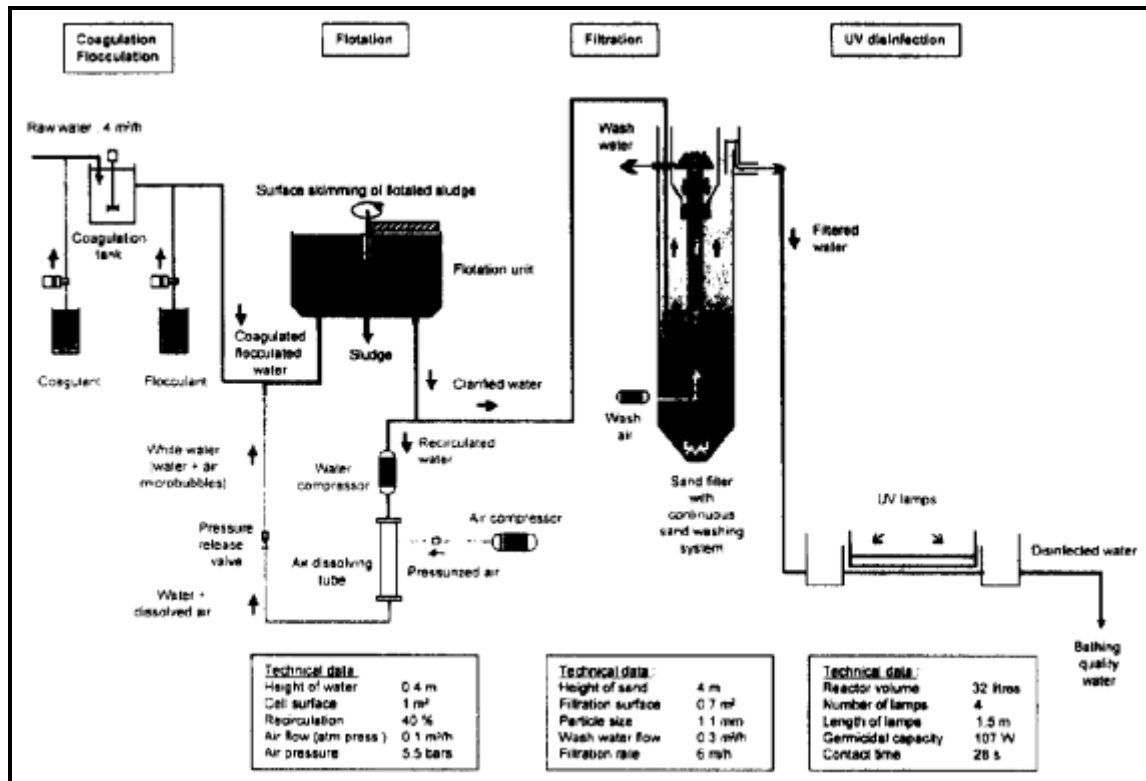


Figure 3.4 Treatment process diagram (Lainé et al. 1998)

3.5. Storage

Optimal design of stormwater storages forms a key part of effective use schemes as they are central to related space constraint, public safety and aesthetics issues. Typical examples include open storages; above or under ground tanks; and aquifers through aquifer storage and recovery (ASR). The availability of suitable storages for large-scale stormwater harvesting varies among cities in Australia (Productivity Commission 2008).

Each storage type has respective advantages and disadvantages (see Table 3.3). Open storages are susceptible to losses due to seepage along the wetted perimeter and evaporation. Seepage losses may be substantial as it is a continuous process, while evaporative losses may be reduced by designing the storage to have a small surface area to volume ratio (Mitchell *et al.* 2006a). Alternatively, during extended dry periods stormwater can be preferentially stored in sections with the smallest surface area to volume ratio (Hatt *et al.* 2004). Storage tanks can minimise water losses but they may be large and inconvenient to position, require deep excavation to install below ground, create aesthetic issues if above ground, and may require sheltering from weather.

Table 3.3 Comparison of storage types (DEC 2006)

Storage type	Potential advantages	Potential disadvantages
Open storages	Low capital and maintenance cost	Public safety Mosquito-breeding potential Higher potential for eutrophication Aesthetic issues with fluctuating water levels
Above-ground tanks	Moderate capital and maintenance costs No public safety issues	Aesthetic issues
Underground tanks	No visual issues No public safety issues	Higher capital cost Higher maintenance costs
Aquifer	Little space required Cost effective Prevents saltwater intrusions to aquifer	Requires suitable geology Potential to pollute groundwater unless pre-treated

Pratt (1999) discussed the problems associated with developing sufficient storage space in the urban environment and suggested the storages could be constructed under paved areas. Stormwater could then be stored in either tanks or a suitable soil medium under an appropriate paved surface enclosed within an impermeable membrane. This would optimise the space currently available, reduce construction costs and could be completed as part of the urban renewal process when infrastructure upgrades or maintenance are required. It is also highly unlikely that there will not be adequate areas of paved surfaces to provide the required storage of a harvesting scheme in the urban environment (Pratt 1999).

Based on a survey of Australian stormwater use projects, Hatt *et al.* (2004) determined several trends in storage type in relation to catchment size, end use and local climate characteristics. For example, although tanks were the most commonly used storage technique their use decreased with increasing catchment size. Conversely ponds, basins and lake storages were increasingly used with increasing catchment size. All storage types were used for all end uses, apart from ASR which was only adopted for uses with low human contact (see Figure 3.5). This is likely to be due to the possibility of contamination from polluted groundwater and the relative lack of experience with this technique (Hatt *et al.* 2004). Finally the potential losses due to evaporation also appear to influence choice of storage type (see Figure 3.6). In areas with low evaporation, ponds and basins were the most common storage type, whilst in areas with high evaporation potential tanks and aquifers were most commonly used (Hatt *et al.* 2004).

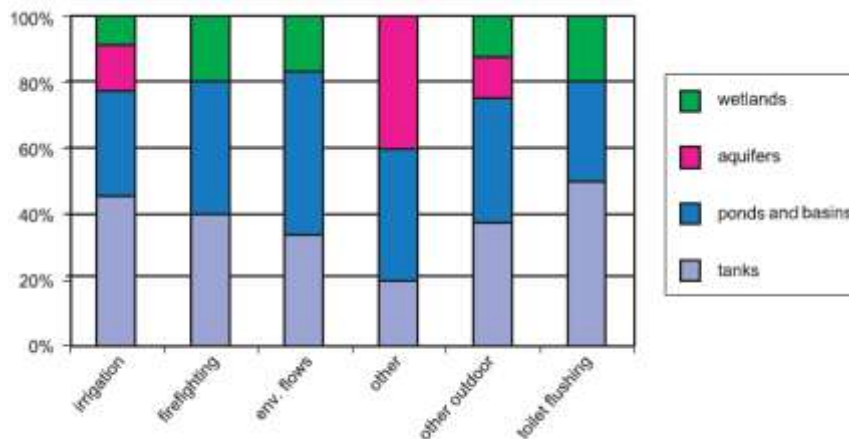


Figure 3.5 Percentage of storages used for various end uses (Hatt et al. 2004)

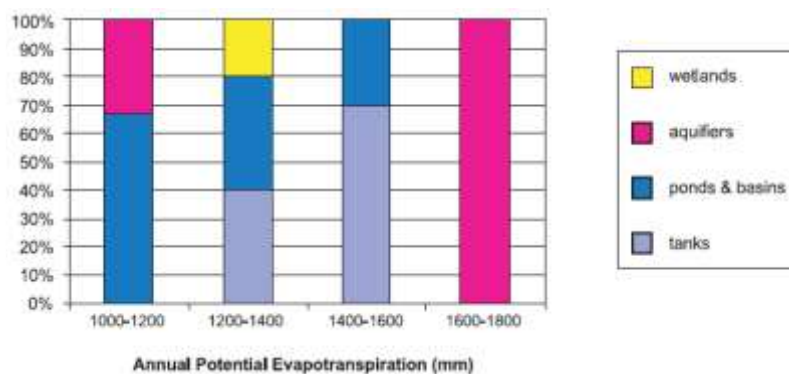


Figure 3.6 Influence of evaporation on storage type (Hatt et al. 2004)

In general, stormwater storages vary in terms of three key aspects: function, location and capacity (DEC 2006; Mitchell *et al.* 2006a):

- **Function** – Storages can be either single or multi-purpose and provide one or more of the following functions: water supply, flood mitigation, recreational amenity, aesthetic amenity, water quality improvement, habitat provision and fire-fighting supplies. Open storages are most commonly designed to achieve multiple objectives. See section 3.5.1 for a discussion of the issues surrounding utilising wetlands for stormwater harvesting storages.
- **Location** – Storages can be either inline with the waterway they harvest from or offline from a waterway. In the latter case the storage receives water through either pumping or flow diversion (see Table 3.4 for a comparison of inline and offline storages). Offline storages are suggested by DEC (2006) to be most appropriate for natural waterways. Storages may also be located above or below ground in tanks or through injection into aquifers.
- **Capacity** – storage capacity will vary according to the reliability of supply required for a given end use in a local climatic regime (refer to section 3.5.2).

Table 3.4 Comparison of online and offline storages (DEC 2006a; Mitchell et al. 2006a)

Consideration	On-line storage	Off-line storage
Barrier to fish passage and connectivity of aquatic ecosystems	Potential barrier if constructed on natural channel	No or little impact
Downstream water quality benefits (additional to use benefits)	Relatively high	Relatively low
Potential for scouring of natural channels downstream of storage	Relatively high	Negligible
Relative yield for a given storage volume	Slightly higher	Slightly lower
Spillway costs	Relatively high	Negligible
Maintenance costs (e.g. sediment removal)	Relatively high	Relatively low
Flood mitigation	Effective if appropriately designed	Negligible

3.5.1. Utilising Wetlands for Stormwater Storage

As discussed in Section 3.4.1, natural and constructed wetlands are commonly used in Australia and overseas for stormwater runoff treatment. The use of wetlands has the combined benefit of providing a storage body for the treated stormwater in stormwater use schemes. Despite this advantage, several considerations must be taken into account (Wong and Geiger 1997, Mitchell *et al.* 2006a, Greenway *et al.* 2007, Jenkins and Greenway, 2007). For example:

- There is a need to protect the treatment aspects of the wetland from high flows and bypass water when the wetland is full, consequently yields may be reduced;
- Losses due to transpiration, seepage and evaporation. The latter two may be substantial when use capacity is added after construction;
- Stormwater wetlands are subject to a wide range of hydraulic loadings and serve multiple functions. As a consequence, their depth range tends to be wider than wastewater wetlands;
- Wetland vegetation may have specific water depth requirements, which water level fluctuations associated with harvesting may violate;
- The effect of the wetland bathymetry and inundation zones on the vegetation and treatment abilities of the wetland; and
- Aesthetic impacts associated with exposed, muddy banks.

In order to alleviate these design conflicts it is recommended that they be considered at the design stage if multipurpose wetlands are to be constructed (Mitchell *et al.* 2006a). The first two above conflicts can be mitigated through yield modelling using a model such as MUSIC (Cooperative Research Centre for Catchment Hydrology 2005). Yield modelling allows various bypass regimes to be evaluated in terms of yield and treatment performance. If a wetland can be constructed that is 1-1.5% of the catchment area it is generally possible to capture 80-95% of the mean annual flow using either a high flow bypass channel, or inlet structures designed to capture up to a three month average ARI and divert flows greater than this (Mitchell *et al.* 2006a). In terms of seepage losses from wetlands retrofitted for harvesting, yield modelling can be used to determine whether the cost of installing a relatively impervious compacted clay liner is justified (Mitchell *et al.* 2006a). Previous modelling of evaporative losses indicates that it generally has a minor impact on yield (less than 10%) (Mitchell *et al.* 2006a).

Design issues related to vegetation and aesthetics are complex and can be addressed with either vegetation optimisation using bathymetry, landscape design, operating rules and/or external storage (Mitchell *et al.* 2006a). It is important in the design of constructed stormwater treatment wetlands that the adopted bathymetry provides a balance between adequate storage volume and the provision of vegetation sites, so that the maximum treatment of contaminants entering the system is achieved (Greenway *et al.* 2007). Identifying appropriate vegetation for a particular wetland's water level fluctuations requires a continuous simulation model such as MUSIC to simulate inflows, and a digital terrain model of the wetland bathymetry (Mitchell *et al.* 2006a). The results of the modelling can then be used to develop a probability distribution of the likely duration of inundation depths, for different sections of the wetland banks. This information can be used in combination with guidelines for the appropriate bathymetry and inundation depth regimes for Australian wetland vegetation (Wong *et al.* 2005) to determine suitable vegetation types for the zones of the wetland outlined in Figure 3.7 (Mitchell *et al.* 2006a).

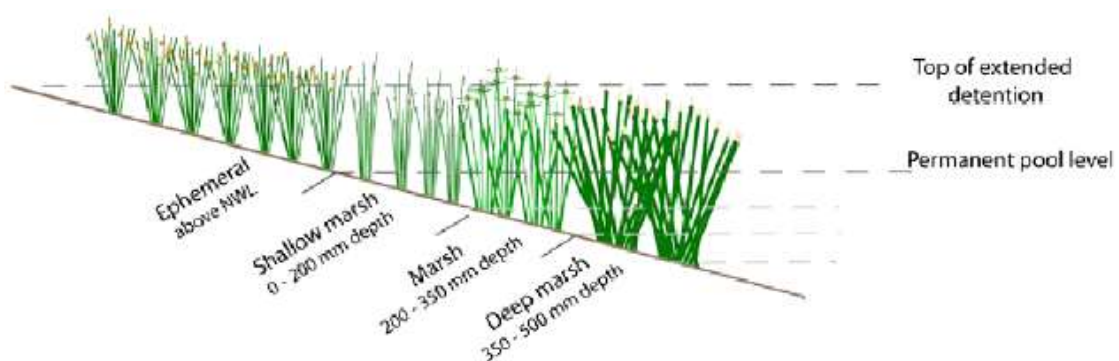


Figure 3.7 Typical water level zones in relation to vegetation within a wetland (Hoban *et al.* 2006)

For constructed wetlands, the bathymetry of the wetland is a key design feature for maximising the vegetative zones of the wetland, and hence increasing the level of treatment the wetland provides. Jenkins and Greenway (2007) found that modifying the bathymetry of the wetland can result in improvements to the inundation characteristics which will result in larger vegetation zones, and therefore higher quality treatment of stormwater runoff. Alternatively the study also found that lowering the outlet structure also increases the area of vegetation zones, however the extended depth of inundation during storm events may adversely affect vegetation survival.

The tolerance of the selected vegetation species to inundation above or below average depths should also be determined. Although this data is not available for Australian species at present, it has been suggested that plants can survive steady-state inundation depths approximately two thirds of their height (Hoban et al. 2006). Duration of inundation will also affect vegetation establishment and should be assessed during the course of modelling to determine if vegetation should be moved higher or lower within the wetland banks to account for longer or shorter periods of inundation (Mitchell et al. 2006a). Given the above limitations, species with the greatest tolerance to water level fluctuations should be preferentially selected.

The provision of deep pools in the wetland layout, void of vegetation also provides important treatment aspects and should also be included in the design of wetlands. These pools provide areas suitable for harvesting and aesthetically pleasing open water areas. However, some of these deep ponds are required purely for treatment purposes, and are unsuitable for harvesting storage.

Landscape design can be used to ensure the aesthetic values of a wetland are maintained throughout stormwater harvesting. For example, in order to avoid exposed muddy banks a permanently full storage can be constructed around the perimeter of the wetland to maintain appearances, while the majority of the storage volume can be harvested from in relative anonymity (see Figure 3.8) (Mitchell et al. 2006a). Another option for maintaining aesthetics is to enforce an extraction regime that avoids excessive exposure of banks, although the impact on yield from such regimes should be assessed through modelling (Mitchell et al. 2006a). If appropriate an external storage could be installed to preserve optimal water levels in terms of vegetation requirements, and simultaneously reduce seepage and evaporation losses (Mitchell *et al.* 2006a).

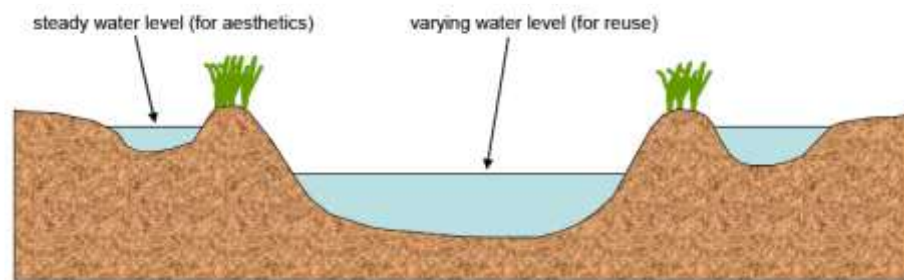


Figure 3.8 Wetland landscape designed to maintain aesthetics (Mitchell et al. 2006a)

3.5.2. Storage Capacity

As the primary function of storage reservoirs is to ensure that end use demands are satisfied in a local climatic regime, the required storage capacity is dependant on a complex interaction between magnitude and variability of supply and demand, and the desired supply reliability and yield (see Table 3.5) (DEC 2006, Mitchell *et al.* 2006a). For example in situations where demand represents a significant proportion of supply, and high levels of supply reliability are required, substantial storage volumes will be required (DEC 2006). Given the majority of end uses for a stormwater use scheme will have backup potable water supply, lower supply reliability will be required for a stormwater storage (70%) compared to a potable urban water supply dam (95%) (Mitchell *et al.* 2006a). However, the desired supply reliability remains a strong influence on the required storage capacity (see Figure 3.9) (Mitchell *et al.* 2006a).

Table 3.5 Relationship between factors affecting storage capacity (DEC (2006))

Increasing	Constant	Effect
Storage size	Demand	Yield and reliability of supply increase
Demand	Storage size	Yield increases, but reliability of supply decreases

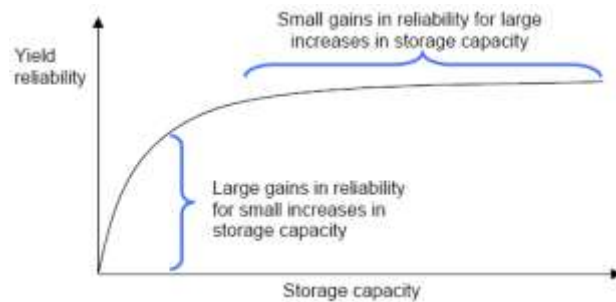


Figure 3.9 Relationship between yield reliability and storage capacity (Mitchell et al. 2006a)

Storage capacity can be separated into active, dead and flood mitigation storages or zones (see Figure 3.10) (Mitchell *et al.* 2006a). The active zone of the storage is the volume that can be harvested for use under normal conditions (Mitchell *et al.* 2006a). The dead zone represents the volume reserved to ensure a minimum water quality and allow for the build-up of sediment, which is vital for harvesting systems that do not undergo treatment prior to storage given the high levels of sediment present in stormwater (DEC 2006). The presence of a flood-mitigation zone is most common in storages inline with waterways.

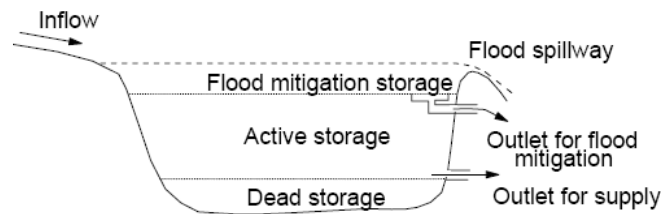


Figure 3.10 Zones within an open storage reservoir (Mitchell et al. 2006a)

Due to the limited open space available for stormwater storages within new and existing urban areas, Mitchell *et al.* (2006a; 2005a) undertook research to determine the optimum supply reliability achievable within these constraints. The authors evaluated several scenarios of varying climates, demand patterns and development densities using a model developed specifically for the task, the Use Analysis Tool (RAT). RAT evaluates the active storage required for different harvesting regimes, excluding flow routing and environmental flow analysis. Mitchell *et al.* (2006a; 2005a) compared the climates of Melbourne (relatively constant rainfall) and Brisbane (seasonal rainfall) in terms of stormwater storage requirements. The authors concluded that the relatively constant rainfall and inflows to Melbourne storages ensured minimal storage capacity was required to produce high supply reliability for constant demands such as toilet flushing. For large, highly seasonal demand significant storage capacity was needed to ensure high volumetric reliability (Mitchell *et al.* 2006a). In Brisbane which has seasonally varying rainfall yet relatively constant irrigation demand, it was found there is less need for prioritising between indoor and outdoor end use (Mitchell *et al.* 2006a; Mitchell *et al.* 2005a). These studies found that low development densities had the highest seasonal demand due to high irrigation demand, however, these areas also had significant space available for storages. Conversely, constructing stormwater storages in high density areas faces considerable space restrictions. In high density areas seasonal demand will be reduced, due to less open space, but constant demand for indoor uses will increase (Mitchell *et al.* 2006a). Although higher impervious levels will increase inflows into storages, this appears to be offset by the increased demand (Mitchell *et al.* 2006a).

3.6. Distribution

The required form of distribution is determined by a number of factors, including the spatial scale of the distribution area (e.g. a single open space area such as a park or golf course, through to thousands of residential properties), the density of the end uses (if there is more than one) and the inclusion or exclusion of fire fighting requirements within the stormwater distribution system (Mitchell *et al.* 2007b). The provision of collected and treated stormwater on a regional scale would require a storage and distribution system which is separate from the potable water supply system (WBM 1999). Currently stormwater use practices for larger scale systems employ two broad categories of stormwater distribution systems: open space irrigation systems, and non-potable distribution systems (also referred to as dual reticulation) (Mitchell *et al.* 2007b). Hatt *et al.* (2004) showed that irrigation systems are the most common method employed for stormwater distribution, followed by dual reticulation and pumping, as illustrated in Figure 3.11. The use of irrigation systems was restricted to use schemes with catchment area under 200 ha. Dual reticulation, where potable water is piped through the usual mains and recycled water is distributed through a separate purple pipe, is a viable distribution option for use schemes from the neighbourhood scale up (Hatt *et al.* 2004).

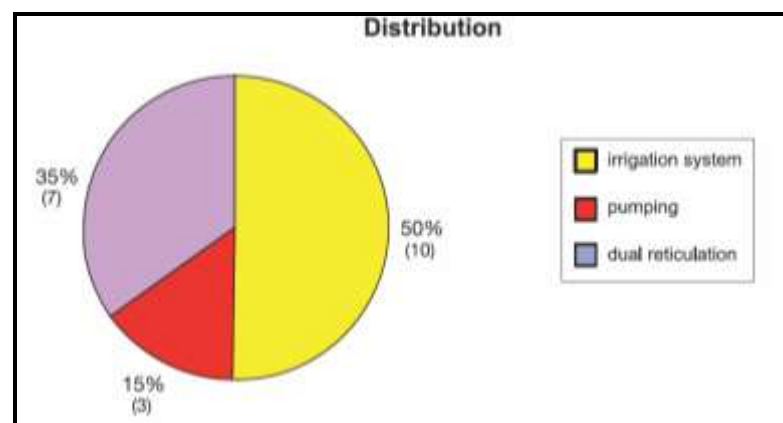


Figure 3.11 Frequency of distribution methods (Hatt *et al.* 2004)

Mitchell *et al.* (2006a) highlighted key points for consideration in the design of the distribution system of a stormwater harvesting scheme:

- **Consideration of customer requirements** – Can the timing of the demand be easily regulated, such as irrigating, or is a constant supply required, for example toilet flushing?
- **Adjusting design criteria** – The type of end use impacts on the design criteria and the level of reliability required. If a non potable distribution system does not provide water to an essential end use such as fire fighting, then a lower level of supply reliability may be appropriate. The pressure of the distribution system will need to be maintained at a high level at all times including during peak hourly demand periods.
- **Selecting design peak factors** – The peak hourly rate of water usage is a key parameter used to design the size of delivery pumps and pipes, and therefore will strongly influence the cost of the system. The appropriate peak factor depends on a number of site specific parameters. Gold Coast City Council's Land Development guidelines state different peaking factors for the dual water distribution system that depend on land use, with lower values for industry and higher values for residential dwellings.
- **Methods for peak levelling** – Peak levelling reduces the maximum hourly demand and therefore has the potential to decrease the cost of the distribution system. Peak levelling can be achieved by a variety of methods, the two main methods are: requiring on site or point of use storage, and scheduling different demands to distribute the load on the system.

- **Controlling distribution of non potable water** – The fundamental principle in the design of a stormwater harvesting distribution system is the prevention of any cross connections to avoid potential health risks. To prevent the accidental misuse of the stormwater from an unintended application a range of measures can be taken including signage, the use of taps and hose connections that are incompatible with those used in the potable system, and the removal or locking of taps etc when the stormwater is not being used. In non potable distribution systems, both the distribution system and the point of use i.e. taps must be clearly marked as supplying non potable water. The use of purple pipes to distinguish non potable recycling systems is becoming standard within Australia.
- **Minimisation of bacterial and algal build up** – The nutrient levels acceptable in the non potable system depending on the end use, may be higher than those found in potable water supply. This can lead to problematic levels of bacterial and algal build up in the distribution system. This can be managed using appropriate treatment measures as discussed in Section 3.4 .
- **Corrosion risk** – The salt and pH levels in the stormwater may result in higher corrosion risk for the distribution system.
- **Drainage of distribution system** – The distribution system should be designed to minimise environmental risk if flushing of the system for maintenance is required or a pipe bursts.
- **Identification of distribution system key risk points** – A standard part of the design process for the nature of the water to identify all key risk points and identify appropriate mitigation/management plans.
- **Converting an existing potable distribution system** – There may be situations where a potable distribution system is converted to a non-potable system, with say a smaller potable water system constructed in place of the old potable distribution system. USEPA (1998) presents research which recommends the installation of a new, smaller, potable water system and conversion of the existing system to non-potable supply. If this approach is taken, considerable effort should be made to ensure there are no cross connections.
- **Converting existing irrigation systems** – An existing open space irrigation system could easily switch to using non potable water. A key part of the conversion process would be to ensure there are no cross connections.
- **Metering usage** – This is an important mechanism for determining water use in the system, and possibly billing.

3.7. Summary

Figure 3.1 illustrates the non-linear and complex relationships between the various components used in stormwater harvesting systems. The above discussion has highlighted the breadth of the technology and practices available for stormwater harvesting, and clearly shows there is no single correct way to undertake this activity. While this allows stormwater harvesting and use to be applied in a wide variety of situations, it also introduces an element of uncertainty as there is no industry standard application for this water source option. Selection of appropriate components of the system and their design requires consideration on a case by case basis for stormwater harvesting systems.

4. REGULATIONS AND LEGISLATION

Mitchell *et al.* (2006a) proposed that stormwater harvesting systems should not only be undertaken with end use in mind, but should also take into account the range of other guidelines, regulation and legislation which may be applicable to the scheme, such as:

- Environmental protection policies, regulation and licenses, covering protection of receiving waters and in-stream habitat;
- Diversion limit requirements and the potential need for extraction licenses;
- Groundwater extraction/injection requirements;
- Dam safety requirements (depending on the nature of the stormwater store); and
- Dual reticulation and plumbing codes.

4.1. National

Figure 4.1 illustrates the policies and guidelines applicable to recycled water and the relationships between the various components. Of main interest to this project are the ANZECC guidelines for fresh and marine water quality, the Australian drinking water guidelines for cases of potable use, and the water recycling guidelines including the stormwater specific guidelines.

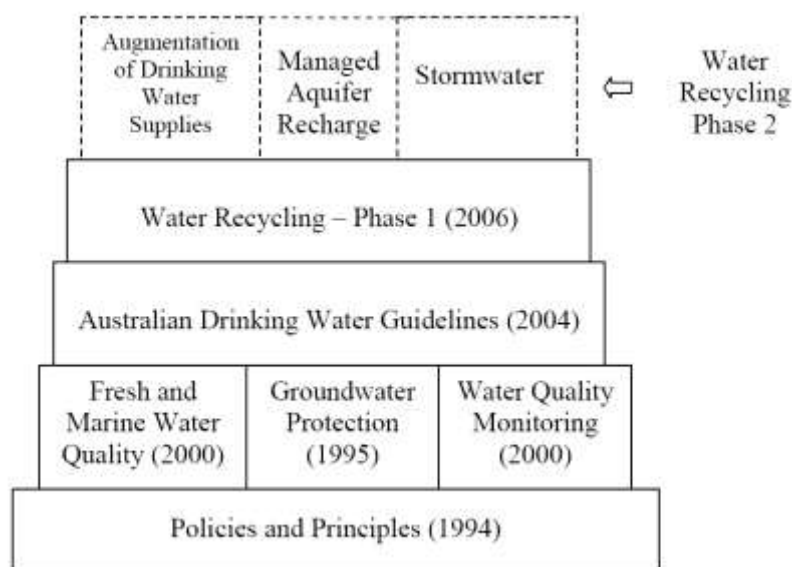


Figure 4.1 National framework for water quality (EPHC 2008)

- **ANZECC Guidelines for Fresh and Marine Water Quality** – The guidelines are part of an overall objective to define and protect the environmental values of water resources from the effects of degradation in order to achieve a sustainable use of the nation’s water resources. As part of this, environmental values are required to be developed in line with community needs and the water quality maintained in accordance with the environmental values to be protected. The guidelines consider five environmental values:
 - Ecosystem protection (both inland and marine), including protection of waters used for shellfish and fish production and by wildlife;
 - Recreation and aesthetics;
 - Raw water for drinking water supply;

- Agricultural water; and
- Industrial water.

The guidelines have incorporated recent overseas criteria with relevant Australian information in the development of water quality objectives. These guidelines do not override any state and territory or council requirements.

- **Australian Drinking Water Guidelines** - The Australian Drinking Water Guidelines (ADWG) provide a framework for managing drinking water supplies to ensure safety and aesthetic quality at point of use. The ADWG are not mandatory standards, however, they provide a basis for determining the quality of water to be supplied to consumers in all parts of Australia. These determinations need to consider the diverse array of regional or local factors, and take into account economic, political and cultural issues, including customer expectations and willingness and ability to pay.
- **National Guidelines for Water Recycling, Managing Health and Environmental Risks** – As a part of the National Water Quality Management Strategy a series of guidelines are in development for water recycling in Australia. *Phase 1 Managing Health and Environmental Risks* was released in November 2006. The Phase 1 guidelines deal primarily with grey water and sewage use. Phase 2 of the guidelines includes modules on stormwater use and augmenting drinking water supplies (see below).
- **Australian Guidelines for Recycled Water: Stormwater Harvesting and Use** – These draft guidelines released in May 2008 provide a set of operating principles and technical procedures to make sure that water recycling is safe for people and the environment. The stormwater harvesting and use guidelines apply to the capture of stormwater runoff from urban areas and rainwater from non-residential roofs, for purposes other than drinking. The recycling of water for drinking is covered by different guidelines – the Australian Guidelines for Water Recycling: Augmentation of Drinking Water Supplies (Phase 2: Module 1) and the Australian Drinking Water Guidelines. The guidelines detail a comprehensive 12-step system based on a preventative risk management approach for ensuring the safe operation of water recycling facilities and schemes. These guidelines do not override any state and territory or council requirements.
- **Australian Guidelines for Recycled Water: Augmentation of Drinking Water Supplies** – The first module undertaken in Phase 2 of the development of the guidelines, extends the guidance given in Phase 1 on the planned use of recycled water including both treated sewage and stormwater to augment drinking water supplies. The document focuses on the source of water, initial treatment processes and blending of recycled water with drinking water sources.

4.2. South East Queensland

Table 4.1 lists the relevant stakeholders and their functions in relation to harvested water in the SEQ region.

Table 4.1 SEQ relevant agencies and stakeholders (Hogan pers com, 2008)

Agency	Role
Dept. of Natural Resources and Water	Manages freshwater, including water resource planning and allocation Regulation of water service providers Drought contingency
Queensland Water Commission	Plans for water security in SEQ Facilitates infrastructure development and the implementation of regional water security programs Ensures compliance with programs and water restrictions
Queensland Treasury	Provides upfront funding of major infrastructure through government owned corporations
Dept. of Infrastructure and Planning	Responsible for facilitating, undertaking or procuring water infrastructure projects and planning and building requirements to improve water management
Dept. of Local Government, Sport and Recreation	Administers state subsidies to council funded water and sewerage infrastructure projects
Environmental Protection Agency	Manages tidal and coastal waters Oversees the regulation of water quality for the environment and licences businesses whose activities can impact on water quality
Queensland Health	Sets standards of water quality for drinking Sets health related standards for recycled water sourced from sewage
Local Governments	Local government policies, guidelines and plans Local government funded projects

Understanding the local policies and guidelines is essential in establishing stormwater harvesting projects. The following points discuss a selection of the relevant policies and guidelines operating in the SEQ region:

- **Water Resource Plans for SEQ catchments** – Catchment-specific water resource plans have been developed to determine current and future water demands and allocation priorities. Plans applicable to the SEQ region are Condamine-Balonne, Mary, Moreton, Gold Coast, and Logan Water Resource Plans. Major stormwater harvesting projects would need to be compatible with objectives set down in the WRP, or require legislative change. For example there are provisions for the regulation of capture or interference with overland flow in the Moreton catchment.
- **SEQ Water Strategy** – as discussed in section 1.1, the Queensland Water Commission have developed *Water for today, Water for tomorrow - South East Queensland Water Strategy* [draft] (2008). This document outlines a 50 year strategy for securing water supply for South East Queensland in an integrated and sustainable manner. Stormwater harvesting practices in SEQ to date were identified to provide a boutique solution requiring more research to identify opportunities within the region.
- **SEQ Water Supply Reform** – The establishment of the SEQ Water Grid is part of a new model to re-align the management of water and streamline SEQ’s previously complex water supply arrangements. These new institutional arrangements initiated by the Queensland Water Commission (QWC) align ownership and control of water assets with public accountabilities so that the Queensland Government is accountable for water supply security and in control of the water and assets to deliver that security. Figure 4.2 illustrates the proposed structure of the urban water supply system in SEQ as outlined in the Draft SEQ Water Strategy, March 2008.

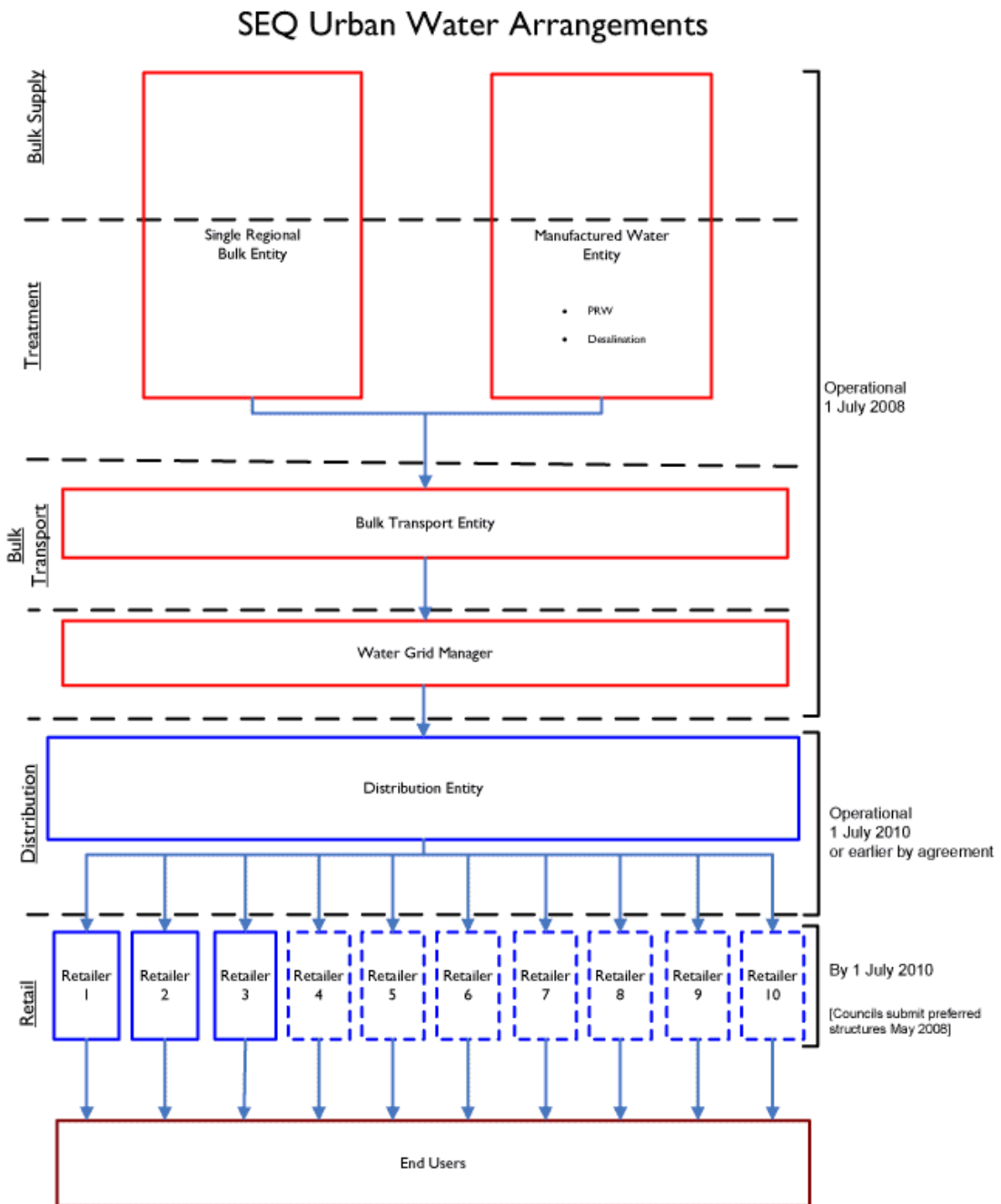


Figure 4.2 SEQ Urban Water Arrangements (QWC, 2008)

- **Environmental Protection (Water) Policy 1997** – This has the purpose of achieving the object of the Environmental Protection Act 1994 in relation to Queensland waters. The purpose is to provide a framework for:
 - Identifying environmental values for Queensland waters;
 - Deciding and stating water quality guidelines and objectives to enhance the environmental values;
 - Making consistent and equitable decisions about Queensland waters that promote efficient use of resources and best practice environmental management; and
 - Involving the community through consultation and education, and promoting community responsibility.

- **Water Act 2000** – The Water Act provides for sustainable management and efficient use of water in Queensland by establishing a system for the planning, allocation and use of water.
- **Queensland Water Recycling Guidelines** – The Queensland Water Recycling Guidelines were released in December 2005. The guidelines were developed to fulfil the requirements of the Queensland Water Recycling Strategy (2001) and use the same risk management framework adopted under the national guidelines. The guidelines promote sustainable use of recycled water sourced from sewage treatment plants predicated on the protection of public and environmental health using appropriate control measures at the point of use. Various treatment classes specified dependent on end use (Table 4.2).

Table 4.2 Classes of recycled water use (EPA 2005)

Class	Suitable Use
Class A+	Domestic and commercial property use Food crops (consumed raw) Retail nurseries Industrial use Fire fighting and aquifer storage and recovery
Class A	Unrestricted use on food crops not consumed raw Public open spaces Same uses as Class A+ except where risk is lower
Class B	Pasture with dairy animals
Class C	Restricted access on recreational areas Pasture/fodder for animals
Class D	Non food crops

- **Surface Water and Groundwater Management Policy** – The Water Act 2000 provides a water planning framework for water entitlements, adequate environmental flows, and future water use options. Water allocations can be traded separately to land in some areas of Queensland based on the applicable water resource plan. Resource operations plans give effect to the water resource plans and define allocations, operations and trading rules and conditions at the operational level. The central Lockyer Valley contains the only declared groundwater management area within the study area.
- **Guidelines for Financial and Economic Evaluation of New Water Infrastructure in Queensland** – Under the Water Act (2000), the Queensland Government has an increased focus on strategic water resources planning. Within the water industry framework, the guidelines outline the rationale and processes for financial and economic analysis of investment in new water infrastructure. Specifically these guidelines indicate that new water infrastructure should only proceed where they can be demonstrated to be economically viable and ecologically sustainable.

Additionally in the local region there are guidelines specifically related to stormwater collection and harvesting. Design guidelines for stormwater harvesting systems may also be applicable in the various council areas. There are currently guidelines under way for Brisbane City Council areas on a policy front. Gold Coast City Council currently have design guidelines for dual reticulation systems that may also need to be adhered to in any future harvesting schemes in the area. Healthy Waterways are currently developing technical design guidelines for stormwater harvesting infrastructure. The Healthy Waterways have also developed a set of design objectives for water sensitive urban design (Healthy Waterways, 2007). These objectives provide guidance on frequent flow management from an ecological perspective suggesting design runoff capture depths from impervious surfaces to allow for the changes in hydrology experienced in the urban environment. This guideline provides opportunities for stormwater capture and recovery. Collection of these small events will result in a harvesting of a large proportion of the total amount of runoff (Mitchell *et al.* 2007b). However, in harvesting for alternative water supply source opposed to ecosystem protection results in a different discussion regarding over abstraction. These issues are dealt with further in Section 5.2.

5. SOCIAL, ENVIRONMENTAL AND ECONOMIC PERSPECTIVES OF STORMWATER HARVESTING

5.1. Social Perspectives

5.1.1. Community Acceptance

Analogous to stormwater quantity and quality, community acceptance of stormwater schemes varies spatially and temporally. Surveys are generally the only means to assess a community's attitude toward stormwater use, but these only represent a snapshot in time and space. Community attitudes are influenced by a range of factors including knowledge of urban water issues; frequency and severity of water restrictions; familiarity with use of alternative sources; and either positive or negative support from water authorities, government agencies and researchers (Mitchell *et al.* 2006a, Nancarrow *et al.* 2007). In general, however, community acceptance is dependent on the individual characteristics of a stormwater use scheme such as: level of service expected from the supply; cost of the scheme; degree of human contact with water; benefit to the environment (such as protection of water resources); knowledge about water quality and the applications of the water; confidence in the water authority managing the scheme; measures implemented to protect public health and safety; and the income and education of the community involved (Mitchell *et al.* 2006a).

Community acceptance is crucial to a successful stormwater use scheme (DEC 2006; Hurlimann 2007). Although generally the community is more supportive of stormwater use than wastewater use (ACTEW 1994; ARCWIS 1999), this support is conditional on several factors. Community support declines when the end use of stormwater involves more personal contact (ARCWIS 1999; Hurlimann 2007; Radcliffe 2004). For example in a study on stormwater use, ARCWIS (1999) found 96% support for garden irrigation, 95% support for toilet flushing, 68% support for laundry purposes, 50% support for personal washing and 29% support for stormwater as a potable source. Although at present the majority of use schemes have irrigation end uses, research indicates that community attitudes are changing and there is generally increasing support for using stormwater for domestic end uses such as clothes washing and toilet flushing (DEC 2006).

The spatial scale of a use scheme also influences community acceptance. For example research indicates that acceptance is highest for either small household scale use or large centralised systems (Maheepala *et al.* 2004; Mitchell *et al.* 2006b). This trend is possibly a reflection of responsibility, as at the household scale individuals can control water quality, while at large scales legislation and/or regulations are likely to be in place to ensure a minimum water quality (Maheepala *et al.* 2004; Mitchell *et al.* 2006a).

There has been little research into community attitudes toward stormwater use for commercial or industrial purposes, but this holds great potential as these land uses represent a concentrated high demand (Mitchell *et al.* 2002).

Wegner-Gwidt (1998) outlines several steps that are crucial for community acceptance of wastewater use schemes, which are equally relevant to stormwater use schemes. These include:

- Being upfront and proactive;
- Developing a basic information campaign;
- Working with local media;
- Use of credible third party testimony;
- Presenting successful projects elsewhere;

- Being visible and creative;
- Increasing public awareness; and
- Using demonstration projects.

Research has shown that a crucial aspect of community acceptance for water use projects is that the process undertaken by authorities is seen to be fair and unbiased and a genuine partnership is developed with the community (Po *et al.* 2004; Radcliffe 2004). Although recycled water projects have been shown to be technically feasible, the Australian community has relatively little experience with recycled water use (Hurlimann 2007). Despite the fundamental role community acceptance has to play in successful water use projects, to date there has been little research conducted (Hurlimann 2007).

Community acceptance is also related to the perceived risk of a stormwater use scheme. An individual's perception of risk is dependant on a range of subjective factors such as complex aspects of emotion, values, beliefs, ethics, superstitions, preferences and attitudes (Daughton 2004). In a study focusing on marketing relationships, Selnes (1998) found that trust and satisfaction can reduce perceived risk. Trust also increases when information is communicated by sources which are seen to be unbiased (Anderson and Narus 1990; Frewer *et al.* 1996).

In relation to water use projects, Hurlimann (2007) found similar results from a survey of residents in a suburb of Adelaide, South Australia. For example, perception of risk was found to be significantly related to a lack of trust in the local water authority and a perception of being ill-informed and unfairly treated throughout the process (Hurlimann 2007). There was a strong relationship between trust in the local water authority to manage risks associated with a recycled water project and communication of information, perception of integrity and belief the water authority had a vested interest in the project (Hurlimann 2007). Consequently, community acceptance can be greatly enhanced by readily supplying accurate information in a fashion perceived as transparent and fair to local residents (Hurlimann 2007).

It is important to recognise the following points in relation to stormwater use projects and water recycling schemes in general (Radcliffe 2004):

- Opposition is commonly experienced when people are introduced to new concepts;
- Education of the public should be accomplished through a range of techniques and media;
- It is essential to involve the stakeholders (public, regulators, etc.) in the early stages of the project;
- Independence of information sources will increase trust;
- Specific community groups affected by a project should be individually targeted;
- Small public meetings should be conducted in preference to larger meetings;
- Personal communication is an effective means of communication for residential customers;
- Extensive information on a project should be made available to the public to avoid speculation;
- Approval from officials and the public can reinforce each other. Similarly political opposition candidates and opponents may also reinforce each other;
- To reduce negative connotations before a project begins, disruptions during the construction phase should be minimised;
- It should be reinforced that recycled water is also a finite resource; and
- Public consultation costs are relatively insignificant in relation to other project costs such as engineering work.

Brown and Clarke (2007) noted several key factors in the transition from traditional drainage practices to WSUD in Melbourne, Australia. Although not focused on stormwater harvesting, these factors are relevant for these projects. The factors included:

- **Socio-political capital** – presence of community and political concern for a subject.
- **Bridging organisation** – presence of a key entity that can unite stakeholders and facilitates learning and dissemination of resulting knowledge.
- **Trusted and reliable science** – the community’s view of the reliability and effectiveness of the scientific expertise involved in the project.
- **Binding targets** – scientifically informed, effective and measurable targets which bind industry to a standard of practice.
- **Accountability** – presence of formal responsibility for improvement of waterway health.
- **Strategic funding** – presence of the funding necessary to complete the necessary research and technology development.
- **Demonstration projects and training** – allows innovative technologies to be showcased and imparts practical knowledge on design, construction and maintenance processes that can be experienced.
- **Market receptivity** – presence of clear business opportunity.

During a survey of community attitudes toward stormwater management Nancarrow *et al.* (1995) found that on average the majority of respondents in Brisbane were willing to pay a relatively substantial amount of money to reduce the negative effects of stormwater on receiving waters. As one of the associated benefits of stormwater harvesting is a reduction in stormwater pollution, it may be reasonable to assume that residents would be willing to pay some amount for stormwater harvesting schemes, although this will need to be tested through further research.

A more recent study by Nancarrow *et al.* (2007) examined community acceptance of purified recycled water in South East Queensland. Part of the study involved assessing preferred alternative water sources. The results indicated that following rainwater tanks, stormwater irrigation, dual pipe systems, State transfers, purified recycled water and using grey water on gardens were the next most favourable alternative sources for the respondents (Nancarrow *et al.* 2007). This suggests that there is considerable community approval for stormwater use for irrigation purposes and, as dual pipe systems were also favoured, this may extend to using stormwater for non-potable internal uses such as toilet flushing. This will however need to be confirmed through targeted research and surveys.

5.1.2. Public Health and Safety

Stormwater use schemes potentially involve public health and safety risks (see Table 5.1). To reduce public health risks related to human contact with stormwater not treated to suitable levels, the following actions can be taken (DEC 2006):

- Operating rules can restrict use to times with minimal public activity;
- Surrounding landscape can be designed to reduce the risk of human contact with spray drift; and
- Subsurface irrigation systems can be employed.

Table 5.1 Summary of Stormwater Use Schemes Potential Hazards (modified from DEC 2006)

Area	Hazard
Public Health	Microorganisms (pathogens) in water: <ul style="list-style-type: none"> • Bacteria • Viruses • Protozoa • Helminths Chemical toxicants in water: <ul style="list-style-type: none"> • Inorganic chemicals (e.g. metals, nutrients) • Organic chemicals (e.g. pesticides, hydrocarbons)
Public Safety	Water storages (above ground – mainly open storages): <ul style="list-style-type: none"> • Drowning • Embankment failure/overtopping

Water quality in stormwater storages is pertinent to public health issues. Water quality issues are heightened when treatment levels are low and when stored water has long detention times, due to demand representing a small proportion of storage volume (DEC 2006). In general management of public health risks can be guided by the end use for the harvested stormwater and the criteria outlined in Table 5.2.

Table 5.2 Criteria for public health risk management associated with various end uses of harvested stormwater (ANZECC and ARMCANZ 2000; DEC 2004, 2006; NSW RWCC 1993)

Level	Criteria ¹	Applications
Level 1	<i>E. coli</i> <1 cfu/100 mL Turbidity ≤ 2 NTU ² pH 6.5–8.5 1 mg/L Cl ₂ residual after 30min or equivalent level of pathogen reduction	Reticulated non-potable residential uses (e.g. garden watering, toilet flushing, car washing)
Level 2	<i>E. coli</i> <10 cfu/100 mL Turbidity ≤ 2 NTU ² pH 6.5–8.5 1 mg/L Cl ₂ residual after 30min or equivalent level of pathogen reduction	Spray or drip irrigation of open spaces, parks and sportsgrounds (no access controls) Industrial use, dust suppression, construction site use (human exposure possible) Ornamental water bodies (no access controls) Fire fighting
Level 3	<i>E. coli</i> <1,000 cfu/100 mL pH 6.5–8.5	Spray or drip irrigation (controlled access) or subsurface irrigation of open spaces, parks and sportsgrounds Industrial use, dust suppression, construction site use, process water (no human exposure) Ornamental waterbodies (access controls)

¹ Values are median for *E. coli*, 24-hour median for turbidity and 90th percentile for pH

² Maximum is 5 NTU

In any storage with elevated organic matter levels and insufficient aeration, anaerobic conditions can develop due to the action of oxygen consuming bacteria (DEC 2006; EPHC *et al.* 2008). This can be a significant issue in closed storages where oxygen input from the atmosphere is limited. Upstream treatment measures and management of storage levels can be used to successfully control anaerobic conditions in storages.

Many of the public health and safety issues surrounding stormwater harvesting schemes, however, are centred on open storages. For example, long detention times and lack of nutrient removal can result in eutrophication and algal blooms (DEC 2006). If the bloom involves a toxin-producing species of algae it can pose a serious health risk to people coming into contact with water during irrigation, maintenance workers or members of the public playing or swimming in the storage (EPHC *et al.* 2008). To prevent the risk of algal blooms it is recommended that stormwater detention times do not exceed those presented in Table 5.3 (Melbourne Water 2005; EPHC *et al.* 2008). Design modifications can also be used to reduce the risk of algal blooms, such as (EPHC *et al.* 2008):

- Installation of gross pollutant and sediment traps, buffer strips, vegetated swales and bioretention systems in drainage lines leading to the storage; and
- Treatment of water flowing into the open storage to promote processes such as sedimentation, filtration, chemical adsorption and biological uptake.

Consequently at the planning stage, water balance modelling should be undertaken for all design options to determine the detention times likely to be experienced by a particular storage. Where the recommended detention times in Table 5.3 are exceeded measures should be taken to mitigate the risk of an algal bloom, such as nutrient removal before storage or diversion/demand operating rules to restrict conditions suitable for growth of problem algae. With any design combination water quality monitoring remains an important part of managing the health risk posed by algal blooms (EPHC *et al.* 2008).

Table 5.3 Recommended detention times to reduce risk of algal blooms (EPHC et al. 2008; Melbourne Water 2005)

Detention Time (Days, 20 th percentile)	Average Daily Temperature (°C)
50	15
30	20
20	25

Note: based on assumptions that there are sufficient nutrients available for algal growth and there are no light limitations.

Another consideration for open storages is the possibility of waterbirds and animals depositing faecal matter containing pathogens (Abulreesh *et al.* 2004; DEC 2006). Waterbirds may be discouraged from a storage through the construction of relatively steep side slopes; having a minimum depth of 0.5m; and minimising macrophytes, aquatic plants, roosting trees and structures (EPHC *et al.* 2008). If waterbirds remain problematic, netting can be installed above the storage, followed by incorporation of a conservative additional 1 log reduction in pathogen levels in the treatment before end use system, and performance of a detailed health risk assessment supported by monitoring (EPHC *et al.* 2008). Generally however, wild birds introduce only low levels of bacterial pathogens which are infectious to humans and consequently do not present a significant additional risk to users of non-potable water (EPHC *et al.* 2008). If birds and animals are suspected of feeding on sewage treatment plant areas or tip refuse, added risks may arise (EPHC *et al.* 2008).

Open storages may also promote mosquito breeding. In temperate and tropical locations it is important to minimise the associated public health risks of mosquito-borne diseases (EPHC *et al.* 2008). This can be achieved through the following (DEC 2006; Queensland Health 2002; Moreton Bay Waterways and Catchment Partnership 2006):

- Locating the storage so the prevailing wind direction will promote wave action;
- Design of the storage to minimise stagnant areas of water;
- Provision of a permanent pool of deep water that will ensure survival of mosquito predators;
- Construction of steep side slopes;
- Ensuring a minimum operating depth of 0.3m;
- Minimise the growth of aquatic plants and water weeds;
- Selection of bank vegetation that will not invade the storage and design of a bank gradient that minimises vegetation growth;
- Allow for field operators to monitor and treat mosquito larvae; and
- Ensure that monitoring practices (for example creation of wheel ruts) do not create localised depressions which may result in isolated, shallow pools of water.

Public safety issues surrounding open storages will depend on local conditions, but in general are pronounced when the public, and in particular children, have access to the site. It is recommended that barriers be constructed on top of concrete or stone walls if a storage has any of the following characteristics (Moreton Bay Waterways and Catchment Partnership 2006):

- There is a risk of serious injury if a fall occurred (banks more than 0.5m high and too steep to easily walk up and down, or the lower surface has sharp or jagged edges);
- It is located in an area with high pedestrian or vehicular exposure (for example near footpaths, sports fields or playgrounds);
- There is water on constructed surfaces of concrete or stone to a depth of greater than 300mm;
- It is likely to contain concentrated pollutants; and
- There are adjacent areas which require mowing.

These barriers could include a pool fence compliant with Australian Standards for areas where there is a drowning or infection hazard, a galvanised tubular handrail in other places or, if vandalism is not an issue, a dense hedge of vegetation at least 2m wide and 1.2m high (Moreton Bay Waterways and Catchment Partnership 2006). Adequate signage must also be installed, that is compliant with AS 1319 Safety Signs for the Occupational Environment, to inform the public of potential risks (Hatt *et al.* 2004; DEC 2006). If appropriate the following actions should also be taken to ensure the safety of the public (Hatt *et al.* 2004):

- Remediation of any contaminated soil present on site during construction; and
- Storage tanks and ASR headworks should be placed underground or have restricted access. Similarly access must be restricted where open storages are single purpose only.

Although it is recommended that open storages are designed with shallow side slopes to allow people to exit easily should they fall in (DEC 2006), this is in contradiction to measures to prevent other issues surrounding open storages. Therefore careful planning is needed in open storage design which accounts for the local conditions likely to be experienced by a particular storage.

As the principal function of stormwater drainage systems is flood mitigation and preventing infrastructure foundations from becoming water-logged, elevated flood risks due to stormwater harvesting schemes must be assessed (Mitchell *et al.* 2006a; Walsh *et al.* 2004; EPHC *et al.* 2008). Stormwater harvesting schemes that involve installing a weir across a drain or waterway may have backwater effects, increasing water levels upstream especially during high flow events. This may affect riparian vegetation, bank stability and result in the inundation of land adjacent the channel. Extensive surveys and modelling should be undertaken in the initial phases of the project to determine the backwater effects of the scheme and methods developed to mitigate any impact (Hatt *et al.* 2004). Harvesting of stormwater from flood retarding basins has been found to have a slight positive effect on flood mitigation, however the effect is more significant for smaller flood events, such as less than one in five year events (Mitchell *et al.* 2006a).

Overall, the sustainable use of stormwater should be guided by the following principles (NRMMC and EPHC 2005):

- Protection of public and environmental health should never be compromised;
- Application of control measures and water quality requirements should be proportionate with the source of recycled water and the intended uses; and
- Ongoing protection of public and environmental health depends on implementing a preventative risk management approach.

Risk assessment and management is a crucial aspect of the stormwater use design process, and is discussed further in section 5.1.3.

5.1.3. Risk Management

The concept of risk represents a combination of the likelihood of a threat occurring and the resultant impact of the threat if it did occur. Consequently consideration of the hazards outlined in Table 5.1 is required in the planning, design and operation stages of a stormwater use project to minimise the overall risk (Mitchell *et al.* 2006a). If risk assessment and management is considered only in the operational stage of a project, the costs of risk mitigation is likely to substantially increased (DEC 2006).

As relatively little is known about the potential human health risks associated with stormwater use compared to greywater or wastewater use, the preventative and proactive nature of risk assessment has obvious advantages (Mitchell *et al.* 2006a). As water use is a relatively new practice for urban areas, a high profile public health or environmental failure could easily undermine public confidence and hinder the adoption of this necessary technology (Hatt *et al.* 2004). Consequently monitoring of stormwater should only be used to validate a risk management approach, not as the principal risk management activity due to the inevitable time lag between collection of samples and obtaining

monitoring results (DEC 2006). The method used to identify and assess hazards must be structured, consistent, comprehensive and transparent. This involves the identification of hazardous contaminants and their sources, identification of events that could lead to exposure of humans or the environment, the determination of risks along which different hazards can be ranked and finally the establishment of a set of actions to mitigate risks (EPA 2005).

The draft national guidelines for water recycling (NRMMC and EPHC 2005) contain a risk-based framework for evaluating hazards. The framework adopts a preventative approach and includes elements of hazard analysis and critical control point (HACCP) assessment and Australian (AS/NZS 4360) and international (ISO 9001) risk assessment standards, adapted to apply to recycled water and more specifically stormwater in Phase 2 of the guidelines (refer section 4.1).

The Australian – New Zealand risk management standard (AS/NZS 4360) includes a variety of approaches regarding the evaluation of hazardous events, their potential impacts and likelihood of occurrence. The ability to accurately quantify impacts and their likelihood is a function of the quantity, quality and availability of information related to the issue. Different levels of information can be taken into account by using qualitative, semi-quantitative and fully quantitative evaluation approaches where the latter approach implies the highest state of knowledge including the specification of probability distributions to quantify likelihoods. As little is known about the potential human health risks associated with stormwater use a qualitative approach is a suitable method for application as both impact and likelihood are qualitative descriptors. The risk evaluation can then be performed by means of an impact-likelihood matrix as shown in Table 5.4. Other risk assessment tools used in water use schemes include Quantitative Risk Assessment (QRA) and Quantitative Microbial Risk Assessment (QMRA) (Mitchell *et al.* 2006a).

Table 5.4 Qualitative risk analysis matrix showing level of risk (EPA 2005)

Likelihood	Impact				
	1 <i>(insignificant)</i>	2 <i>(minor)</i>	3 <i>(moderate)</i>	4 <i>(major)</i>	5 <i>(catastrophic)</i>
A <i>(rare)</i>	Low	Low	Low	Medium	High
B <i>(unlikely)</i>	Low	Low	Medium	High	High
C <i>(moderate)</i>	Low	Medium	Medium	High	Very high
D <i>(likely)</i>	Low	Medium	High	Very high	Very high
E <i>(almost certain)</i>	Low	Medium	High	Very high	Extreme

Beyond identifying possible hazards, estimating likelihoods and consequences, and undertaking risk analysis; a comprehensive risk management process also includes an evaluation stage where risks are prioritised and mechanisms to reduce risks are suggested. A monitoring stage finally controls the performance of the suggested mechanisms. These control mechanisms imply the definition of critical control points, quality control points, control measures as well as critical limits for these control measures that indicate if taking action is required. The monitoring stage also includes a periodical audit and review of the implemented management plan. To ensure that standards are maintained or improved these audits should preferably be conducted by external parties.

5.2. Environmental Aspects

The impacts of urban stormwater on receiving waters are well known, and include degraded water quality, flow induced erosion and habitat loss (House *et al.* 1993, Marsalek 1991; Novotny and Witte 1997; Rutherford and Ducatel 1994; Walsh 2000; Wong *et al.* 2006). The consequence of changes to these indicators is degradation in the structure, composition and function of aquatic ecosystems (Booth and Reinelt 1994; Roy *et al.* 2003; Walsh *et al.* 2005; Walsh *et al.* 2000; Mitchell *et al.* 2007a). Predicting site specific impacts of urbanisation on runoff levels and stormwater quality is complex due

to the spatial and temporal interaction of contributing factors. For example in terms of water quantity, volumes are influenced by levels of imperviousness and connectivity of those surfaces to receiving waters. In terms of water quality, the chemical characteristics of stormwater are dependent on the nature of the surfaces (roads, roofs etc) with which it comes into contact during the runoff process as well as natural processes and anthropogenic activities in the catchments (Goonetilleke *et al.* 2005; Eriksson *et al.* 2007).

The changes in hydrology and water quality related to stormwater harvesting in an urban environment and the treatment measures required for use, have the potential to shift the receiving ecological systems back towards pre-development conditions. For example, pollutants are removed both through the extraction of water, and also through the treatment processes within the stormwater use system (Fletcher *et al.* 2007, Mitchell *et al.* 2006a, Wong 2006). However, it is also acknowledged that stormwater harvesting could be detrimental to environmental health. For example if critical aspects of the flow regime which are necessary to maintain the ecological health and function of a waterway were changed away from, rather than toward, their pre-urban condition (Mitchell *et al.* 2006a; Fletcher *et al.* 2007). Additionally pollution of runoff, groundwater or soil may occur if inadequately treated stormwater is used for irrigation (DEC 2006). Identifying the impact of potential stormwater harvesting schemes is also a complicated task, due to the complexities in understanding the runoff quality from catchments which lack significant monitoring data.

Goonetilleke *et al.* (2005) report on an ongoing water quality research project established in 1999, based on the Gold Coast (Figure 5.1). This project has undertaken an in depth investigation of pollutant wash-off by analysing the hydrological and water quality data from three primary catchments and three sub catchments. Stormwater quality varied within all catchments and sub catchments. This can be attributed to the fact that the land use and land cover characteristics, spatial distribution of impervious areas and management practices of the three sub catchments are appreciably different and the results obtained reflect these differences.

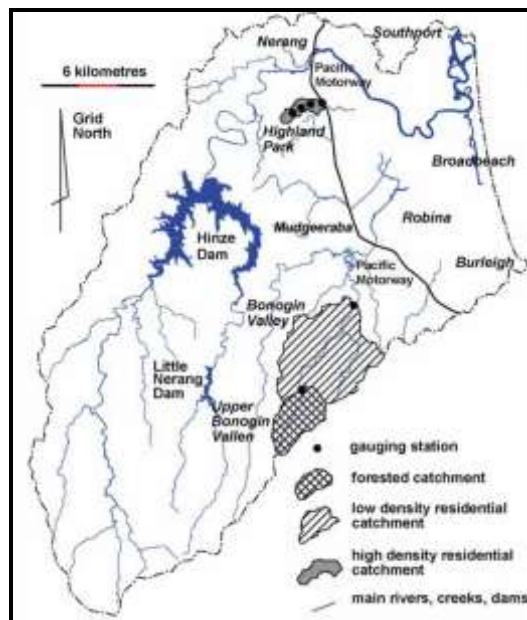


Figure 5.1 Locations of main catchments used in Gold Coast water quality analysis (Goonetilleke *et al.* 2005)

Mitchell *et al.* (2006a) and Fletcher *et al.* (2007) evaluated the impact of several stormwater harvesting scenarios on flow and water quality in Brisbane (sub-tropical climate) and Melbourne (temperate climate) using MUSIC (Cooperative Research Centre for Catchment Hydrology 2005). The studies found that in Melbourne stormwater harvesting in peri-urban and high density areas may result in over-extraction. For high density areas in sub-tropical climates, such as Brisbane, the characteristic high intensity short duration rainfall events may result in stormwater harvesting schemes increasing

the frequency of runoff (Mitchell *et al.* 2006a; Fletcher *et al.* 2007). This is due to the stormwater storage spilling and releasing water over several days, although peak flows will be reduced (Mitchell *et al.* 2006a; Fletcher *et al.* 2007). Similar results were found for pollutants loads, in that in Melbourne levels could be reduced to pre-development levels or below. In Brisbane pollutant loads could be reduced to near pre-development levels. Careful design and operation of stormwater harvesting systems are therefore necessary to ensure that the optimal solution is achieved for locally relevant flow and water quality targets (Mitchell *et al.* 2006a; Fletcher *et al.* 2007).

Online stormwater storages located on natural waterways may increase upstream flood levels with possible run on effects for riparian vegetation, aquatic ecosystem connectivity and cause erosion downstream (EPHC *et al.* 2008). The ecological health of these modified urban waterways may be dependent on a flow regime which is a “hybrid between pre- and post-development regime” (Mitchell *et al.* 2006a). Consequently local environmental impacts should be assessed on a case by case basis to develop appropriate mitigation measures.

One major issue that should be considered is the energy implications of the proposed stormwater harvesting scheme. Mitchell *et al.* (2006a) propose that the design of the system should aim to minimise both the embodied energy and the operational energy of the system. The majority of the embodied energy of a system will be determined by the pipe materials selected while the operational energy requirements will be determined by the amount of pumping required, which is in turn determined by the quantity of water being moved around and spatial characteristics of the distribution system. Minimising operational energy use may also coincide with an economical benefit in reducing the operation costs of the system.

5.3. Economic Considerations

At face value, stormwater harvesting schemes appear to impose an additional cost on urban water systems. However, there are a range of economic and non-market social and environmental benefits of stormwater recycling that need to be taken into account. Once these other aspects are considered, then stormwater recycling becomes a much more economically attractive option.

For instance, the introduction of stormwater harvesting schemes into urban areas may translate into a reduction of potable water usage from water mains. There are also savings associated with a reduction of the requirement to augment existing potable water storage and distribution systems to cater for new urban areas (WBM 1999). Furthermore, the construction of urban lakes and wetlands for stormwater storage and recycling purposes can increase property values due to aesthetic and recreational benefits. Many of the lakes in residential developments are actually stormwater detention or retention ponds. Developers usually design the wet ponds to look like natural lakes, which often enhances the value of surrounding property (US EPA 1995). Other financial benefits are gained by the multi-use of waterway corridors for recreation and environmental enhancement (WBM 1999).

The environmental benefits of stormwater recycling include pollution control, reduced flood risk and habitat provision. There are many financial benefits linked to improvement in these environmental services. For instance, savings may be achieved from the reduced need for downstream stormwater detention facilities (Taylor 2005). Also, there are likely to be considerable savings due to the removal of the requirement to clean up waterways of sediment, nutrients and debris from stormwater discharge (WBM 1999). Section 5.2 provides a more detailed discussion of environmental perspectives related to stormwater harvesting.

Table 5.5 summarises the multiple benefits that have been achieved by stormwater harvesting schemes in Australia and the United States.

Table 5.5 Costs and Benefits Associated with Stormwater Harvesting Schemes (Hatt et al. 2004)

	Costs			Benefits									
	Capital (\$' 000s)	Operating (c/KL)	User Price (c/KL)	Reduced demand for potable supply	Reduced discharge to waterway/ocean	Reduced discharge to sewage system	Delays need for drainage infrastructure upgrade	Pollution control	Environmental flow of improved quality	Abatement of former flooding problem	Nutrient recycling	Habitat Provision	Other ³
Altona Green	250		n/a	√	√		√	√					
Bowies Flat	2400 ¹		n/a	√	√			√	√	√		√	
CSU Thurgoona			n/a	√√	√√√	√√√		√	√			√	√
Figtree Place	109.0			√√√	√√		√	√					
Hawkesbury	3900 ²			√√√	√√√	√√	√	√	√		√		
Homebush Bay	15800 ²	180	77.5	√√√	√√√	√√	√	√	√			√	
Inkerman D'Lux	434 ²			√√√	√	√	√	√			√		
Kogarah	629			√√	√		√	√					
Manly STAR	1300		n/a	√	√			√					
Oaklands Park	73			√√√	√√√	√√√		√					
Parafield	4500	30		√√√	√	√√	√	√	√	√			√
Parfitt Square			n/a	√	√√		√	√					√
Powells Creek	400		n/a	√	√		√	√	√				
Santa Monica	16600	212		√√	n/a			√					
Solander Park	615		n/a	√	√√		√	√		√			
Taronga Zoo	2200 ²		n/a	√√	√√	√		√					

¹Capital cost of total redevelopment i.e. not just use component

²Includes capital costs for both stormwater and wastewater recycling

³Other benefits: CSU Thurgoona – part of the campus is unsewered; Parafield – provides local job opportunities and economic stability; Parfitt Square – aquifer recharge

A recent study by Marsden Jacob Associates (2006) has investigated the costs (unit cost – dollars per kilolitre) of the major water supply and demand options available to Australian cities, including stormwater use (Figure 5.2). The analysis is based on water supply plans for Sydney, Adelaide, Perth and Newcastle. Figure 5.2 shows that the stormwater use option compares favourably to other water supply augmentation options such as desalination, dams, rainwater tanks or long distance pipelines. However, comparing the unit costs for individual water supply options has several caveats. For instance, the unit cost approach may not fully capture the wider benefits and costs of different supply options (Productivity Commission 2008). Indeed, one of the main challenges of stormwater harvesting schemes is the fact that many of the environmental and social benefits, including environmental flows, flood protection, pollution prevention and public amenity, are not easily measured (Fletcher *et al.* 2004). This difficulty of defining potential benefits appears to have discouraged attempts to fully quantify costs and benefits of stormwater harvesting schemes so far.

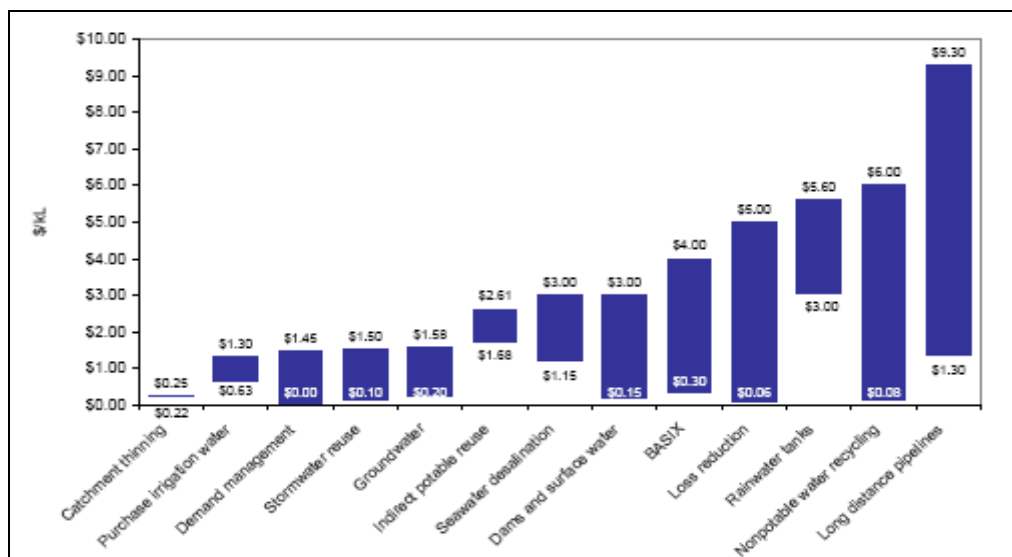


Figure 5.2 Direct costs of water supply/demand options in Sydney, Adelaide, Perth and Newcastle (Marsden Jacob Associates 2006)

Overall, there is great variability in the pricing of recycled water in urban areas of Australia (Table 5.6). Hurlimann and McKay (2007) found that the adopted pricing policies for recycled water do not reflect the recovery of the full costs of amortised capital, operating costs and environmental/social costs. The full costs of recycled water have been estimated to range from \$1.45 per kL (Springfield, QLD) to over \$3 per kL (Rouse Hill, NSW) (Radcliffe 2004). Table 5.6 clearly shows the prices charged are much lower than the actual full costs of the recycled water. In addition, available real cost estimates for the provision of recycled water (the term recycled water here includes stormwater, greywater and wastewater) have shown economic feasibility seldom occurs (Hurlimann and McKay 2007). In fact, a large number of exemplary recycled water projects are subsidised by government.

Table 5.6 Price of recycled water for selected urban areas in Australia (MacDonald 2004; Radcliffe 2004; Hurlimann and McKay 2007)

Location	Use	Class	Price/kL	Type of recycled water
Springfield, QLD	Toilet flushing Garden watering	A	43c	Not specified
Sydney – Rouse Hill, NSW	Toilet flushing Garden watering Washing cars	A	28c	Wastewater
Olympic Park, NSW	Toilet flushing Garden watering Washing	A	83c	Wastewater Stormwater
Mawson Lakes, SA	Toilet flushing Garden watering	n/a	77c	Wastewater Stormwater
Sandhurst, VIC	Residential supply Parklands Golf courses	A	50-60c	Wastewater

Compared with other countries and with other products, the price of potable water in Australia is very low. In the past, most cities and utilities in the world have provided water to their customers almost free of charge because water is considered a basic necessity, and has been a relatively cheap and abundant resource (Rogers *et al.* 2002). Also, it has been possible to keep water prices low since neither the costs of taking the water from the environment nor of protecting the catchments from

which it is collected are required to be included in current pricing regimes (Commonwealth of Australia 2002). Residential users in Brisbane before 1 July 2008, for instance, paid \$1.19/kL for the first 255kL of potable water used per year in a stepped pricing system (in addition to a water access charge of \$140/year and sewerage charges) (BCC 2008). In comparison, residential users in Hamburg, Germany, currently pay EUR1.52/kL (= approximately \$2.5/kL) for water. This low price of potable water in Australia is a major reason for the lack of economic feasibility of recycled water as making it difficult for recycled water to compete.

To address these challenges, the Council of Australian Governments water reform process seeks to achieve full cost recovery (COAG, 2004). Full cost recovery takes into account the costs of infrastructure provision and maintenance as well as delivery costs and externalities. This approach is supported by MacDonald (2004) who suggests that it is vital that externalities are accounted for in the price of potable as well as recycled water.

Externalities are defined as *'the biophysical impacts, attributable to a human based action, which in turn have direct and indirect effects on communities'* (MacDonald 2004, p.5). For example, if the application of recycled water raises watertables or imports salt to an area, then salinity costs and the potential for leaching need to be considered as part of pricing.

Life cycle costing is a process that should be used to comprehensively assess the financial input into a particular stormwater project. Life cycle costing is defined as a *'process to determine the sum of all expenses associated with a product or project, including acquisition, installation, operation, maintenance, refurbishment, discarding and disposal costs'* (Standards Australia 1999, p.4). Taylor (2003) has looked at the life cycle cost of infrastructure projects to improve urban stormwater quality in Australia. These costs often represent significant financial investments and long-term financial commitment and include:

- Costs associated with site selection processes;
- Grant application costs (i.e. to obtain funding for capital works);
- Costs of undertaking feasibility studies;
- Conceptual, preliminary and detail design costs;
- Project and contract management costs;
- Construction costs;
- Routine maintenance costs;
- Renewal and adaptation costs; and
- Decommissioning costs.

Mitchell *et al.* (2006a) used a scenario analysis approach to determine the life cycle costs and yield of stormwater use systems in metropolitan Melbourne. Two residential densities (15 and 40 households) and three spatial scales (100, 1,000 and 10,000 connections) were considered. Their analysis explored how location within a city's rainfall gradient, number of connections, residential density and end use selection influences the long term average annual yield and cost per ML of yield. The four residential end uses investigated in the scenario analysis approach included (i) toilet flushing, (ii) toilet flushing plus clothes washing, (iii) garden irrigation, and (iv) toilet flushing plus clothes washing plus garden irrigation.

The costing was based on a net present value analysis over a 50 year period using a discount rate of 5.2% per annum. Inputs to the life cycle costing analysis included (i) capital costs, maintenance costs, renewal/adaptation costs and decommissioning costs of the stormwater use infrastructure and (ii) savings associated with avoiding the need to use potable water from the mains water supply system and removing nitrogen from stormwater, a pollutant of concern in Melbourne.

The scenario analysis showed that the end use of stormwater harvesting is more important than the location of the stormwater harvesting system. For instance, it was found that supplying large and constant end uses (e.g. toilet flushing plus clothes washing) had much larger yields than supplying smaller demands (e.g. toilet flushing alone) or seasonal demands (e.g. garden irrigation). From a financial perspective, the use scenarios that performed best in the analysis included:

- Centralised stormwater storage and use for toilet flushing and clothes washing using a 20 ML storage pond in a 10,000 lot scale low density suburban development; and
- Centralised stormwater storage and use for toilet flushing and clothes washing using a 2 ML storage pond in 1,000 lot scale high density urban development.

The results of the analysis by Mitchell *et al.* (2006b) show that there are economies of scale with respect to stormwater and rainwater harvesting. Figure 5.3 demonstrates the upper and lower bound cost per kilolitre. Overall, the cost of stormwater harvesting falls rapidly as the scale grows from one to 100 connections and then levels out between 1,000 and 10,000 connections. This shows that there need to be at least 100 to 1,000 connections to provide economies of scale for stormwater harvesting initiatives.

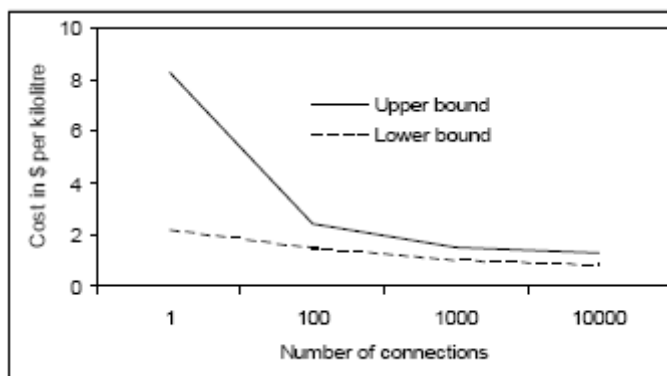


Figure 5.3 Cost of stormwater and rainwater harvesting for different residential scales (Mitchell et al. 2006b)

Ensuring the presence of a market for recycled water and the requirements of that market are also important factors for consideration in the development of a stormwater harvesting scheme. Radcliffe (2004) summarised several components that need to be considered in surveying the potential market for recycled water. These components are listed below, with comments illustrating Australian experience or potential issues to address in relation to the UWSRA stormwater capture and use project.

- **Specific potential uses of recycled water** – The objectives of developing the market for the recycled water needs to be clearly defined. In the case of SEQ, the objective of developing stormwater use follows the need for securing potable water supplies for the expanding population (QWC, 2008). In parallel to this other objectives of the project may be to provide environmental benefits, a more sustainable and cheaper water supply, or security for greenfield developments or sports facilities to allow irrigation.
- **Location of users** – Infrastructure and pumping are major costs impacting on the economics of stormwater harvesting schemes. Previously smaller scale stormwater harvesting schemes have relied on gravity fed systems or close proximity irrigation systems (Hatt *et al.* 2006). Larger scale systems may require a more complex network for distribution.
- **Recent historical and future quantity needs** – In developing the recycled water network it is important to ensure that there is always going to be a demand for the new water source. With demand management, rapidly increasing population pressure and climate change, the future water balance of SEQ is likely to be different to the current and historical urban water balance. There is a need to determine what demand there will be for harvested stormwater.

- **Timing of needs (seasonal, daily, and hourly water demand variations)** – Industrial markets tend to be much more regular in their demands than seasonal irrigation markets. This is also affected by the irregularity of stormwater flows. The end use and their needs will impact on the design of the system.
- **Water quality needs** – Water quality should be fit for its intended purpose, though it may well be ultimately more economical to generate all the water to more advanced Class A to provide greater diversity or market opportunity.
- **Water pressure needs** – Radcliffe (2004) discusses recycled water in South Australia as an example. Recycled water is supplied by the Virginia Water Reticulation Services to irrigators unpressurised, with irrigators then having to install their own storage, pumping and distribution systems whereas the Willunga Basin Pipeline Company supplies recycled water pressurised to irrigators who maintain only a filtration and distribution system, but their water price is higher (albeit also because the scheme was totally funded without external grants and subsidies).
- **Reliability needs (how susceptible is user to supply interruptions?)** – The variability in volumes and the seasonality of stormwater flows, neglecting the consistent dry weather flows, will result in fluctuations in the availability of stormwater for use depending on the system selected. If a reliable supply is needed by the targeted end use, the system needs to be designed with this in mind, however if the system is designed for a seasonal end use such as irrigation the supply reliability may not be critical.
- **Identification of the onsite retrofitting needed to accept the recycled water** – For large scale stormwater use schemes, distribution may require dual reticulation pipelines not only to distribute the water through a network but also within buildings. Existing buildings or other uses will require a retrofitted second pipeline system and explanatory signs where stormwater is used. Similar issues also exist for industries which may require further on site treatment of the water for industrial processes.
- **Needed monetary savings to recover site costs or the desired rate of return on capital** – This issue relates to the costing of the used stormwater with respect to other alternative sources. Unfortunately costing methods to date do not effectively capture the true cost of stormwater harvesting systems with respect to existing potable water supplies. For example Argue and Argue (1998) compared the unit cost of water with the water savings and cost of a waster sensitive urban design stormwater harvesting facility in NSW. This analysis found the resultant pay back period to be greater than the expected life of the project. However when the project costs were compared to the costs of new conventional infrastructure to satisfy the additional demand, the stormwater use scheme was shown to be profitable after one year.
- **Present source of water, who supplies and at what cost?** – Although Australia has in recent years separated water resource management and supply functions, they have remained within government, even in the case of Adelaide where the service functions are subcontracted from SA Water to the private sector (Radcliffe 2004). This allows governments to maintain an effective integrated policy overview of water and wastewater services, in contrast to much of North America where the water supply and sewage treatment/recycling services may be provided by unrelated private sector companies leading to greater regulatory difficulties. There have been examples where a wastewater district implementing a recycling program was sued by a local water district on the basis that the availability of recycled water in the community cause a drop in potable water sales and reducing the revenue to support the loan commitments made to establish the potable water supply infrastructure (Radcliffe 2004). There are likely to be competing suppliers, for example in Brisbane between Brisbane City Council's stormwater harvesting schemes, potable water suppliers, and IPR scheme providers.
- **When would the user be willing to start taking recycled water?** – Attracting users to harvested stormwater may require financial incentives and it may be difficult to determine the correct level of incentive required.

- **Future land use trends that could eliminate recycled water use, such as conversion of farm lands to urban development** – Some rural areas, as identified in the SEQ Regional Plan, are expected to expand in the next 20 years, involving land use changes from agricultural or rural residential, to residential or commercial areas. The changes in land use will also result in different water requirements – an important consideration in the development of a long term stormwater use scheme for the regions.
- **For developing user projects, when would access be required, and what is the current status and schedule for the development?** – It has previously been highlighted that many overseas projects have over estimated the likely market demand. Examples in Australia include the establishment of an industrial precinct with reticulated recycled water at Springfield by Ipswich Water, but yet to attract industrial uptake (Radcliffe 2004).
- **After informing users of potential project conditions, a preliminary indication of the willingness of the user to accept recycled water** – Accurate forecasts of the water market are necessary to avoid unrealistic cost recovery projections for new projects. An example where this will be important is the Sydney Water scheme to seek a market for up to 100 ML/d of recycled water from the 53km Glenfield-Liverpool-Malabar pipeline, with potential markets identified for about half the flow (Radcliffe 2004).

5.4. Economic Evaluation Frameworks

Four main economic evaluation frameworks have been suggested to comprehensively evaluate stormwater harvesting options (DEC 2006; Hatt *et al.* 2004; Mitchell *et al.* 2006a). These include:

- Benefit-cost analysis (BCA);
- Cost-effectiveness analysis (CEA);
- Cost-utility analysis (CUA); and
- Multiple criteria analysis (MCA).

The process for choosing which of the above mentioned methods to apply depends largely on the valuation of benefits (Figure 5.4). BCA is the type of analysis which has traditionally been used by economists. It is assumed that all costs and all benefits can be measured in monetary units.

BCA therefore faces limitations if non-market values or intangibles like cultural, societal or aesthetic benefits are to be considered (Acreman, 2001). CEA assumes that all benefits can be aggregated into a single attribute (e.g. tons of sediment prevented, years of good health). This single attribute is then put in relation to its costs expressing how effectively expenditure is spent. If BCA and CEA are considered not to be feasible, then CUA may be appropriate. In CUA the costs for decision options or proposed management activities are put in relation to their benefits which are expressed via a benefit (or utility) function. Alternatively, the utility scores can be computed using a multi-criteria analysis approach. In the latter case, CUA can be considered an extension of MCA which makes the transition from CUA to MCA smooth. If there is no monetary cost data, e.g. the options are strategic policy directions, then MCA can be used. This does not mean that MCA cannot be used if there is monetary data available, where “cost” is defined as one of the criteria. However, it has recently been argued to exclude “cost” as a criterion and to use CUA instead (Hajkowicz *et al.* 2007) since cost is a constraining factor and not relevant to the measurement of benefits.

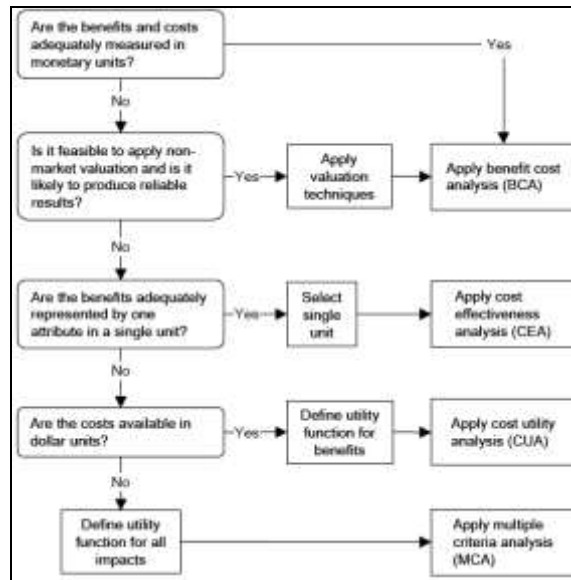


Figure 5.4 A framework for choosing an evaluation framework (Hajkovicz 2006).

Figure 5.4 shows a framework for choosing an evaluation framework. It should be pointed out that Figure 5.4 is not meant as a means to distinguish between superior and inferior methods. The framework is made from an economist’s perspective focussing on monetary aspects and how these can be integrated into a decision process.

5.4.1. Multiple Criteria Analysis

In environmental and resource economics, MCA has mostly had a positive reception (Acreman, 2001, Hajkovicz *et al.* 2007). Like many environmental and resource management decisions, stormwater harvesting decisions are guided by multiple objectives that are represented by multiple criteria. MCA has therefore been repeatedly suggested as a tool to evaluate stormwater harvesting options (DEC 2006; Hatt *et al.* 2004; Mitchell *et al.* 2006a; Taylor 2005). It has also been highlighted that MCA is potentially capable of improving the transparency, auditability and analytic rigour of decision processes (Dunning *et al.* 2000; Hajkovicz and Collins 2007).

Some of the benefits that are returned by stormwater harvesting are highly intangible and cannot easily be measured. Furthermore, many of these benefits, such as public amenity, flood protection and pollution control, are non-monetary in nature. Traditional BCA struggles to adequately quantify costs and benefits other than the asset’s direct costs (Acreman 2001; Taylor 2005). MCA overcomes these shortcomings and allows for systematic processing of heterogeneous triple bottom line information.

Therefore, many researchers find MCA is a useful supplement to conventional BCA when intangible nonmarket goods are important (Eder *et al.* 1997; Joubert *et al.* 1997; Prato, 1999; Fernandes *et al.* 1999; Dunning *et al.* 2000, Hajkovicz 2008). MCA also allows for the management of competing objectives. For example, a stormwater recycling project might have an objective of minimising life cycle cost, while at the same time trying to enhance recreational values. The MCA process enables decision makers to grasp the inherent conflicts and trade-offs among these objectives and to rationalise the comparison among different alternative solutions (Diakoulaki *et al.* 2005).

Figure 5.5 reflects the basic principle of an MCA. Decision options are scored along criteria that may represent policy objectives. These performance measures form the evaluation matrix. The information provided in this matrix is aggregated to produce performance scores for each of the distinct decision options. To reflect the relative importance of the criteria involved almost every MCA involves a criteria weighting scheme.

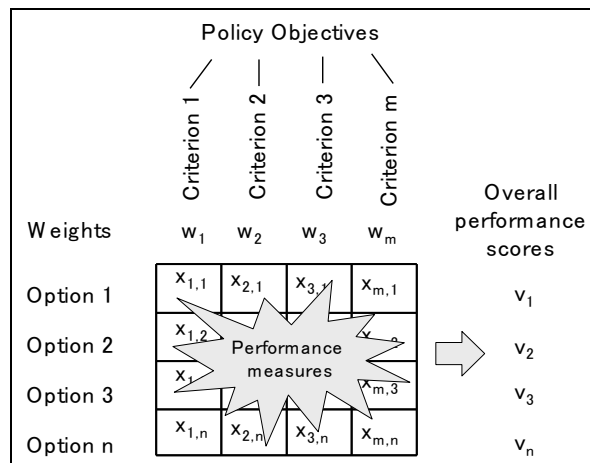


Figure 5.5 Principle of an MCA evaluation (Hajkowicz 2005)

MCA has been widely used in the field of water resource management. Hajkowicz and Collins (2007) reviewed 113 published water management MCA studies from 34 countries. They found that MCA is being heavily used for water policy evaluation, strategic planning and infrastructure selection.

A literature search showed that the use of MCA for stormwater management seems to be less common. Martin *et al.* (2007) utilised the MCA outranking methodology ELECTRE III to evaluate the performance of eight BMPs for urban stormwater management. Technical, hydraulic, environmental, social, economic and maintenance criteria were considered. The authors found that the development of a MCA approach can serve as a supporting decision-aid tool to guide users in the choice of stormwater management solutions. In another study, Ellis *et al.* (2004) utilised MCA to select a construction site for a county retention basin in Blanc-Mesnil, France from four possible locations. The main objective of the retention basin was to provide effective drainage and treatment of stormwater runoff from a local highway. County officials were able to use the MCA as a support tool to present and explain the advantages and disadvantages of the four possible sites to the local inhabitants.

This study shows that MCA provides a simple, robust and readily understandable methodology that can be appropriately applied to guide decision making about urban stormwater structures. Azzout *et al.* (1995) found that stormwater management decisions are often influenced by the complexity of the issue and a lack of knowledge coordination. To better inform decision makers and to help identifying constraints and possibilities regarding stormwater management options they suggested a multi-criteria based decision support concept. In Australia, the Cooperative Research Centre for Catchment Hydrology has developed guidelines to assist triple bottom line assessment of new stormwater projects that aim to improve waterway health (Taylor 2005). The decision support methodology adopted in these guidelines is also primarily based on MCA.

A variety of MCA methodologies have been developed in the last decades that have been successfully applied in a variety of research and policy fields. A comparison of the performance of various MCA methods was conducted by Hajkowicz and Higgins (2007). They found that different MCA methods were in strong agreement and showed high correlations amongst rankings. In other words: different MCA techniques produce very similar results. They concluded that whilst the selection of an MCA technique is important, more emphasis is needed on the initial structuring of the decision problem, which especially involves choosing criteria and decision options. The challenge facing the designers of stormwater harvesting systems is therefore not to develop a new MCA method but to put effort into defining a comprehensive set of criteria and specifying the decision options. Regarding the definition of decision options, it must be noted that the evaluation of stormwater harvesting options is inherently a spatial problem. The performance of a distinct stormwater option will strongly depend on the spatial characteristics of a variety of biophysical criteria such as precipitation, runoff, overland flow and vegetation cover. It also depends on a variety of distance criteria (e.g. distance to residential houses, distance to existing water supply infrastructure etc.). Given the complexity of the issue it is therefore

advisable to integrate GIS technologies which – given the visualisation capabilities of a GIS – considerably enhance the comprehension of the problem. A challenge is therefore the provision of a comprehensive solution that integrates both MCA as well as GIS.

5.5. Triple Bottom Line Implications on Stormwater Harvesting Planning and Design

Given the substantial variability in physical stormwater characteristics, demand patterns and social acceptability there is no single approach to stormwater harvesting that will be appropriate for all areas (DEC 2006). Subsequently in the absence of accepted design and planning guidelines, several authors have developed procedures for assessing stormwater harvesting options (Maheepala *et al.* 2004, DEC 2006, Goonrey *et al.* 2006, Mitchell *et al.* 2006a).

It is crucial for approval of a stormwater scheme that all key stakeholders are identified and involved in the planning process, particularly those with regulatory responsibility (Hatt *et al.* 2004). Involvement of stakeholders in the planning process provides an opportunity to educate both the community and proponents; allows concerns to be identified and addressed through design modifications; and helps building user confidence (DEC 2006). If objectives are clearly defined and conveyed to all stakeholders, a project has much higher chances of success (Mitchell *et al.* 2006a).

Figure 5.6 shows a simplified workflow of a stormwater harvesting design and planning process. It implies a variety of stages covering various spatial scales (e.g. catchment, site), various analysis techniques (e.g. hydrological modelling techniques, social analysis techniques), evaluation methods and tools (e.g. multi-criteria analysis) as well as strong stakeholder involvement. Triple bottom line aspects are being taken into account through all stages of the process. Approaches, tools and methods to be used to make triple bottom line assessments are discussed in section 5.4 of this report.

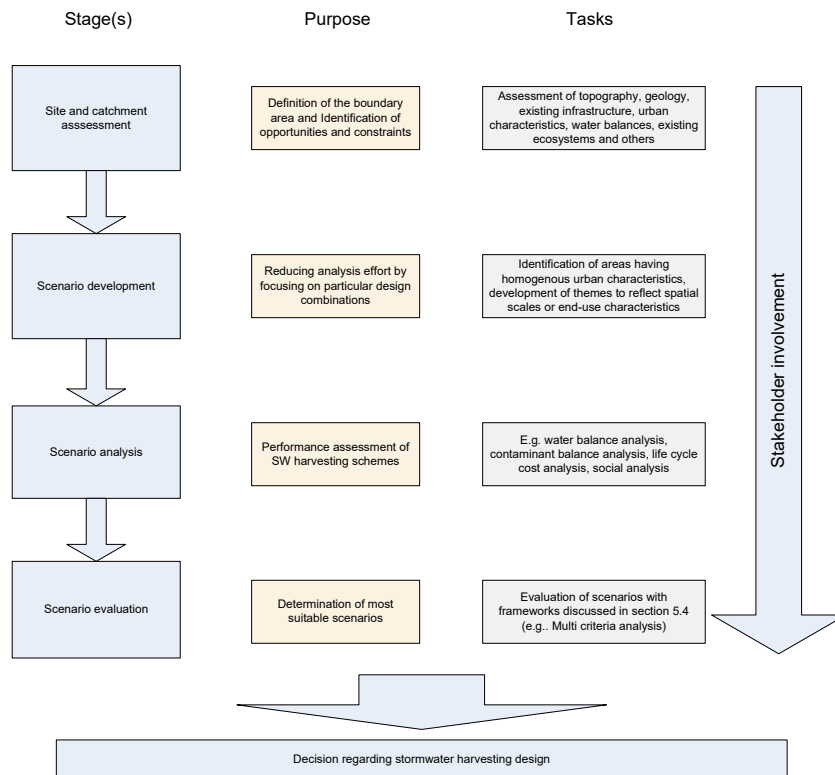


Figure 5.6 Simplified workflow of a stormwater harvesting planning and design process

5.6. Summary

In summarising the social perspective of stormwater harvesting and use, a key component of community acceptance is trust. An interesting conclusion of the study by Nancarrow *et al.* (2007) is that scientists and the CSIRO were the most trusted professions and organisations out of a range of options for respondents. This implies that the Urban Water Security Research Alliance is well placed to gain public acceptance for stormwater harvesting schemes, if information is readily disseminated and stakeholders involved early. In regards to addressing the factors outlined by Brown and Clarke (2007), the current water shortages in SEQ provide the necessary socio-political capital. The Urban Water Security Research Alliance could also act as a bridging organisation and the source of the strategic funding. As stated above there should be general support for the science, given the partners in the Alliance. Although several of Brown and Clarke's (2007) components are not present as yet, they could be realised through strategic planning. Managing public health and safety can be achieved by applying the national guidelines for water recycling (refer Section 4.1) which employ the risk management framework outlined in AS/NZS 4360: 2004 and any design requirements enforced by local agencies.

From an environmental perspective, stormwater harvesting stems from a general approach of ensuring sustainability of resources. As such an important component in the development of stormwater use schemes should be to uphold the principles of sustainability. This requires stormwater harvesting to be undertaken not only from an augmenting water resources approach, but also from an ecological approach to allow for the health of reliant ecosystems through the consideration of the timing, quantity and quality of environmental flows.

Investigating the economics of stormwater harvesting has proved to be a difficult task due to issues in defining the true costs and benefits of stormwater harvesting in comparison to traditional urban water supplies. Decisions about stormwater harvesting options have distinct characteristics. For instance, they are typically guided by social, environmental and economic objectives measured in a range of financial and non-financial units. Furthermore, they usually involve a range of decision makers and can affect numerous stakeholders from diverse constituencies. These characteristics of stormwater harvesting make MCA an attractive approach for stormwater decision making processes.

6. CURRENT RESEARCH AND PRACTICES

6.1. International Research, Practices and Pilot Projects

Even though the harvesting and use of urban stormwater provides a range of benefits, including flood protection, pollution control and protection of habitat (Wanielista 2007, Shapiro 2002, Mitchell *et al.*2007), its application in countries outside Australia has been limited. Overall, there are only a few examples where stormwater harvesting schemes have been implemented on a large scale overseas. Instead, most work in urban areas to date still focuses on roof rainwater harvesting, desalination and wastewater recycling.

This international literature review has identified a small number of stormwater harvesting case studies in the United States, Europe, Africa and Asia. Most occur in the United States, where local city councils increasingly utilise stormwater as a resource to irrigate parks and other public areas. One example is the Santa Monica Urban Runoff Recycling Facility (SMURFF), a dry weather runoff recycling operation that treats and produces cost-effective and high-quality water for use in landscape irrigation and toilet flushing (Antich *et al.*2002).

In Singapore, storage reservoirs have been in operation since the 1960s to collect surface runoff from urbanised areas for potable use. Membrane technologies ensure that World Health Organisation drinking water guidelines are met. Once the construction of the country's 15th reservoir, the Marina Barrage Scheme, is finalised in 2008, almost two-thirds of Singapore's total land area will be harnessed for water resources (PUB 2005).

In South Africa, the Atlantis artificial aquifer recharge scheme is a complex and large-scale urban stormwater collection system that includes twelve detention and retention basins and interconnecting pipelines with peak flow reduction features. It has a total capacity of 2 GL/year and provides water for domestic and industrial uses (IGRAC 2003). Table 6.1 provides an overview of international stormwater harvesting case studies. It shows the different storage and treatment aspects of each stormwater harvesting scheme and also details the end uses.

6.1.1. United States of America

In the United States of America (USA), total gross water consumption exceeds the total available freshwater supply in many southern states, including California, Florida, Texas and Arizona (Fan and Field 2002). To address the decline of per capita freshwater availability, the USA has introduced a variety of innovative water management practices, including roof rainwater harvesting, wastewater reclamation and aquifer recharge measures. Stormwater harvesting schemes are also increasingly being utilised. The states where stormwater harvesting schemes already exist are California and Florida.

Table 6.1 International Stormwater Harvesting Case Studies

Project	Location	Storage	Treatment	End Uses	Reference
SMURFF	Santa Monica, California, USA	Concrete storage tank	Bar screens; Flow equalisation; Dissolved air floatation; Microfiltration; UV disinfection	Landscape irrigation; Toilet flushing	Antich <i>et al.</i> (2002); City of Santa Monica (2007); Shapiro (2002)
Renaissance Project	West Palm Beach, Florida, USA	Natural lake	Bar screens; Alum and polymer injection; Settling basin; Wetland; WTP	Potable drinking water	City of West Palm Beach (2005); City of West Palm Beach (2007); Rearden (2007)
Lake Greenwood Urban Wetland	Orlando, Florida, USA	Constructed wetland	Sediment and trash screening device; Aerators; Littoral zone with vegetation	Landscape irrigation	Bateman <i>et al.</i> (1998); Chamberlin (1998); McCann and Olson (1994)
City of Cape Coral Dual Water Reticulation System	Cape Coral, Florida, USA	Freshwater canals	Coarse screen; Fine screen; Chlorination	Landscape irrigation; Other non-potable uses	City of Cape Coral (2003); City of Cape Coral (2008a)
University of Edinburgh Infiltration Ponds Pilot Project	University of Edinburgh, UK	Constructed Wetland	Silt trap; Littoral zone with vegetation; Infiltration pond	Not specified	Zheng <i>et al.</i> (2006)
Belss-Luedecke-Strasse Project	Berlin, Germany	Underground storage tank	Not specified	Garden watering; Toilet flushing	Villarreal and Dixon (2005)
Artificial Aquifer Recharge Scheme	Atlantis, South Africa	Aquifer	Detention basins; Retention basins	Industrial uses; Potable drinking water	Tredoux <i>et al.</i> (1999); Tredoux <i>et al.</i> (2002); Tredoux (2003);
Sungei Seletar-Bedok Reservoir Scheme	Singapore	Storage reservoirs		Potable drinking water	Kog (2004); Lim and Lim (1999)
Marina Barrage Scheme	Singapore	Storage reservoir	Membrane technology	Potable drinking water	PUB (2005)

In Florida, various city councils have constructed stormwater harvesting facilities to augment water supplies. The climate of north and central Florida is humid subtropical, whilst the south of Florida is considered to have a tropical climate. Almost 70% of south Florida's rainfall occurs from May to September, which means that storage of stormwater has a lot of potential (O'Malley 2007). The state of Florida is currently experiencing a severe drought which began in November 2005.

Most regions in south Florida could potentially harvest stormwater during the wet season and employ it for irrigation and other uses during the dry period (Shukla and Jaber 2006). In many areas of the State, nearly 50% of the potable water delivered to residential units is used for irrigating lawns (Wanielista 2006). The potable water used for irrigation could be supplemented with non-potable water from stormwater storage facilities.

The Stormwater Management Academy, initiated in December 2002 at the University of Central Florida, is a leading source for stormwater management research. Scientists at the Academy undertake extensive research into reusing stormwater as an alternative water supply. The Academy is researching both on-site storage/treatment systems (i.e. green roofs, cisterns, pervious concrete) and regional/off-site methods (i.e. retention ponds, detention ponds, chemical treatment, solid separators, irrigation ponds, etc.). The Stormwater Management Academy also encourages 'treatment trains' as a means to maximise the effectiveness of stormwater storage/treatment systems (Wanielista 2007).

Renaissance Project, West Palm Beach

The City of West Palm Beach in southern Florida has designed an integrated water resource management program for urban runoff in an inner city area called the 'Renaissance Project'. This project utilises the 'treatment train' method to maximise the effectiveness of treating the City's stormwater (Rearden 2007).

The Renaissance Project diverts stormwater runoff from various sites (i.e. Convention Center, Pineapple Park Neighbourhood) to a canal (the Stub canal) and from there to a 0.02km² settling basin (Figure 6.1). In this settling basin heavy debris is removed as the water passes through traditional bar screens. As a next step, chemicals (alum and polymer) are added to the standing water to remove heavy metals, oils and grease. After this treatment, the water is pumped into a natural lake, where it is further cleaned through natural processes and interaction with wetlands plant materials. Finally, the water is pumped into the West Palm Beach Water Treatment Plant where it is treated in order to become potable drinking water. An integral component of the Renaissance Project is the pump station, which started operating in September 2002. The pump station pumps water from the Stub canal to the settling basin while blending chemicals to enhance settling.

The Renaissance Project has been a major undertaking and the total cost of the completed project was US\$17.6 million. At the same time, the project created many benefits, including increased water supplies, improved water quality to Lake Worth Lagoon, and flood protection in low lying areas. Overall, more than 1,136 ML of treated stormwater are added to the City's water supplies each year (City of West Palm Beach 2005).

The City of West Palm Beach has expanded its stormwater use capacity. The construction of the Ironhorse Stormwater Reuse Project cost US\$1.4 million in total.

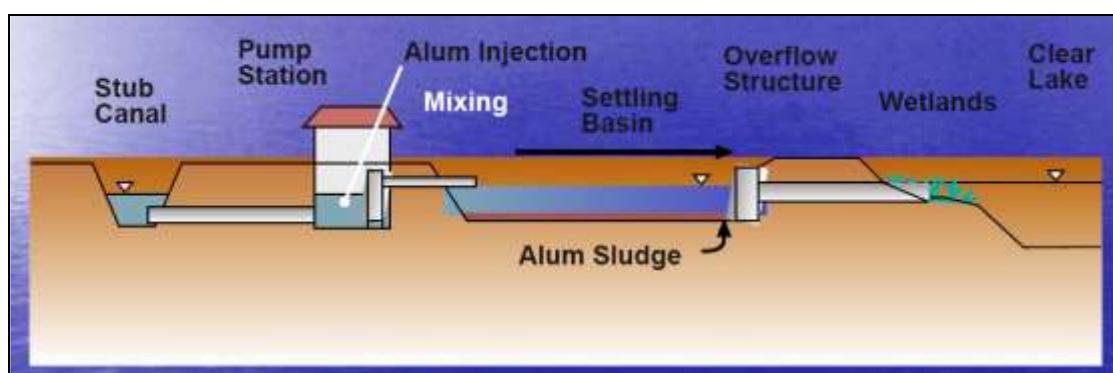


Figure 6.1 Treatment process of the Renaissance Project (Rearden 2007)

Lake Greenwood Urban Wetland, Orlando

The City of Orlando, Florida, utilises a variety of innovative stormwater treatment systems and retrofit methods including stormwater wetlands, alum injection, exfiltration, lake aeration, sediment control devices, trash screens and shoreline and littoral zone vegetation. One of the many major retrofit projects in the Orlando area is the Lake Greenwood Urban Wetland, which is a wetland and stormwater management system in an urban environment. This artificial wetland was built to alleviate flooding, to pretreat stormwater runoff prior to discharge into drainage wells that flow to the upper Floridian aquifer, and to use the stored water for irrigation. Lake Greenwood Urban Wetland was constructed in 1991 and became Florida's first example of a stormwater treatment train. The BMPs included in this treatment train include a sediment and trash screening device; a littoral zone with vegetation; and aerators to increase microbiological activity (Chamberlin 1998).

Lake Greenwood Urban Wetland is located within a 2km² drainage basin. Nearly the entire basin draining into the wetland has been developed into residential, commercial, industrial and recreational uses. Runoff collected within the basin flows into Lake Greenwood, which lies at the lowest point in a 12km² urbanised area. The system was designed to detain the runoff from 64mm of rainfall over a three hour period (McCann 1994) of the drainage basin discharges into the wetland from Fern Creek, which is a free flowing stream, and functions as a central conveyance channel for runoff in the drainage basin. Runoff enters Fern Creek from a kerb and gutter stormwater system (McCann and Olson 1994).

The construction of the wetland required the expansion of Lake Greenwood to over six times its original size and the wetland is now more than 0.05km² in surface area. Approximately 229,366m² of material was removed to create the flood control reservoir (McCann and Olson 1994).

Lake Greenwood Urban Wetland has many innovative design features (Figure 6.2). For example, a sediment control basin pre-treats runoff before it enters the wetland. Weirs have been constructed to control water levels and establish three ponds to maximise stormwater retention.

To increase pollutant removal efficiencies, four fountains have been built to aerate deeper pools. Also, a bypass canal was built leading to five drainage wells. Furthermore, the entire system was extensively landscaped. Over 0.05km² of wetland and upland vegetation were planted (Chamberlin 1998).

Reusing the stored stormwater to irrigate a park and an adjacent city-owned cemetery saves the City of Orlando US\$25,000 annually (Bateman *et al.* 1998). The City has repeated this concept, on a slightly smaller scale, with the construction of another urban wetland, the La Costa Urban Wetland.

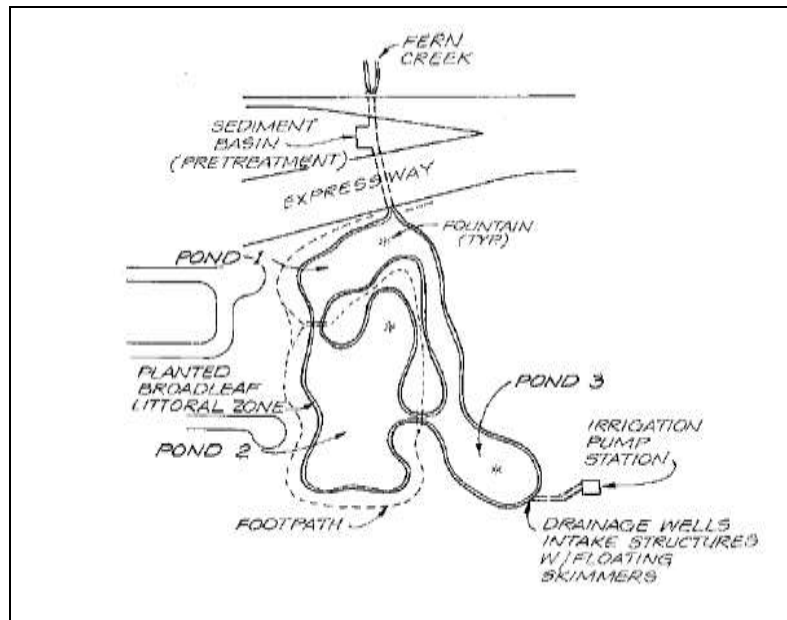


Figure 6.2 Schematic of the Lake Greenwood Urban Wetland (McCann and Olson 1994)

Cape Coral

The City of Cape Coral, Florida, provides an example of a dual water reticulation system. Cape Coral is one of the fastest growing areas on the Gulf Coast of Florida with a population of more than 160,000 people (City of Cape Coral 2008a). Due to the drought, it is currently under phase III watering restrictions. Cape Coral has developed an extensive stormwater management system that routes surface water flows generated during storm events to an interconnected network of canals, swales, pipes and catch inlets. One function of the canals is to create a freshwater reservoir in order to supply secondary irrigation demands. There are approximately 475km of freshwater canals within the city of Cape Coral (Figure 6.3). To create these freshwater canals, 27 weirs were constructed to separate the freshwater from brackish water (City of Cape Coral 2003). Community volunteers regularly monitor the environmental integrity of the City's canal network.

Cape Coral has two wastewater treatment facilities that recycle wastewater to provide irrigation for households and commercial buildings. When the demand for irrigation water is higher than both of these facilities can supply, the canal water is used to supplement the system (City of Cape Coral 2003). Water is pumped from the freshwater canals with the help of five canal pumping stations into a dual reticulation system. The water is filtered through a coarse screen followed by a fine screen and is chlorinated before it enters the use system. In total, this system supplies water to almost 45,000 properties (WBM 1999).

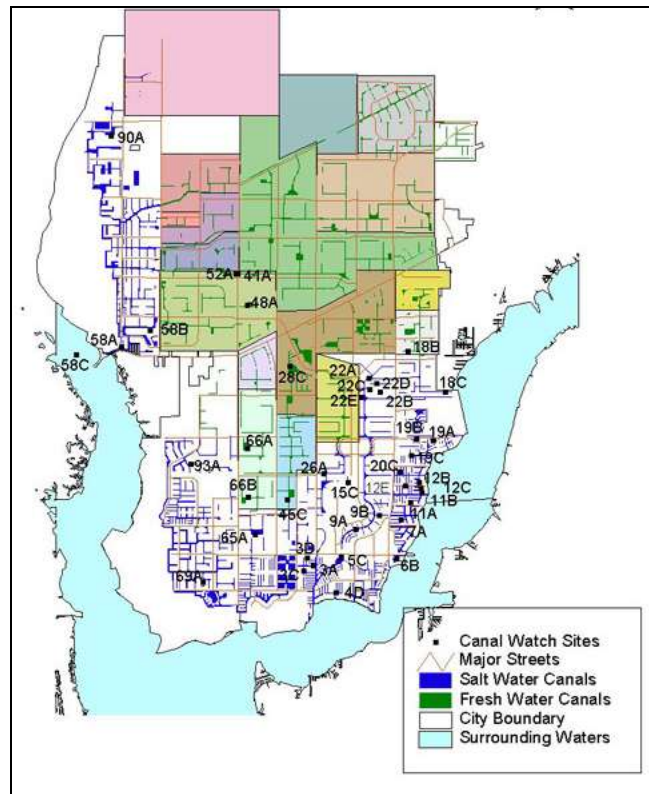


Figure 6.3 Cape Coral's Freshwater Canal System (City of Cape Coral 2008b)

SMURFF, Santa Monica

The City of Santa Monica, California, has a population of approximately 90,000 and is located in a semi-arid region with a small amount of annual rainfall. The region is characterised by a Mediterranean climate with dry summer months. Most of the precipitation occurs between the months of November and April. Average annual precipitation is typically less than 400mm (Chralowicz *et al.* 2001).

In 2006, water use for the City of Santa Monica was nearly 51 ML/day (City of Santa Monica 2007). About 80% of the water supply was imported from Northern California and the Colorado River (Shapiro 2002). The development of an additional water supply source for use throughout the City was critical. At the same time, urban runoff was the single greatest source of water pollution in Santa Monica Bay, threatening the long-term health of marine ecosystems and local economies. To address these issues, the City adopted a range of strategies to eliminate pollution of Santa Monica Bay caused by urban runoff and to increase urban water supply. The key strategies included:

- Harvesting stormwater runoff from new development;
- Treating all dry weather urban runoff leaving the city through storm drain lines; and
- Constructing and operating the Santa Monica Urban Runoff Recycling Facility (SMURRF).

The Santa Monica Urban Runoff Recycling Facility (SMURFF) is the first dry weather runoff recycling facility in the United States and started operations in February 2001 (Shapiro 2002). Its primary objectives are to:

- Eliminate pollution of Santa Monica Bay caused by dry-weather runoff; and
- Treat and produce cost-effective and high-quality water for use in landscape irrigation and toilet flushing.

The SMURFF harvests urban runoff from the City’s two main stormwater drains; Pico-Kenter and Pier (Antich *et al.* 2002). Combined, these two stormwater drains contribute approximately 90% of the City’s total daily dry weather runoff and drain an area of 20.6km². The SMURFF can process up to 1.89 ML of runoff per day, which is about 4% of the City of Santa Monica’s daily water use (City of Santa Monica 2007). Dry weather runoff from the Pico-Kenter and the Pier stormwater drains vary greatly throughout the dry season. Based on visual observations and field measurements, the average flows of the Pico-Kenter stormwater drain are estimated to be around 0.85 ML per day. This combines with an additional 0.15 ML per day from the Pier stormwater drain.

The SMURFF incorporates a 5-stage treatment train, consisting of bar screens, flow equalisation, air floatation, microfiltration and UV disinfection (Figure 6.4). The preliminary treatment includes a flow-equalisation basin, bar screens and grit chambers. These are necessary for the proper functioning of downstream processes in the treatment plant. The dry weather runoff is first ‘coarse’ screened in a Continuous Deflective Separation (CDS) unit. This unit removes large floating debris and trash that typically flow down open drains in streets (i.e. bottles, twigs, etc.). The ‘coarse’ screened flows are then pumped to the recycling facility.

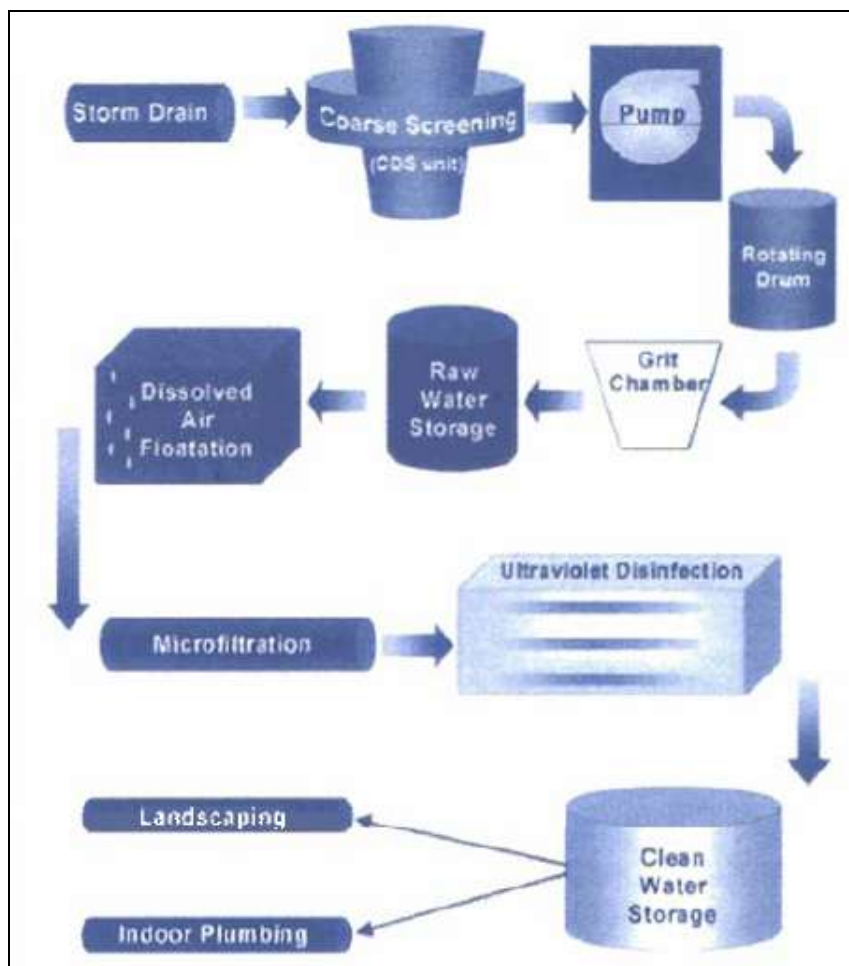


Figure 6.4 SMURFF treatment process (City of Santa Monica 2007)

At the recycling facility, the rotating drum screen removes fine floating particles which escaped the coarse screening. From here, the water flows to the cyclone-type grit chamber, which removes grit and sand. From the grit chamber the preliminary treated water is stored in the raw water storage tank which dampens the fluctuations in the influent flows. This allows downstream filtration and disinfection processes to operate at a steady rate (City of Santa Monica 2007).

During the secondary treatment, the dissolved air flotation unit removes oil and grease by injecting compressed air into the water at the unit inlet. After this process, the microfiltration treatment units force water through membranes, thereby filtering out the turbidity. From the microfiltration unit the water flows to the disinfection process, where ultraviolet radiation is used to kill bacteria and viruses. Finally, treated water is stored in the clean water tank, from where it is pumped into the distribution system for use.

The highly-treated SMURFF water is being used for landscape irrigation and for indoor commercial building use. The treatment process ensures that the water is safe for all landscape irrigation and dual-plumbing systems. Landscape irrigation customers include the Olympic Boulevard centre median, City of Santa Monica parks and the Woodlawn Cemetery.

In order to generate community support, the SMURFF has been designed to be a walk-through facility that provides educational information to visitors. It also serves as an access way for the public to reach the beach and adjacent businesses. In addition, the design of the SMURFF includes visually appealing elements, such as water features, innovative architecture, dramatic lighting and colourful tile work. This was done to ensure that the SMURFF integrates with the lively atmosphere of the adjacent Santa Monica Pier. Incorporating art in public works has ensured public acceptance of a treatment facility near a major tourist attraction (Shapiro 2002).

The SMURFF cost approximately US\$12 million including the distribution system for recycled water (City of Santa Monica 2007). Money was provided from various funding sources. Approximately US\$750,000 of the plant cost was related to architectural components specifically designed to incorporate public art and education (i.e. tile work and mosaics, an area designed specifically for display of educational material, special lighting). Another expensive item of the SMURFF was the concrete storage tank (US\$2 million). The actual cost of stormwater treatment is estimated at US\$1.53/kL (Antich *et al.* 2002).

Hawaii

Apart from Florida and California, other states in the United States are now also beginning to investigate stormwater harvesting opportunities. For example, in 2005 the United State Bureau of Reclamation undertook a study to evaluate the possibility of using stormwater as an alternative source of water on the islands of Hawaii (CH2MHill 2005). Hawaii has only limited water resources and high population growth projections. Potential stormwater harvesting and use opportunities were appraised for each of the Hawaiian Islands as a way to augment the state's water resources. After an initial screening process nine candidate opportunities were identified for further conceptual development and evaluation. A range of criteria, including ease of delivery, storage capacity and cost, was used to assess the nine opportunities. The nine candidate opportunities were then numerically ranked according to specific criteria on a scale from one to 10 (CH2MHill 2005). To further this research, the Bureau of Reclamation recently commenced a study in order to identify challenges to reclaiming stormwater, determining the viability of recharging aquifers with runoff and treated wastewater, and investigating creative methods for stormwater capture, storage and use that are suitable for implementation in Hawaii.

6.1.2. Europe

Even though there have been increasing pressures on Europe's freshwater resources during recent decades (European Commission 2007), stormwater harvesting schemes are still relatively uncommon in Europe. Water supply augmentation measures such as roof rainwater harvesting, desalination and wastewater recycling, on the other hand, are increasingly being utilised in various European countries (CWWA 2002).

One rare example of stormwater harvesting research in northern Europe is a case study from the United Kingdom. Here, the Institute for Infrastructure and Environment at the University of Edinburgh is undertaking research into urban water. One of their recent pilot projects looked at the design and operation of sustainable urban infiltration ponds to store, treat and use urban stormwater (Zheng *et al.* 2006).

The pilot plant was designed according to BMP guidelines of the British Research Establishment and the German Association for Water, Wastewater and Waste. The BMP is based on a combined wetland and infiltration pond design. Figure 6.5 shows that stormwater runoff flows from the road into a silt trap (1), then via a gravel ditch (2) into a constructed wetland (3). If the wetland attenuation system is full, the water flows via a swale (5) into the infiltration ponds (6) and (7). The ponds accommodate maximum volumes of 9.7m³ each during heavy storm events before flooding of a nearby lawn occurs (Zheng *et al.* 2006).

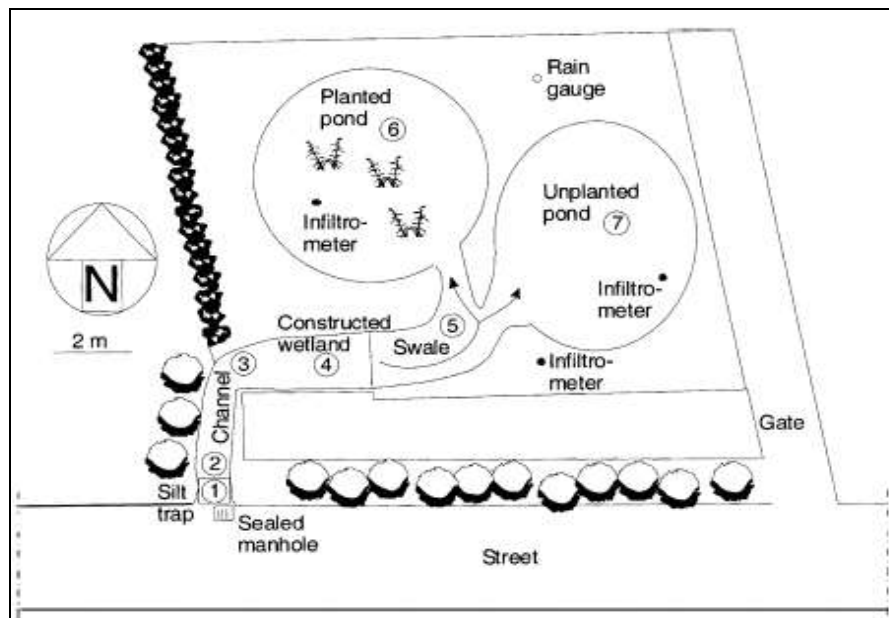


Figure 6.5 Stormwater use pond at the University of Edinburgh (Zheng *et al.* 2006)

Another example of an existing stormwater harvesting scheme from northern Europe is the ‘Belss-Luedecke-Strasse’ project in Berlin, Germany. In this building estate rainwater from rooftops (7,000m²) is stored in a 160m³ tank together with stormwater runoff from streets, parking places and pathways (4,200m²). After treatment, the water is used for services such as toilet flushing and garden watering. A 10-year study has shown that the combined rainwater/stormwater harvesting system reduces runoff volumes by 58% and provides annual potable water savings of approximately 2.43 ML (Villarreal and Dixon 2005).

6.1.3. South Africa

The City of Atlantis near Cape Town in South Africa utilises an urban stormwater collection system in the form of artificial aquifer recharge through infiltration basins. Atlantis is located along the semiarid west coast of South Africa and receives 450mm of mean annual rainfall between April and September (Tredoux *et al.* 2002). The city has over 100,000 inhabitants and water consumption is approximately 7 GL annually. There are only very few surface water resources available in the region. Stormwater is regarded as a valuable water source for augmenting freshwater supplies in this semiarid region, which prompted the construction of an urban stormwater runoff collection system (Tredoux *et al.* 2002).

Construction of the urban stormwater collection system began in 1982. Today, it is a complex and large-scale scheme managed by the Water Department of the City of Cape Town. Treated domestic wastewater and urban stormwater are being infiltrated into a sandy aquifer. The collection system consists of twelve detention and retention basins and interconnecting pipelines with peak flow reduction features. The basins are around 1-4 m deep to prevent excessive growth of algae and water plants. The system was designed with the flexibility to control water flows of differing salinity and to collect the best quality water for infiltration into the aquifer.

While low salinity flows are channelled into two large spreading basins for subsequent infiltration into the Witzand aquifer (Basin 7 and Basin 12), higher salinity baseflows are diverted to the coastal basins or to the Donkergat River (Figure 6.6). A weir in the stormwater system separates the slightly more saline baseflows from the low salinity peak flows (Tredoux 2003).



Figure 6.6 Map of Atlantis artificial aquifer recharge scheme (Tredoux 2003)

The Atlantis artificial aquifer recharge scheme has a total capacity of 2GL/year (IGRAC 2003). Discharges during storm events can reach up to 72 ML per day, while summer baseflow averages 2.16 ML per day (Wright 1994). Water extracted from the aquifer is used for domestic and industrial water supply.

Since the Atlantis artificial aquifer recharge scheme has been in operation for over 20 years there are several lessons to be learned. These include (Tredoux 2003):

- Infiltration ponds require a relatively large surface area for spreading. Therefore ponds are only suitable where there is ample room for installation. Because infiltration ponds are very vulnerable to contamination, they should be located in protected areas;
- Maintenance of the recharge structure is important. The bottom of the pond must be inspected and treated regularly in order to minimise clogging to maintain infiltration rates and keep evaporation from open water to a minimum;
- Iron-related clogging of abstraction boreholes due to overpumping of the boreholes has proven to be an extensive and serious problem. From 1999 to 2002, boreholes were examined and rehabilitated using special treatment techniques; and

- Managing water quality and salinity has been one of the greatest challenges for the scheme. Management actions to control salinity in the Atlantis water supply have included the launching of a detailed chemical investigation of the salinity sources. Regular monitoring takes place around the recharge and abstraction areas and at potential pollution sources. This also provides an early warning system against any potential uncontrolled spills and illegal discharges of harmful contaminants.

6.1.4. Singapore

Singapore is a city state with an area of about 680km² and a population of more than four million people. It is a small but highly urbanised country with a large population density. Singapore has an annual water consumption of about 500 GL. This is increasing by approximately 4% annually (Kog 2004). In 2004, per capita consumption was 162 litres per day (Ministry of the Environment and Water Resources 2005).

Singapore suffers from freshwater scarcity. Even though the country is not short of rainfall (on average 2,400 mm of rainfall annually) the problem is the capture and storage of this rainfall on limited amounts of land areas (Lee 2005). Since 1932, Singapore has depended on the southern Malaysian state of Johor to meet its water needs. Water supply from Johor became a security issue in 1965 when Singapore left the Federation of Malaysia. Since then, relations between the two countries have been marked by periodic tensions (Kog 2004). At present, Malaysia still supplies around 40 percent of Singapore's water needs.

In recent years, the government of Singapore has moved in the direction of reducing its reliance on outside sources and strengthening its own internal water supply capacities. In the late 1990s, it introduced a comprehensive and long-term water strategy to augment domestic supplies. The main objective of this strategy is 'sustainable water supply' for Singapore, to be achieved with a series of initiatives and actions (World Bank AAA Program 2006).

A major component of the water strategy is to develop ways to diversify water supply sources and to conserve demand. This approach is reflected in the 'Four National Taps Approach' (Figure 6.7). Water is sourced from (i) Johor, Malaysia, (ii) recycling of wastewater (NEWater), (iii) desalination, and (iv) stormwater reservoirs (PUB 2005).



Figure 6.7 Singapore's Four National Taps Approach (PUB 2005)

The first three storage reservoirs (MacRitchie, Peirce, and Seletar) have been in operation in Singapore since the 1960s to collect surface runoff from urbanised areas. This has increased to 14 stormwater storage reservoirs, with a combined total storage capacity of 140 GL (Lee 2005). One of the largest storage reservoirs is the Sungei Seletar-Bedok Reservoir Scheme, which was completed in 1986. This scheme collects surface runoff from newly urbanised areas in north-eastern and eastern Singapore for storage in reservoirs at Bedok and Lower Seletar. The runoff involved the simultaneous construction of two reservoirs together with a water catchment plant and a network of storm collection depots (Kog 2004).

Since then, eight more urban stormwater pond collection systems have been built in the northern and north-western parts of Singapore. Today, Singapore has reached a point where about half of its total land area is harnessed for water resources (Lim and Lim 1999). This will increase to two-thirds of its land area once the construction of Singapore's 15th reservoir, the Marina Barrage Scheme, is finalised (PUB 2005).

The Marina Barrage Scheme involves the construction of a dam built across the 300m wide Marina Channel in the city of Singapore. The dam is comprised of a concrete base and a series of steel gates (Figure 6.8). All up, there are nine hydraulically operated steel crest gates (each 26.8m in height) spanned across the Marina Channel. There are also seven 40m³/second drainage pumps housed within the pump building (PUB 2005). During heavy rains, the nine steel gates will be lowered if there is any excess water in the basin. When heavy rains coincide with high tide, the drainage pumps will allow the water to be pumped out (World Pumps 2008).

Once the dam is in place, the Marina Basin will turn into a body of freshwater through natural flushing over a period of one to two years. Stormwater from an area of 10,000 ha, which is about one-sixth of Singapore's total land area, will flow into the reservoir. Water from the reservoir will be treated to drinking water standards using membrane technology. The construction of the Marina Barrage Scheme started in early 2005 and is near completion at the time of writing. The project costs approximately US\$163 million (PUB 2005).

Apart from adding to Singapore's water supply, the dam acts as a tidal barrier to prevent high tides from flooding low-lying city areas. A visitor centre showcases the environmentally sustainable development of this massive engineering project.

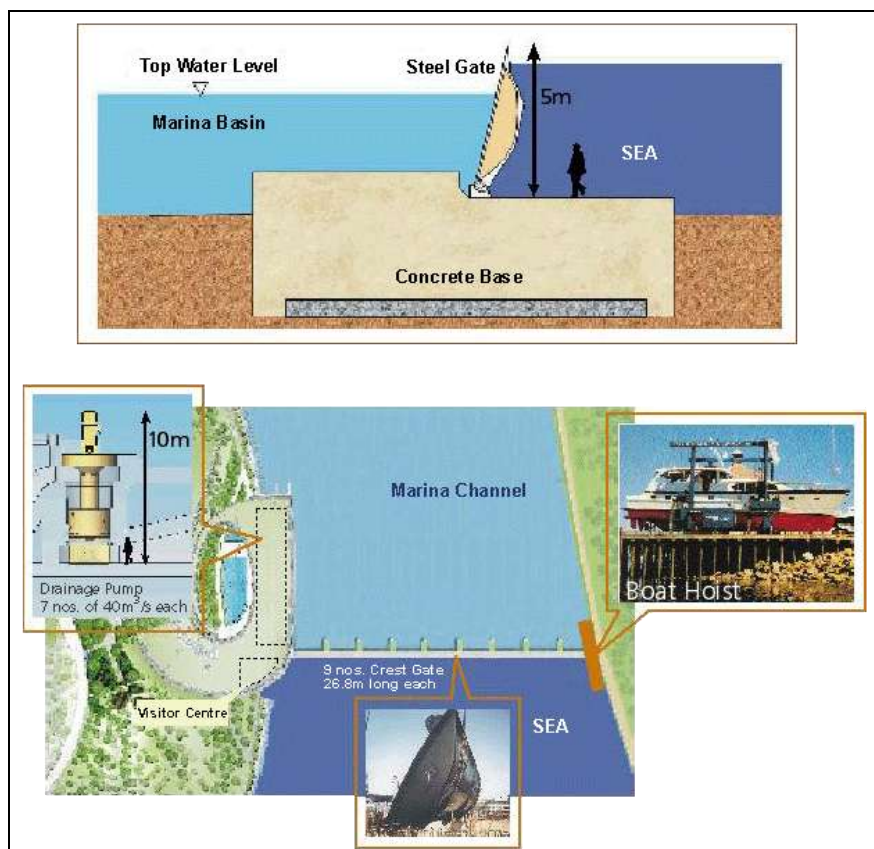


Figure 6.8 The Marina Barrage Scheme (PUB 2005)

6.2. National Practices and Case Studies

Stormwater harvesting for potable water substitution is becoming increasingly common across Australia. While the majority of these projects operate on a small scale, there are several projects operating on a major, city wide scale. In developing this review of national stormwater harvesting practices a series of case studies from across the country have been collected to reflect the different operations occurring in the various states, illustrate projects on a scale similar to the projects considered by the current study, and the technology and innovation being used in selected projects across Australia. These case studies are briefly summarised in Table 6.2. Appendix A contains more detailed information on each of the projects. No case studies were found for substituting treated stormwater for potable drinking water. The majority of the case studies reflected the current practice of using harvested stormwater as a substitute for irrigation water, as supported by the Australian practice review conducted by Hatt *et al.* (2004).

In developing the case studies, the lack of information available became apparent. At the moment there are many stormwater harvesting schemes being undertaken or planned within developments or by local governments but little information is available in the public realm. Information sharing not only between designers and managers, but also with the public is key in developing stormwater harvesting as an acceptable alternative water source. Information sources used for this project were either anecdotal, sourced from publicly available funding applications, or from literature, which represent only a fraction of the projects operating across Australia. This has highlighted the importance of developing a national register for stormwater harvesting projects, to allow information sharing and develop a consistent approach to projects across the country.

Stormwater harvesting is frequently used in New South Wales, South Australia and Victoria. No information was available for stormwater harvesting schemes operating in Tasmania or the Northern Territory, as a result of this it is assumed that stormwater use is not common practice in these areas. Western Australia's legislation ultimately results in stormwater use through indirect means, as discussed further in the following paragraphs. In the ACT a major investigation is currently under way looking at stormwater harvesting options for Canberra. The following paragraphs further explore the stormwater harvesting being undertaken in the relevant states.

Several large scale NSW projects highlight how stormwater harvesting can be effectively undertaken in an urban environment. Darling Harbour is located in Sydney's CBD. The area is mainly impervious due to buildings and pavements. In 2002 the Foreshore Authority responsible for the management of the area recognised the significant resource available from the stormwater runoff and commissioned a study to develop a stormwater harvesting system for the area (Phillips *et al.* 2007, SIA NSW 2007). The high costs related to storage options of the scheme in the already developed area resulted in smaller scale options being pursued and resulted in an innovative solution whereby stormwater is collected from the roofs of the large entertainment centre complex. The water collected from this area was found to be of sufficient quality to receive only preliminary treatment from a first flush device before being stored in tanks that occupy vacant car parks within the entertainment centre complex. The harvested water then feeds into the irrigation network for the Darling Harbour parklands area. This project successfully highlights how stormwater harvesting can be undertaken in an urban setting by considering innovative alternatives for storage measures.

A stormwater harvesting scheme at Homebush Bay demonstrates how effluent use and stormwater harvesting can be successfully combined for the substitution for all non potable uses in an inner Sydney suburb (Radcliffe 2004). The combined use of effluent and stormwater results in potable water savings up to 850 ML/a. The water is treated in a combined facility using advanced treatment processes including microfiltration and reverse osmosis to achieve high quality recycled water that is distributed through a dual reticulation network and used for all non-potable end uses in the Olympic Park area and the adjacent suburb of Newington. The scheme's innovative approach also extends to storage facilities. Treated stormwater and surplus treated effluent are stored in an old brick pit with 300 ML capacity. The use of existing infrastructure to serve as the storage for the scheme saves on space, the cost of establishing a new storage and reduces the environmental impact of the project by minimising the new resources required for the project.

South Australia has been a leader in the development of large scale stormwater harvesting and WSUD schemes in Australia for nearly 50 years. The City of Salisbury especially is at the forefront of integrated water management and is currently implementing Australia's first totally integrated water management plan to efficiently harness and manage systems for rainwater, stormwater, groundwater, recycled wastewater and potable water (Radcliffe 2004, City of Salisbury 2007; 2008). The City of Salisbury covers an area of 161km² and has developed 20 strategic stormwater harvesting sites and wetlands. Wetlands are used for storage in conjunction with aquifer storage and recovery technology, which allows water to be accessed during drier months. Not only have the council been innovative in their approach to the management of water in the area, they have also developed a local market for recycled stormwater. Treated stormwater is distributed via mains and sold to end users which include industrial, commercial and community facilities. The large scale stormwater harvesting systems have been integrated into the existing urban environment and also provide economic incentives for the local government. In a residential environment, also within the City of Salisbury, Mawson Lakes has developed a conjunctive effluent and stormwater use system (Marks and Eddleston 2000). Combined potable water saving for the development including stormwater use from the local catchment, effluent and stormwater from the City of Salisbury integrated scheme, amounts to over 1.1 GL/a. The development was designed to incorporate the stormwater harvesting and WSUD features into the urban residential environment, with open water bodies, leading to high aesthetic values and increased land values through out the area. The recycled water is used for all non potable uses including toilet flushing, and has a high level of community awareness and acceptance.

Several large scale stormwater recycling schemes are operating in major urban and rural centres across Victoria. These large scale projects are also complemented by a host of smaller scale projects. The availability of state government funding for projects of this nature has helped proliferate projects across Victoria and resulted in developing local knowledge and innovative techniques and end uses. The Stawell SWANS project demonstrates how stormwater harvesting on a whole of city scale can be undertaken successfully in a regional centre (Municipal Association of Victoria 2004, Manivasagasivam pers com 2008). The Northern Grampians Shire Council has undertaken a city wide stormwater harvesting scheme in Stawell, located in country Victoria. The project has been developed in three stages to complete a harvesting, treatment, storage and distribution network across the town. On-ground works to complete Stage 2 are currently under way concurrent with the design of Stage 3. The water provides irrigation supplies for the town and road construction and maintenance requirements, with the added benefit of flood protection in the region. The development of this scheme has been undertaken in an existing urban environment and been designed to the constraints present. While the level of urbanisation may not be as intensive as say Brisbane, this case study certainly has implications for what can be achieved in regional areas identified by the urban footprint of the SEQ Regional Plan.

Another large scale stormwater harvesting project is the Docklands area on the eastern side of Melbourne's CBD (City of Melbourne 2004). This project incorporates a major redevelopment of the port area and covers 200ha. The multiple projects have been undertaken in this space in such a way that all measures have been integrated from a systems perspective but also from an urban landscape perspective, to provide a great example of what can be achieved within the urban renewal process of a city. Victoria also provides us with an example of an innovative end use. Altona Recreation Centre collects roofwater from the complex and stormwater runoff from the surrounding area, which is treated and used in the centre's swimming pool (DPI 2008). Harvested water is stored onsite using an old, unused pool that otherwise would have been demolished in the refurbishment of the complex.

Stormwater use in Western Australia consists of widespread indirect recycling on the sandy soils of the coastal plains, water sensitive design, and direct use through rainwater tanks throughout rural areas. A significant proportion of the total water cycle is supplied through indirect recycling. Around 130,000 homes (~25%) in Perth have private bores into the shallow groundwater for non-potable supplies (WBM, 1999). Residents in Perth are prohibited from discharging stormwater off their properties. This has resulted in the majority of domestic residences having soak wells and other infiltration systems to dispose of roof runoff and stormwater into the groundwater system on site. As such, Perth has developed an efficient indirect urban stormwater recycling scheme, where a significant proportion of the total water cycle is recycled. Stormwater use projects for the region are therefore related to assisting the indirect use scheme.

An example of this is the Cottesloe Peninsula Groundwater Restoration project (National Water Commission, 2008). Effectively stormwater use occurs via the Swan Coastal Plain groundwater system. The Cottesloe Peninsula Groundwater Restoration Project involves the replacement of open sumps with seven new underground sumps and 280 new soakage pits throughout Cottesloe to trap and filter stormwater, which is then used to replenish the groundwater aquifer. Harnessing the stormwater runoff to replenish the groundwater system will result in the decommissioning of ten stormwater outfall pipes along the coast. In addition to these measures, a public education programme will aim to reduce private groundwater use, decrease the installation of new private bores and reduce stormwater pollutants.

The Canberra Integrated Waterways Feasibility Study aims to identify the feasibility of achieving 3 GL/a in water savings in the ACT by 2015, by utilising stormwater as a potable water substitute (CSIRO, 2008). Stage 1 of the analysis included a detailed physical analysis of water flows to evaluate the feasibility of the water saving target. Stage 1 of the project resulted in the development of a set of portfolios of supply – demand options that have the ability to meet the 3 GL target. The study has also found that meeting the potable water saving target was achievable by 2015. Mixing stormwater with reclaimed water was not necessary as it is likely to be more expensive and was not favoured by the community, as determined in the social analysis. Use of existing lakes and ponds in the Canberra area was recommended as it was found to be both cost effective and had the support of the community. Further investigations should also be undertaken to analyse the opportunities for constructing new

ponds in association with local aquifer storage, transfer and recovery schemes. Stage 2 of the study (in progress) will see the development of a set of triple bottom line criteria which will be used to assess the various portfolios.

In Queensland outside of the SEQ region, little information is available regarding practices for stormwater harvesting. An exception to this is the Wide Bay Water stormwater and effluent use scheme occurring just north of the SEQ region, in Hervey Bay (Figure 6.9) (Heron and Lever 2000). The scheme harvests urban stormwater at night using existing sewer infrastructure in conjunction with a wastewater use scheme. The urban stormwater is harvested from flood retardation basins and channelled into existing sewers during low flow periods at night, which can normally result in odour and corrosion problems. The water is then transferred to the sewage treatment plant and is then pumped into irrigation schemes. The scheme developed by Wide Bay Water has a number of attractive features, it:

- Exploits existing sewer infrastructure;
- Optimises existing effluent use infrastructure;
- Harnesses innovative hydraulic modelling;
- Decreases farm water demand from other water sources;
- Reduces urban nuisance floods;
- Increases the water available for agricultural irrigation and improves farm productivity; and
- Minimises odour production and corrosion within the sewerage network, which therefore prolongs the life of the existing infrastructure.

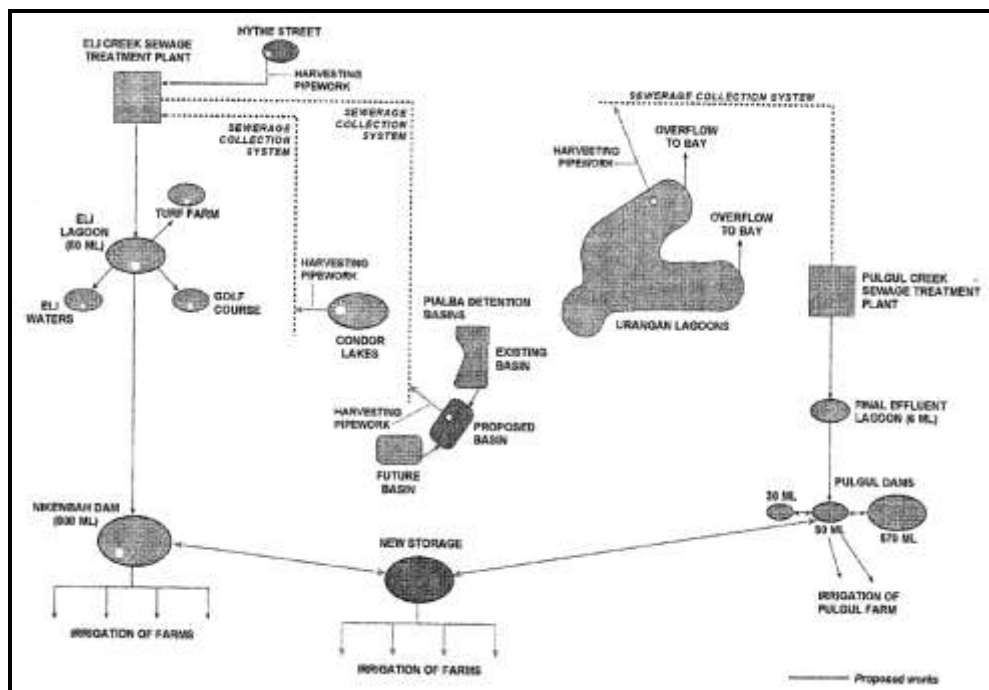


Figure 6.9 A schematic of the Wide Bay Water integrated stormwater and wastewater use system (Heron and Lever 2000)

Table 6.2 National Case Studies Summary

Project	Location	Capture	Treatment	Storage	Distribution	End Use
Barnwell Park Golf Course	NSW	Weir diversion on stormwater pipe	GPT, sand filter infiltration basin	Above ground tanks	Irrigation network	Irrigation – golf course
Sydney Smith Park	NSW	Stormwater pipe diversion, extended detention storage	GPT, rapid sand filter	Underground concrete tank	Irrigation network	Irrigation – sports ground
Bexley Municipal Golf Course	NSW	Inline pond storage created by constructing a weir on an existing concrete lined channel	Trash rack, mechanically aerated pond	Constructed ponds	Irrigation network	Irrigation – golf course
Black Beach Foreshore Park	NSW	Diversion pit on existing stormwater pipe	Sand filter, UV disinfection	Underground tank	Irrigation network	Irrigation – public open space
Manly Stormwater Treatment and Use	NSW	Permeable pavers	Filtration	Geo cell underground storage	Irrigation network	Irrigation – public open space
Powells Creek Reserve	NSW	Pervious road gutter	Filtration	Plastic cell retention tank	Irrigation network	Irrigation – public open space
Hawkesbury Water Use Project	NSW	Flood detention basins	Constructed wetlands and settling pond	Dam	Irrigation network	Irrigation – university and TAFE grounds
Scope Creek	NSW	Diversion pit on existing stormwater channel	Trash rack, sedimentation basin, oil and grit separator	Underground tanks	Irrigation network	Water quality improvement
Solander Park	NSW	GPT and surface water detention basin	GPT, electrolysis, filtration	Underground tank	Irrigation network	Irrigation – public open space
Taronga Zoo	NSW	Retention basin	Screening, aeration, biological treatment plant, continuous membrane microfiltration, UV disinfection	Tanks	Dual reticulation	Exhibit washdown, moat top up water, public toilet flushing, irrigation
Riverside Park	NSW	Constructed wetland	Constructed wetland	Constructed wetland	Irrigation network	Irrigation – sports grounds
Hornsby Shire Depot	NSW	Bioretention trench	Bioretention trench, sediment trap, filtration tank	Above ground concrete tank	Irrigation network	Toilet flushing, Irrigation – nursery
Prince Henry Development	NSW	GPT	Sediment arrestors, GPT, bioretention, irrigation filter	Ponds	Irrigation network	Irrigation – public open space, golf course
Darling Harbour Stormwater Harvesting System	NSW	Downpipe diversion	First flush device	Above ground tanks	Irrigation network	Irrigation – public open space
Homebush Bay Water Recycling	NSW	Diversion of existing stormwater infrastructure	Constructed wetlands, advanced treatment	Old brick pit	Dual reticulation and irrigation network	All non drinking purposes of residential, commercial and sporting facilities
Mulga Creek Catchment Wetland	NSW	Diversion of existing stormwater infrastructure	Constructed wetland	Aquifer	Irrigation network	Irrigation – public open space

Project	Location	Capture	Treatment	Storage	Distribution	End Use
City of Salisbury Integrated Water Management	SA	Diversion of existing stormwater infrastructure	Constructed wetlands, swales	Aquifer, constructed wetlands	Distribution mains	Industrial, commercial and community use
Regent Gardens	SA	Stormwater drainage designed to feed into use system	GPT, constructed wetland	Aquifer	Irrigation network	Irrigation – public open space
New Brompton Estate	SA	Roof water harvesting	Infiltration trench, geotextile filter	Aquifer	Irrigation network	Irrigation – public open space
Parfitt Square	SA	Gutter entry pits	Sediment trap, reed bed, bioretention trench, geotextile filter	Aquifer	Irrigation network	Irrigation – public open space
Mawson Lakes	SA	Traditional stormwater system	GPTs, settling basins, constructed wetlands, filtration, chlorination	Tanks and/or aquifer	Dual reticulation	Irrigation of lawns, parks and gardens, toilet flushing, washing cars, filling ornamental ponds and water features.
Catani Gardens	VIC	Diversion from existing stormwater pipe	GPT, bioretention, UV disinfection	Underground tank	Irrigation network	Irrigation – public open space
Footscray Park	VIC	Diversion from existing stormwater pipe	Constructed wetland	Underground tank	Irrigation network	Irrigation – public open space
Sorrento Stormwater Use	VIC	Not specified	GPT, constructed wetland	Dam	Irrigation network	Irrigation – golf course
Charlton Community Stormwater Use	VIC	Diversion of existing stormwater pipe	Primary treatment – method not specified	Dam	Irrigation network	Irrigation – public open space
Mernda Villages ASR	VIC	Swales, constructed wetland	Bioretention, swales, constructed wetland	Aquifer	Irrigation network	Irrigation – public open space
Albert Park Stormwater Use	VIC	Diversion of existing stormwater pipe	In-lake pollution control ponds	Albert Park lake	None	Maintaining lake levels
Trinity Grammar Billabong Restoration	VIC	Diversion of existing stormwater pipe	Constructed wetland	Constructed wetland	Irrigation network	Irrigation – sports grounds
Stawell Stormwater Alternative Natural Solutions (SWANS)	VIC	Diversion of existing stormwater infrastructure	Constructed wetlands, litter and sediment traps, nutrient filters	Ponds and large central dam	Irrigation network, tankers	Irrigation, road construction and maintenance
Altona Green Park	VIC	Swales	Swales	Underground tank	Irrigation network	Irrigation – sports grounds
Altona Leisure Centre	VIC	Roof collection, surface runoff capture method not specified	Chlorination	Old swimming pool	Existing swimming pool system	Swimming pool
Edinburgh Gardens	VIC	Diversion of existing stormwater pipe	Constructed wetland, UV disinfection	Underground storage	Irrigation network	Irrigation – public open space
Docklands	VIC	Stormwater drainage designed to feed into use system	Constructed wetlands, GPTs, bioretention systems	Constructed wetland, underground storage	Irrigation network	Irrigation – public open space
Queen Victoria Markets	VIC	Bioretention, roof water harvesting	Bioretention, first flush diverter	Ecotanks (in pipe storage), toilet header tanks	Toilet network, wash down pipe network	Toilet flushing, wash down

Project	Location	Capture	Treatment	Storage	Distribution	End Use
City Oval Drainage Retention System	VIC	Diversion of existing stormwater pipe	GPT, sand filter	Underground tanks	Irrigation network, tankers	Irrigation – public open space
Beechworth Recreation Reserves Strategy	VIC	Stormwater drainage designed to feed into use system	Not specified	Retention basin	Irrigation network	Irrigation – golf course, sports grounds
Wodonga Sustainable Sports Grounds Project	VIC	Diversion of existing stormwater infrastructure	Constructed wetlands	Constructed wetlands	Irrigation network	Irrigation – sports grounds
Cranbourne Turf Club Irrigation	VIC	Diversion of existing stormwater infrastructure, roof water harvesting	Not specified	Clay lined dam	Irrigation network	Irrigation – race course
Bendigo Harness Racing Track Water Harvesting Project	VIC	Diversion of existing stormwater infrastructure	No treatment undertaken	Retention dam	Irrigation network	Irrigation – race course
Barry Brothers Water Use	VIC	Pumped out of service pits	Method not specified – Class C	Above ground tanks	Irrigation network	Street sweeping, irrigation – public open space
Cottesloe Peninsula Groundwater Restoration Project	WA	Stormwater sumps, soakage pits	Infiltration, geotextile filter	Aquifer	Groundwater bores	Unrestricted

6.3. Stormwater Harvesting in South East Queensland

Limited knowledge is available on stormwater harvesting in the SEQ region in peer reviewed literature. Developing knowledge of the stormwater harvesting practices in the SEQ region has to date relied on reviewing background documents for Queensland State Government plans and guidelines and interviewing local stakeholders such as Brisbane City Council and Healthy Waterways. As a result, much of the information presented following relates to generic information on stormwater harvesting in SEQ based on desktop studies supported by the anecdotal information available on schemes operating in the region.

WBM (1999) conducted a review of international and Australian stormwater harvesting practices as a background document for the Queensland Water Recycling Strategy. MWH (2006) and Cardno (2006) prepared background documents on various aspects of stormwater harvesting to inform the draft SEQ Water Strategy (QWC, 2008). MWH (2006) investigated opportunities for customer side source substitution whereas Cardno (2006) prepared a review of the use of stormwater and recycled water as alternative water resources. MWH (2006) reviewed the opportunities for recycled water in SEQ using a screening process to determine which options may produce regionally significant potable water savings if implemented. This report considered localised individual and small communal applications for recycled water in non potable schemes specifically for irrigation and toilet flushing purposes. The complementary Cardno (2006) report considered opportunities and constraints associated with suburban scale stormwater harvesting and use in greenfield developments. Brisbane City Council have also conducted theoretical investigations into the development of major greenfield stormwater recycling schemes within the metropolitan area (BCC, 2007). All reports independently reiterate many of the same points with respect to stormwater harvesting.

All reports highlighted constraints to the widespread uptake of stormwater harvesting in the SEQ region. The lack of regulation and design criteria including lack of clear design guidelines for the collection, treatment and storage of runoff was identified as a constraint to the implementation of stormwater harvesting. As discussed in Section 4, this constraint is now being addressed on several statutory levels.

The economics of stormwater harvesting systems was again identified as a constraint to uptake due to the lack of a method to assess the costs and benefits associated with stormwater recycling systems against conventional systems. The cost of typical stormwater use schemes was found to be significantly higher than the cost of existing potable water supply systems. Cardno (2006) estimated the cost of supply of harvested stormwater in greenfield developments at between \$1.30 and \$2.80 per kL. This cost of supply however does not take all aspects of the stormwater use system into account e.g. water quality benefits. WBM (1999) also concluded stormwater harvesting is not an economically attractive water supply option when considered purely from principal cost perspective. However, when other issues such as water quality benefits are factored in, the option becomes much more economically attractive. The report suggests that the following factors are considered in the economic analysis of stormwater harvesting:

- Reductions in non point source pollutants and peak flows;
- Reduced requirement to augment existing potable water storage and distribution systems, and stormwater drainage to cater for new urban/developed areas;
- Potential for achieving multiple uses of public space e.g. for recreation, environmental enhancement, and stormwater storage and recycling purposes; and
- Stormwater recycling costs should be compared to the cost of developing alternative sources of water and not the current price of potable water.

Another economic limitation is the limited opportunity for market forces to assist in the uptake of stormwater recycling as a result of the current low prices of the conventional potable water supply to customers.

Storage size was again identified as an issue for stormwater harvesting, especially in respect to SEQ due the local rainfall patterns. The ephemeral nature of stormwater runoff means that significant storage is required. Cardno (2006) estimated the surface storage of a greenfield residential development with a stormwater use scheme would likely occupy around 5% or more of the area to be developed. This is greater than the area that is normally needed for stormwater quality treatment. In ASR schemes, storage is also required as the rate of recharge is much lower than the runoff rate during a storm event. ASR also requires area set aside for pre-treatment and injection processes. Treatment of runoff is necessary prior to ASR to prevent irreversible damage to the aquifer if it is contaminated with pollutants or silt.

Widespread use of stormwater is potentially limited by the quality of the water harvested. A high level of treatment is required to reach the quality required for domestic non potable use. Disinfection may be necessary depending on the application. As a result the cost of treatment may be higher than traditional water sources. Disposal of the treatment by-products may also incur additional expense.

Large scale potable recycling of stormwater, as practised in Singapore (see Section 6.1.4), was not considered a viable proposition for Queensland at the time the WBM (1999) report was compiled, for the following reasons:

- Difficulties in the application of the necessary strict land use planning and enforcement controls necessary to minimise runoff contamination;
- Poor track record in regulating and enforcing necessary construction and operational controls required to ensure the supply of suitable quality raw water; and
- At the time of publication, there was not a significant shortage of water supply to warrant the efforts required to develop a functioning large scale stormwater use system.

Notwithstanding these constraints, the overall finding of WBM (1999) was that the climate in SEQ and the range of technologies available make stormwater harvesting a feasible option for water recycling. The report also concluded that stormwater recycling should be considered as a supplement to existing potable supplies, rather than a sole supply, in order to resolve potential arguments against stormwater harvesting due to a lack of available storage. Cardno (2006) also suggests several situations where stormwater becomes an attractive alternative source:

- Significant storage is available, for example in the form of natural wetlands, water quality treatment ponds, or disused quarries, located near urban or industrial development – reducing storage costs for the development of the scheme.
- Recycled water is being produced by a wastewater treatment plant, and facilities are available for treatment of the stormwater. Stormwater harvesting and use then becomes a supplementary source to the wastewater stream, and advantages could be gained in a joint scheme, such as that operated by Wide Bay Water (Heron and Lever 2000).
- Mitigation measures are required to manage the flows and pollutant loads impacting the receiving waters.

MWH (2006) concluded that stormwater harvesting and use does not present the potential of generating regionally significant potable water savings in SEQ, and therefore should not be carried forward for further evaluation as a major component of the SEQ Water Strategy (QWC 2008). Of the six scenarios investigated by BCC (2007), it was found that the greenfield residential developments and the major renewal/transit oriented developments represented the greatest opportunity for significant investment in stormwater harvesting in Brisbane. This is further supported by the calculation of levelised costs, with the major greenfield development scenario estimated to produce water at \$1.10/kL, comparable to the current price of potable water.

The focus on the use of greenfield developments in these existing studies highlights the need for a more detailed assessment of opportunities for stormwater harvesting within established areas. So far this issue has not been considered due to initial assumptions about the anticipated difficulties and the expected high cost of retrofitting stormwater use facilities. However, the urban renewal cycle will require the replacement or augmentation of existing facilities on the future leading to opportunities to integrate stormwater harvesting projects. There are a large number of renewal projects required over SEQ due to the infrastructure requirements of the rapidly expanding population. Investigation of these opportunities should be a high priority.

During the time this literature review was undertaken, major changes were under way with local government areas in the SEQ region. As a result, consultation with local governments was restricted primarily to Brisbane City Council. Consequently, much of the specific information presented here relates to stormwater harvesting activities in the Brisbane metropolitan area. Further consultation is currently under way with local governments in the SEQ region to document stormwater use activities. Presently, Brisbane City Council have identified nineteen stormwater harvesting projects in various stages of development in SEQ, mostly situated in the greater Brisbane area. Available details regarding the projects are presented in Table 6.3.

Table 6.3 Brisbane City Council Stormwater Harvesting Activities

Project	Current Status	Estimated Water Savings	Approximate Catchment Area	End Use	Collection Method	Treatment	Storage	Distribution
Southbank Stormwater Harvesting, City/South Brisbane	Detailed design phase	4-9 ML/a (To be determined)	30 ha	Irrigation, swimming pool top up, water features	Diversion of existing stormwater infrastructure	Various measures including membrane technology and UV disinfection	Tanks	Retrofit existing irrigation system
St Aidens School, Corinda	Awaiting funding for detailed design	Yet to be determined	Yet to be confirmed	Sports field surface irrigation	Diversion of existing stormwater infrastructure	Filtration and aeration (methods to be confirmed)	Open water body	Pumped irrigation
Corinda High School, Corinda	Awaiting funding for detailed design	Yet to be determined	Yet to be confirmed	Sports field surface irrigation	Rainwater and stormwater diversion from school property	Yet to be confirmed	Above ground tanks	Pumped irrigation
Mt Coot-tha Botanic Gardens	Proposed	50 ML/a supplemented with 10 ML/a groundwater that undergoes on site solar desalinisation	55 ha	Irrigation of gardens	Pumped	Settling pond	Pond	Pumped, irrigation (drip and spray)
City Botanic Gardens, Brisbane	To be confirmed	To be confirmed	To be confirmed	To be confirmed	To be confirmed	To be confirmed	To be confirmed	To be confirmed
Willawong Bus depot Roof runoff harvesting	Under construction	5.5 ML/a	7,300 m ²	Hot water, toilet flushing, bus wash top up	Roof runoff	Filtration and UV disinfection	760kL rainwater tank	Piped
Willawong Bus depot Stormwater Harvesting	Under construction	3.8 ML/a	35,770 m ² (pavement)	Irrigation (1 ha landscaped area)	Drainage collection	Biofiltration swales	Constructed wetland	Pumped and piped
Chelmer Landfill Remediation, Queenscroft St Chelmer	Pre-construction (ordering equipment)	Up to 3 ML/a	2.8 ha	Irrigation of 2 ha sports field	Stormwater diversion	Pre-irrigation pump filter and GPT	260kL above ground tank	Pop up sprinklers

Project	Current Status	Estimated Water Savings	Approximate Catchment Area	End Use	Collection Method	Treatment	Storage	Distribution
Caterson Park Landfill Remediation, Cnr Mt Gravatt-Capalaa Rd and Weedon St West	Construction (storage completed, pump system awaiting electrical connection, Sports club awaiting grant for irrigation system)	Up to 8 ML/a	5 ha	Irrigation of sports field	Stormwater diversion	Pre-irrigation pump filter	Dam	Pop up sprinklers
Yoku Rd Landfill remediation project (Valleys Cricket Club)	Construction (remediation completed, club handling stormwater harvesting)	unknown	3 ha	Irrigation of sports fields	Stormwater diversion	Unknown	Sub surface tanks	Pop up sprinklers
Whites Hill – Boundary Rd, Camp Hill Stormwater Diversion Bund	Design phase	To be determined	4.5 ha	Irrigation of sports fields	Stormwater bund	To be determined	Above ground tanks	Pop up sprinklers
Rasey Park – Butterfield St, Herston landfill remediation project	Preliminary investigation	To be determined	Up to 30 ha	Irrigation	Stormwater diversion	To be determined	Above ground tanks	Pop up sprinklers

The Healthy Waterways Partnership have also identified several projects in the region in addition to the Brisbane City Council's activities listed in Table 6.4 (Hoban pers comm. 2008).

Table 6.4 Current SEQ stormwater harvesting schemes (Hoban pers comm. 2008)

Project	Description	Status
Incitec, Port of Brisbane	Plan to harvest 95% of stormwater runoff	Unknown
Coolum Ridge	Stormwater harvesting to reservoir then internal non-potable uses	Design only, pending headworks charge concessions
Moorooka	Car dealership - use for car washing	Unknown
Cabbage Tree Creek	Distributed harvesting for rehabilitation of waterway	Concept
North Lakes	Stormwater harvesting via wetland and underground storage for irrigation	Under construction
Parkwood Estate	Stormwater harvesting via bioretention and open water storage for irrigation	Unknown
Yatala	Industrial precinct - matching industry type (by water use) to stormwater harvesting yield	Unknown
Southport Parklands	IUWM strategy for waterfront area	Unknown

Further consultation with individual councils and stakeholders may reveal further case studies of stormwater harvesting activities across the region and research needs to further stormwater harvesting in South East Queensland.

7. FUTURE RESEARCH NEEDS

This review has shown that there is sufficient information and technology available regarding stormwater harvesting to validate further investigation as a water supply source for South East Queensland. The case studies investigated in the international, national and local arena have provided examples in diverse situations where stormwater harvesting has been successfully applied using a wide range of techniques at varying scales. However, limitations to stormwater harvesting have also been identified. Following this comprehensive review it is proposed the following areas, as discussed in the subsequent paragraphs, require further research in order to propagate stormwater harvesting in SEQ.

An appropriate water balance estimation is required that is applicable to the level of detail necessary to appropriately analyse stormwater harvesting. This information is required to determine the volume of water that is available for harvesting and how much should be harvested with consideration to the trade off between environmental benefits and augmentation of water supply.

The case studies have illustrated that stormwater harvesting in Australia rarely considers end uses beyond irrigation. Little information is available on stormwater as a supplementary potable water supply. The stormwater capture and use project needs to consider a wider application of the harvested water for SEQ in order to fully appreciate the opportunities for harnessing this resource.

The variable nature of stormwater flows and quality means treatment processes need to be able to cope with large variations in hydraulic and pollutant loads. Effective and economical stormwater treatment measures need to be determined for stormwater harvesting, to ensure the water is always fit for its end use. This topic is also connected with the investigation of expanding end use to potable supplies, a reliable treatment methodology is necessary in order to achieve water quality standards.

One of the identified limitations to stormwater harvesting in SEQ was the storage size required in order to obtain an appropriate security of supply. Storage opportunities need to be identified across the region. A mapping project is currently under way to determine the feasibility of managed aquifer recharge (MAR) in SEQ. Existing urban landscapes provide limited opportunities for the development of new infrastructure, a fact that has limited stormwater use in the past to greenfield areas. Further research is required to determine alternative storage and harvesting options, and how best to use the urban renewal process to achieve integrated water management and stormwater harvesting outcomes.

The practice of stormwater harvesting is rooted in the principle of sustainability; as such the impact of harvesting on the hydrology and health of aquatic and riparian environments is an important consideration. Further work is required to investigate the impact on ecosystem health in response to stormwater harvesting in the SEQ environment.

Increasing awareness and confidence in the application of stormwater harvesting within the community and practitioners is also vital in furthering stormwater harvesting. There are many options for configuration of stormwater capture and use scheme. While this allows projects to be undertaken in a wide variety of situations, it also introduces an element of confusion as to the methods that should be applied. This project has also highlighted the lack of information sharing on stormwater harvesting projects. Developing a stormwater harvesting project register would increase information flow, allowing contact between parties to best achieve stormwater harvesting projects. This would also help raise community knowledge and acceptance of stormwater as a water resource.

To date the application of risk management frameworks outlined by AS/NZS 4360 and as proposed in the National Water Recycling Guidelines have been used to assess the various environmental and public health and safety aspects of stormwater harvesting. Further investigation is required to determine whether this methodology is suitable to be extended to cover other aspects of stormwater harvesting including security of supply issues in relation to climate change and land use activities.

As this document has shown, to date stormwater harvesting schemes have not been able to develop a true comparison between conventional supplies and alternative water supplies. A methodology is required to determine the true costs/benefits of a stormwater harvesting scheme in relation to the conventional water supply/infrastructure option. This review has found that multiple criteria analysis provides an economic evaluation framework that may be applicable to stormwater harvesting using a spatial analysis approach. Further investigation is warranted to develop this methodology.

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APPENDIX A – NATIONAL CONTEXT STORMWATER USE CASE STUDY OUTLINES

PROJECT TITLE: BARNWELL PARK GOLF COURSE, FIVE DOCK

Location:

NSW

Project Manager/Applicant:

City of Canada Bay Council

Project Status:

Completed 2004

Project Objectives:

- Reduce the mains water use at Barnwell Park Golf Course through the use of treated stormwater for irrigation
- Reduce stormwater pollution loads entering Hen and Chicken Bay, Drummoyne.

Catchment and Site Characteristics:

- 7ha catchment upstream of the golf course
- Land use in the catchment includes residential and industrial

Estimated Potable Water Savings:

Unknown

Project Summary:

- Stormwater conveyed to site via stormwater pipe.
- A diversion weir in a pit on the pipe diverts low flows into the use scheme
- Treatment through a gross pollutant trap and then into a 1ML above ground sand filter basin.
- Stormwater filters through the sand media in the basin and is collected by under drains and directed into a monitoring pit
- Treated stormwater is pumped from the monitoring pit to 4 above ground storage tanks with a total capacity of 100kL.
- Overflows from the use system are directed to an adjacent concrete lined stormwater drain.
- Treated stormwater is pumped into a piped irrigation network to spray irrigate 2 fairways on the golf course each with an area of approximately 0.25 ha.
- Annual reliability of supply was estimated to be 81% with mains used as supplementary supply.
- Additional storage could be added in the future to extend the irrigation network and increase reliability of the system.
- Ongoing monitoring of the quality of the treated stormwater

Costs:

Total capital: \$337,530

Recurrent cost: \$27,000

Lifecycle cost: \$572,000

Key Points:

Capture: weir diversion on stormwater pipe

Treatment: GPT and 1ML sand filter basin

Storage: Above ground tanks

Distribution: Piped irrigation network

End Use: Irrigation – golf course

Reference:

Department of Environment and Conservation (NSW) 2006 Managing Urban Stormwater: Harvesting and Reuse

PROJECT TITLE: SYDNEY SMITH PARK, WESTMEAD

Location:
NSW

Project Manager/Applicant:
Holroyd City Council

Project Status:
Completed 1999

Project Objectives:

- Protect downstream properties from flooding
- Reduce pollution loads to Domain Creek and Parramatta River
- Irrigate the sports fields with treated stormwater to partial replace mains water use

Catchment and Site Characteristics:

- Upstream catchment from the park is approximately 26ha of residential land use. The area of the park is 2 ha.

Estimated Potable Water Savings:
Estimated use volume of 12ML

Project Summary:

- Different collection and treatment arrangements for high and low flows
- A diversion pit was constructed on the stormwater pipe under the park.
- Low flows are diverted to 2 underground GPTs for initial treatment.
- A proportion of the water treated by the GPTs then is passed to an underground rapid sand filter for further treatment
- Treated water from the sand filter is stored in a 600kL underground storage tank.
- Any flows greater than the capacity of the low flow diversion flow into the park, which has been excavated to provide temporary storage for floodwaters.
- Filter media under the sports ground surface treats the infiltrated proportion of the stored flood waters and this treated water is conveyed via subsoil drains to the underground storage tank.
- Treated stormwater is pumped from the underground storage tank into a piped underground irrigation system that irrigates an area of 1.5 ha.
- A 35kL above ground storage tank was also constructed for mains back up to the irrigation supply.
- Estimated annual stormwater pollution loads reduced by 30 tonnes of gross pollutants, 12,000kg suspended solids, 15kg for total phosphorus and 70kg for total nitrogen.
- No monitoring of the treated stormwater is undertaken.

Costs:

Capital: \$731,827 (excluding flood mitigation cost of \$400,000)
Recurrent: \$45,000
Lifecycle: \$1,115,000

Key Points:

Capture: diversion of stormwater pipe and extended detention storage on sports ground surface
Treatment: GPTs and rapid sand filter
Storage: underground concrete tanks
Distribution: piped irrigation network
End Use: irrigation – sports ground

Reference:

Department of Environment and Conservation (NSW) 2006 Managing Urban Stormwater: Harvesting and Reuse

PROJECT TITLE: BEXLEY MUNICIPAL GOLF COURSE, BEXLEY

Location:
NSW

Project Manager/Applicant:
Rockdale City Council

Project Status:
Completed 2001

Project Objectives:

- Reduce mains water demand at Bexley Golf Course by using treated stormwater for irrigation
- Enhance visual amenity of the golf course
- Reduce stormwater pollution loads entering the Cooks River

Catchment and Site Characteristics:

- Contributing catchment 77ha urban land use and 5ha golf course
- Water from the catchment flows through the 20ha golf course in a concrete lined channel
- Irrigated area 12.6ha with only 1.35ha requiring intensive irrigation

Estimated Potable Water Savings:

Design annual use volume of 66ML

Project Summary:

- A weir was constructed on the concrete lined stormwater channel and the area upstream excavated to create an initial storage area of 5.3ML
- In 2003 the storage was dredged to clean out accumulated sediment and increase the capacity of the initial storage to 7ML
- Dredging is expected to be required in the initial storage every 10 years
- A supplementary 1.4 ML storage dam was constructed on the high point of the golf course with a two way flow pipe to connect the initial storage to allow top up
- The stormwater is treated by a trash rack upstream of the weir in the concrete channel.
- Further treatment occurs through sedimentation and mechanical aeration of the storage.
- The irrigation system includes self cleaning irrigation disc filters
- Treated stormwater is pumped to a piped spray irrigation system by gravity from the supplementary dam. Total area irrigated is 12.4 ha.
- Mains water is available as supplementary supply
- Annual stormwater pollution loads to Cooks River reduced by 46,000kg of suspended solids, 100tonnes of gross pollutants, 60kg of total phosphorus and 240kg of total nitrogen.

Costs:

Capital: \$594,197
Recurring: \$18,000
Lifecycle: \$728,000

Key Points:

Capture: inline pond storage created by use of weir on concrete lined channel
Treatment: Trash rack, sedimentation and mechanical aeration in the storage ponds
Storage: Constructed ponds
Distribution: Piped spray irrigation system
End Use: Irrigation – golf course

Reference:

Department of Environment and Conservation (NSW) 2006 Managing Urban Stormwater: Harvesting and Reuse

PROJECT TITLE: BLACK BEACH FORESHORE PARK, KIAMA

Location:
NSW

Project Manager/Applicant:
Kiama City Council

Project Status:
Completed 2004

Project Objectives:

- Reduce stormwater pollution to Kiama Harbour
- Irrigates 2 parks with stormwater to reduce mains water consumption

Catchment and Site Characteristics:

- Contributing catchment 6.5ha with a mix of commercial, residential and open space land uses.

Estimated Potable Water Savings:

Estimated annual use volume 12ML/a

Project Summary:

- Stormwater is collected, treated and pumped to an offline storage and irrigated on two parks
- GPTs were placed in numerous drainage pits within the catchment, focussing on the business district
- A diversion pit was constructed on an exiting drain diverting low flows to a sand filter
- Flows enter the sand filter through permeable concrete pipes laid within the filter media.
- Treated stormwater is collected by a subsoil drainage system at the base of the sand filter. Flows exceeding the capacity of the stormwater filter are surcharged into a shallow basin above the filter where they are left to infiltrate through the filter material.
- Treated stormwater flows back into the main drainage system where they are diverted to a holding tank, high flows continue through the main stormwater system
- Stormwater is then pumped from the holding tank to a 45kL underground storage tank
- The water is then pumped through a UV disinfection unit into the irrigation network.
- The scheme irrigates 2ha of parkland
- Mains water is used as supplementary supply
- Estimated annual stormwater pollution load reduction is 5,000kg for suspended solids, 7kg from total phosphorus and 40kg total nitrogen.

Costs:

Capital: \$174,900
Recurring: \$17,000
Lifecycle: \$322,000

Key Points:

Capture: diversion pit on existing stormwater pipe
Treatment: sand filter, UV disinfection
Storage: 45kL underground storage tank
Distribution: piped irrigation network
End Use: irrigation – public open space

Reference:

Department of Environment and Conservation (NSW) 2006 Managing Urban Stormwater: Harvesting and Reuse

PROJECT TITLE: MANLY STORMWATER TREATMENT AND USE

Location:NSW

Project Manager/Applicant:
Manly Council

Project Status: Completed 2001

Project Objectives:

- Provide alternative water source for irrigation of the Manly beachfront, particularly during periods of water restrictions, and reduce stormwater pollution loads to Manly Beach, particularly pathogens

Catchment and Site Characteristics: 2.6ha of road and car park

Estimated Potable Water Savings:

Estimated annual use volume 19ML (however park was previously not irrigated, therefore no reduction in actual mains demand)

Project Summary:

- 500m of concrete dish drain was replaced with pervious paving which receives runoff from the road surface and car park. Stormwater infiltrates the pavers into the soil media below them. Treated stormwater is collected by a plastic channel at the base of the media
- Stormwater is then piped to a 390kL geo cell underground storage, water levels in the tank are influenced by groundwater interactions
- Water is pumped from the storage into a spray irrigation network, irrigates approximately 4 ha of foreshore park
- Estimated annual stormwater pollution loads reduced by 4,000kg for suspended solids, 6kg for total phosphorus and 50kg for total nitrogen

Costs:

Capital: \$359,780
Recurring: \$39,000
Lifecycle: \$698,000

Key Points:

Capture: Permeable pavers
Treatment: Filtration
Storage: geo cell underground storage (synthetic aquifer)
Distribution: piped spray irrigation network
End Use: Irrigation – public space

Reference:

Department of Environment and Conservation (NSW) 2006 Managing Urban Stormwater: Harvesting and Reuse

PROJECT TITLE: POWELLS CREEK RESERVE, NORTH STRATHFIELD

Location:
NSW

Project Manager/Applicant:
City of Canada Bay

Project Status:
Completed 1999

Project Objectives:

- Reduce the level of stormwater pollution entering Homebush Bay, particularly to protect the mangrove wetlands near the Powells Creek estuary
- Irrigate part of Powells Creek reserve using treated stormwater
- Demonstrate an innovative method for managing road stormwater runoff

Catchment and Site Characteristics:

- 5 streets each with a residential catchment area of approximately 1300m²
- The streets feed into a tidal concrete lined trapezoidal channel
- The reserve is located north of the streets

Estimated Potable Water Savings:

Estimated annual stormwater use volume 2ML (however previously not irrigated therefore no reduction in actual mains demand)

Project Summary:

- Stormwater is collected using pervious road gutter
- Atlantis geo blocks were filled with engineered media and grassed to replace gutters along five streets.
- After passing through the filtration media the water is stored in three 17kL plastic cell storage tanks.
- Overflow from the tanks are piped into the main stormwater system
- Treated stormwater from two streets are not collected for use and flow directly into Powells Creek
- Treated stormwater from the retention tanks is piped to a 50kL concrete irrigation header tank at the Park which is topped up with mains water.
- The water is then pumped into an piped spray irrigation network
- A grassed area of 2200m² is irrigated
- Estimated annual stormwater pollution loads reduced by 300kg for suspended solids, 0.5kg for total phosphorus and 4kg for total nitrogen

Costs:

Capital: \$379,183
Recurring: \$30,000
Lifecycle: \$636,000

Key Points:

Capture: Pervious road gutters
Treatment: filtration
Storage: plastic cell retention tanks
Distribution: piped spray irrigation network
End Use: irrigation – public open space

Reference:

Department of Environment and Conservation (NSW) 2006 Managing Urban Stormwater: Harvesting and Reuse

PROJECT TITLE: HAWKESBURY WATER USE

Location:
NSW

Project Manager/Applicant:
Hawkesbury City Council and the University of Western Sydney

Project Status:
Completed 2,000

Project Objectives:

- To manage stormwater in a total catchment context involving structural and non structural strategies
- Develop, trial and implement structural and non structural control strategies for controlling source pollution affecting Rickaby's Creek
- Develop infrastructure to integrate stormwater and effluent use
- Develop an effective monitoring system to provide information for adaptive catchment and infrastructure management
- Promote Richmond as a model stormwater township and transfer experience to other councils and stormwater managers

Catchment and Site Characteristics:

- Two catchments for the project:
- The township of Richmond consisting of residential and golf course areas – 285ha
- The University of Western Sydney rural agricultural area – 130ha

Estimated Potable Water Savings:

Not calculated for the entirety of the scheme.

However, within the university a minimum of 25ML is being used with potentially up to 40-50ML/a.

Project Summary:

- Involves the treatment, storage and use of stormwater and effluent.
- Treated effluent and stormwater is supplied to a number of irrigation users including the university and TAFE campuses.
- Approximately 45% of the stormwater from the town and university flows into a 60ML detention basin constructed to minimise flood risk.
- Stormwater is pumped from the basin to a series of four 1 ha constructed wetlands where treatment occurs
- Wetland detention time is on average 7 days, but can be as low as 2 days.
- Water from the wetlands is transferred at a rate of 3.4 ML/d to a 24ML settling pond for further sedimentation
- Water is then stored in a 90ML dam.
- Stormwater is then pumped to dams located on the university and TAFE grounds for irrigation use.
- Excess treated stormwater is discharged to Rickaby's Creek to maintain environmental flows
- Estimated annual pollution load reductions are 30,000kg for suspended solids, 60kg total phosphorus and 500kg for total nitrogen

Costs:

Unavailable

Key Points:

Capture: Flood detention basin
Treatment: Constructed wetlands and settling pond
Storage: 90ML Dam
Distribution: irrigation network
End Use: irrigation of university and TAFE grounds

Reference:

Department of Environment and Conservation (NSW) 2006 Managing Urban Stormwater: Harvesting and Reuse

PROJECT TITLE: SCOPE CREEK, CRANEBROOK

Location:

NSW

Project Manager/Applicant:

Penrith City Council

Project Status:

Completed 1999

Project Objectives:

- Reduce stormwater pollution levels in low flows from a mixed residential/semi-rural catchment by piloting a range of innovative treatment techniques
- Irrigate a woodlot with treated stormwater during its establishment phase

Catchment and Site Characteristics:

- Scope Creek upstream of project area 220ha catchment
- Site located at the junction of two creeks

Estimated Potable Water Savings:

Approximately 6ML/a during establishment phase

Project Summary:

- The use scheme targets low flows from the catchment
- A trash rack and sedimentation basin was constructed at the inlet to the site with three stormwater pipes leading in.
- A diversion pit was constructed on the low flow pipe beneath the grass lined stormwater channel to direct low flows into the use scheme
- Flows were treated by an underground oil and grit separator
- Treated stormwater from the separator flows to a pumping station with a wet well volume of 4kL.
- Stormwater is pumped into 2 underground concrete storage tanks with a combined volume of 44 kL.
- Overflows are directed to the main stormwater system
- The treated stormwater was initially used on a 1 ha woodlot during establishment.
- Currently the treated water simply flows into the main stormwater system
- Annual reduction in pollutant loads have been reduce by 80,000kg for suspended solids and 90kg for total phosphorus and 260kg for total nitrogen

Costs:

Capital: \$562,452

Recurring: \$44,000

Lifecycle: \$950,000

Key Points:

Capture: Diversion pit from stormwater channel

Treatment: trash rack, sedimentation basin and oil and grit separator

Storage: Underground storage tanks

Distribution: Piped irrigation system

End Use: Irrigation – woodlot establishment, Water quality improvement

Reference:

Department of Environment and Conservation (NSW) 2006 Managing Urban Stormwater: Harvesting and Reuse

PROJECT TITLE: SOLANDER PARK, ERSKINEVILLE

Location:

NSW

Project Manager/Applicant:

City of Sydney

Project Status:

Completed 2001

Project Objectives:

- Reduce the stormwater pollution entering Alexandria Canal
- Reduce flooding in residential areas
- Irrigate Solander Park using treated stormwater in place of mains water
- Provide an educational opportunity for the community

Catchment and Site Characteristics:

- 65ha predominantly residential catchment with some commercial and railway land
- Park is 0.4ha
- Overland flow route through park used to cause flooding problems for adjacent properties

Estimated Potable Water Savings:

Estimated annual use volume 2.7ML

Project Summary:

- Stormwater is collected in a stormwater retention basin or alternately directed into a GPT design to treat all flows up to the 6month ARI.
- The treated water is diverted to a 12kL underground holding tank, then undergoes further treatment by electrolysis in two 1kL Electropure units.
- Water is then directed to a 225kL storage tank and then pumped through the irrigation system of the park.
- The storage also receives surface drainage from the park's stormwater retention basin which is treated by a sand filtration system located beneath the low point of the park.
- All system components are underground
- The project also incorporates interpretive art components
- Estimated annual pollution load reductions by 40,000kg suspended solids, 20 tonnes of gross pollutants, 45kg total phosphorus and 190kg for total nitrogen.

Costs:

Capital: \$544,798

Recurring: \$46,000

Lifecycle: \$946,000

Key Points:

Capture: GPT and surface water retention basin

Treatment: GPT, electrolysis, filtration

Storage: underground storage tank

Distribution: piped irrigation system

End Use: irrigation – public open space

Reference:

Department of Environment and Conservation (NSW) 2006 Managing Urban Stormwater: Harvesting and Reuse

Dallmer, L. (2002). "SQIRTS – an on-site stormwater treatment and reuse approach to sustainable water management in Sydney." Water Science and Technology 46(6-7): 151-158.

PROJECT TITLE: TARONGA ZOO, MOSMAN

Location:

NSW

Project Manager/Applicant:

Zoological Parks Board

Project Status:

Completed 1996

Project Objectives:

- Reduce stormwater pollution loads to Sydney Harbour
- Reduce demand for mains water
- Demonstrate advanced stormwater treatment methods

Catchment and Site Characteristics:

- 38ha catchment of mixed land use including animal enclosures, moats and tourist facilities with a high gross pollutant and organic load

Estimated Potable Water Savings:

Estimated annual use volume 36.5ML

Project Summary:

- The Taronga Zoo scheme is a combined wastewater/stormwater system treating water generated from animal cage washdowns, moats and low stormwater flows
- A stormwater basin was installed upstream of the zoo's treatment plant, providing first flush collection of up to 1200kL/d.
- From here water passes through a chamber with screens and grit removal filters.
- Stormwater then travels to an aeration channel and biological treatment plant to remove N and P
- Then water flows to a buffer tank and feeds through a continuous membrane microfiltration system where further filtration and disinfection occurs.
- Treated stormwater is discharged into a 500kL holding tank and disinfected by UV before use
- The water is then distributed through the zoo via a recycled water supply pipe to supply water for exhibit washdown, moat top up, public toilet flushing and irrigation for 10ha of land on the site.
- Water not required for use is discharged to Sydney Harbour
- Backwash water from the microfiltration unit is returned to the aeration basin
- The system was constructed to treat 240ML (60%) of the annual average runoff from the site

Costs:

Capital: \$2,200,000

Recurring: \$55,000

Lifecycle: \$2,585,000

Key Points:

Capture: retention basin

Treatment: screening, aeration, biological treatment plant, continuous membrane microfiltration, UV disinfection

Storage: tank

Distribution: recycled water supply pipe network

End Use: exhibit washdown, moat top up water, public toilet flushing, irrigation

Reference:

Department of Environment and Conservation (NSW) 2006 Managing Urban Stormwater: Harvesting and Reuse

PROJECT TITLE: RIVERSIDE PARK, CHIPPING NORTON

Location:

NSW

Project Manager/Applicant:

Liverpool City Council

Project Status:

Completed 2002

Project Objectives:

- Reduce mains water use at Riverside Park sporting fields through the use of stormwater for irrigation utilising an existing constructed wetland system for treatment

Catchment and Site Characteristics:

- Catchment 47ha discharging directly into the Georges River
- Land use predominantly industrial (47%), residential uses (31%) and the park itself (22%).

Estimated Potable Water Savings:

Estimated annual stormwater use 12ML

Project Summary:

- Stormwater use facilities were retrofitted to an existing off line wetland system.
- A weir diverts low flows from the catchment through a grass lined stormwater channel to a 2.4ML storage and sedimentation pond.
- Stormwater is then pumped to into the first of three treatment wetlands. The first two ponds provide water treatment through settling and biological processes
- The third pond is a polishing pond where water either flows into the Georges River via groundwater infiltration or is pumped into the irrigation system for use on adjacent sporting fields.
- 2ha of sporting fields are irrigated by the scheme with supplementary mains water
- Estimated annual reduction of pollution loads by 17,000kg suspended solids, 23kg total phosphorus and 37kg for total nitrogen

Costs:

Not including wetland construction and maintenance

Capital: \$68,234

Recurring: \$5700

Lifecycle: \$118,000

Key Points:

Capture: wetland

Treatment: wetland

Storage: wetland

Distribution: piped irrigation network

End Use: irrigation – sporting fields

Reference:

Department of Environment and Conservation (NSW) 2006 Managing Urban Stormwater: Harvesting and Reuse

PROJECT TITLE: HORNSBY SHIRE COUNCIL NURSERY AND PARKS DEPOT

Location:

NSW

Project Manager/Applicant:

Hornsby Shire Council

Project Status:

Completed 2003

Project Objectives:

- Use the nursery/depot site as an example of industry best practice
- Demonstrate cost savings from reusing stormwater to other local governments
- Significantly reduce the volume of stormwater/irrigation water leaving the site

Catchment and Site Characteristics: 0.7ha catchment (council depot)

Estimated Potable Water Savings:

0.72ML/a (average demand of 2kL/day with peak demands during spring/summer)

Project Summary:

- Site regraded to direct all site runoff into a 90m vegetated infiltration trench.
- Stormwater is then directed into a junction pit, a sediment trap and a series of gravel filled, baffled wetland bays for initial treatment.
- Primary treated stormwater is pumped into a 107kL concrete storage tank
- Stormwater is then pumped through a filtration tank which then enters a second 107kL concrete tank for storage
- Water is then pumped into the nursery's irrigation system and toilets
- Project also included the installation of three modular rainwater tanks to collect roof runoff of the buildings for toilet flushing.

Costs:

Capital: \$329,000

Recurring: \$28,000

Lifecycle: \$581,000

Key Points:

Capture: Site graded to direct water to bioretention system

Treatment: Bioretention, sediment trap, filtration tank

Storage: concrete tank

Distribution: irrigation system

End Use: irrigation – nursery, toilet flushing

Reference:

Department of Environment and Conservation (NSW) 2006 Managing Urban Stormwater: Harvesting and Reuse

PROJECT TITLE: PRINCE HENRY DEVELOPMENT, LITTLE BAY

Location:

NSW

Project Manager/Applicant:

Landcom

Project Status:

Completed 2006

Project Objectives:

- Reduce stormwater pollution to Little Bay
- Provide high reliability alternative supply for irrigation, and cost effective stormwater use scheme using existing infrastructure

Catchment and Site Characteristics:

- The catchment of the project site is 49ha consisting of residential development, protected scrub bushland and a golf course.

Estimated Potable Water Savings: Design use volume 70ML/a

Project Summary:

- New greenfield development. Residential runoff was designed to be filtered through sediment/silt arrestor pits before combining with road and open space runoff. Stormwater then passes through on of 6 GPTs to remove gross pollutants and coarse sediments
- Partially treated stormwater is then discharged into 6 bioretention systems.
- Treated water is then passed to one of 3 open storage ponds with capacities of 4.6ML, 3ML and 1ML.
- The treated stormwater passes through an irrigation filter before being use on the opens space areas of the residential development and golf course.
- The system has been designed to remove 40,000kg of suspended solids, 70kg TP and 450kg TN annually.

Costs:

Key Points:

Capture: GPTs

Treatment: Sediment arrestors, GPTs, bioretention, filtering

Storage: open storage ponds

Distribution: piped irrigation network

End Use: irrigation – public open space, golf course

Reference:

Department of Environment and Conservation (NSW) 2006 Managing Urban Stormwater: Harvesting and Reuse

PROJECT TITLE: CATANI GARDENS STORMWATER CAPTURE AND USE, FITZROY

Location:
VIC

Project Manager/Applicant:
City of Port Phillip

Project Status:
Unknown

Project Objectives:

- Harvest stormwater for use in irrigation of public gardens
- Reduce mains demand
- Integrate best practice WSUD techniques into sensitive coastal recreation areas of high significance

Catchment and Site Characteristics:

- Catani Gardens are a high profile public park located on the St Kilda foreshore. Catchment area upstream of project site approximately 39ha

Estimated Potable Water Savings:
12ML/a

Project Summary:

- Opportunity to harvest stormwater for a substitute to potable water irrigation of Catani Gardens. The main Fitzroy St drain runs under the southern end of the gardens before discharging to Port Phillip Bay.
- Water is to be harvested from the main drain and then treated using a GPT and bioretention system.
- Water is proposed to be stored using a geo tank/ underground storage cell
- Water will then undergo UV disinfection before being pumped into the spray irrigation network of the gardens.

Costs:

Estimated capital: \$527,250

Key Points:

Capture: diversion from existing major stormwater pipe
Treatment: GPT, bioretention, UV
Storage: underground storage tank
Distribution: sprinkler irrigation
End Use: irrigation – public open space

Reference:

Stormwater and Urban Water Conservation Fund, Round 1 Funding: Local Council (www.dpi.vic.gov.au)

PROJECT TITLE: FOOTSCRAY PARK

Location:

Victoria

Project Manager/Applicant:

Maribyrnong City Council

Project Status:

Unknown

Project Objectives:

- Reduce potable water use for irrigation through substitution with harvested stormwater
- Reduce pollutant loads entering Maribyrnong River
- Provided education experience for community and Victoria University students

Catchment and Site Characteristics:

- 400ha catchment upstream of project site

Estimated Potable Water Savings:

25ML/a

Project Summary:

- The project aims to install a major stormwater harvesting and use system
- Flows will be diverted from a major stormwater pipe adjacent Footscray Park.
- Water will be treated in a constructed wetland system and stored in an underground tank
- Water will be pumped from the storage tank into the irrigation system of Footscray Park

Costs:

Estimated cost \$767,000

Key Points:

Capture: diversion from existing major stormwater pipe
Treatment: wetland
Storage: underground tank
Distribution: irrigation system
End Use: irrigation – public open space

Reference:

Stormwater and Urban Water Conservation Fund, Round 1 Funding: Local Council (www.dpi.vic.gov.au)

PROJECT TITLE: SORRENTO STORMWATER USE

Location:

Victoria

Project Manager/Applicant:

Mornington Peninsula Shire

Project Status:

Unknown

Project Objectives:

- Reduce potable and groundwater use for irrigation
- Flood protection
- Pollutant reduction

Catchment and Site Characteristics:

- Unknown

Estimated Potable Water Savings:

20ML/a potable water

50ML/a groundwater

Project Summary:

- Stormwater will be harvested for use for irrigation purposes at the Sorrento Golf Club.
- Stormwater that drains to David MacFarlan Reserve will be treated using a GPT before being held in a retention tank.
- Water will then be pumped into a wetland and pumped to a 30ML dam on the golf course for distribution in its irrigation system

Costs:

Estimated capital \$578,000

Key Points:

Capture:

Treatment: GPT, wetland

Storage: dam

Distribution: irrigation system

End Use: irrigation – golf course

Reference:

Stormwater and Urban Water Conservation Fund, Round 1 Funding: Local Council (www.dpi.vic.gov.au)

PROJECT TITLE: STORMWATER USE FOR THE CHARLTON COMMUNITY

Location:

Victoria

Project Manager/Applicant:

Buloke Shire Council

Project Status:

Unknown

Project Objectives:

- Reduce potable water use and pollutant loads entering the Avoca River

Catchment and Site Characteristics:

- Arundel St catchment

Estimated Potable Water Savings:

22ML/a

Project Summary:

- Stormwater from the Arundel St catchment will be treated using a primary treatment method
- Stormwater will also be diverted from Marlo Court drainage catchment
- A pump station will be constructed at the existing storage dams with a pressure pipeline to supply water to recreational users

Costs:

Capital cost \$155,000

Key Points:

Capture: diversion of existing drainage
Treatment: primary treatment
Storage: dam
Distribution: irrigation pipeline
End Use: irrigation – public open space

Reference:

Stormwater and Urban Water Conservation Fund, Round 1 Funding: Local Council (www.dpi.vic.gov.au)

PROJECT TITLE: MERNDA VILLAGES ASR

Location:

Victoria

Project Manager/Applicant:

Stockland developments

Project Status:

Unknown

Project Objectives:

- Develop the first major scale stormwater ASR scheme in Victoria
- Reduce potable water consumption for irrigation purposes

Catchment and Site Characteristics:

- 26km north of Melbourne
- Catchment consists of 450ha of rural land and 165ha of urban development

Estimated Potable Water Savings:

Up to 150ML/a

Project Summary:

- An aquifer storage and recovery system will be installed for pumping harvested stormwater into a 42m deep aquifer
- Stormwater will be collected from the catchment and passively treated through a series of streetscape bioretention and vegetated swale systems, and a constructed wetland
- Treated water from the wetland will be pumped from the wetland into the ASR system
- Water will be distributed via an irrigation network to irrigate regional recreation parks in Mernda

Costs:

Estimated \$1,105,000

Key Points:

Capture: swales and wetland
Treatment: bioretention, swales, wetland
Storage: Aquifer
Distribution: irrigation network
End Use: Irrigation – public open space

Reference:

Stormwater and Urban Water Conservation Fund, Round 1 Funding: Business and Other projects (www.dpi.vic.gov.au)

PROJECT TITLE: ALBERT PARK STORMWATER USE PROJECT

Location:

Victoria

Project Manager/Applicant:

Parks Victoria

Project Status:

Unknown

Project Objectives:

- Ensure sustainability of good water quality and water levels in Albert Park Lake
- Eliminate reliance on potable supply to top up lake

Catchment and Site Characteristics:

- Important inner urban freshwater ecosystem

Estimated Potable Water Savings:

200ML/a

Project Summary:

- Stormwater is diverted from a major pipe to pollution control ponds before being fed into Albert Park Lake.
- The innovative in-lake design of the stormwater treatment measures overcomes the major constraint in urban systems of lack of available surface area.

Costs:

Capital \$674,000

Key Points:

Capture: diversion of existing stormwater pipe
Treatment: in-lake pollution control ponds
Storage: none
Distribution: treatment and use location same
End Use: maintaining lake levels

Reference:

Stormwater and Urban Water Conservation Fund, Round 2 Funding (www.dpi.vic.gov.au)

PROJECT TITLE: TRINITY GRAMMAR BILLABONG RESTORATION

Location:

Victoria

Project Manager/Applicant:

Trinity Grammar

Project Status:

Unknown

Project Objectives:

- Reduce reliance on potable supplies and the Yarra River for irrigation of sports grounds

Catchment and Site Characteristics:

- Major urban stormwater pipelines travel through the school district

Estimated Potable Water Savings:

30ML/a

Project Summary:

- Stormwater diverted from major pipelines entering school grounds
- Stormwater is treated using a wetland on site
- Pumped into an irrigation network that supplies water for two colleges sporting grounds

Costs:

Estimated capital \$365,000

Key Points:

Capture: diversion of existing major stormwater pipeline

Treatment: wetland

Storage: wetland

Distribution: irrigation network

End Use: irrigation – sports grounds

Reference:

Stormwater and Urban Water Conservation Fund, Round 2 Funding (www.dpi.vic.gov.au)

PROJECT TITLE: STAWELL STORMWATER ALTERNATIVE NATURAL SOLUTIONS (SWANS)

Location:

Victoria

Project Manager/Applicant:

Northern Grampians Shire Council

Project Status:

Stage 2 in progress, Stage 3 currently being designed

Project Objectives:

- Innovative construction of stormwater treatment trains that will include water storage and use capabilities

Catchment and Site Characteristics:

- Majority of existing Stawell township – 369 ha

Estimated Potable Water Savings:

25 ML/a

Project Summary:

- The project will construct 9 WSUD treatment trains and retention basins at 4 sites in Stawell
- The project was divided into three stages:
 - Stage 1 involves the construction of ponds on council controlled land which will include use schemes for Central park, Cato Lake Parklands and the Stawell racing complex and showgrounds
 - Stage 2 involves the construction of ponds which will allow stormwater use at a retirement home and school
 - Stage 3 will see the construction of another 4 ponds
- Series of stormwater treatment wetlands and litter and sediment traps, and nutrient filters
- The wetlands are connected with a network of 90mm pipe and pumping arrangements.
- Council is planning to construct an 8ML storage dam and connect the wetlands pipe system to the dam, which will be used as the distribution point.
- Treatment will establish fit for use treatment and reticulation systems at each site
- Treated water will be used for watering of ovals, parks and gardens, and for road construction
- Additional benefit in flood protection for the town

Costs:

Capital cost	\$540,000
Ongoing	\$5,000 p.a

Key Points:

Capture:	Surface runoff and diversion of existing stormwater infrastructure
Treatment:	Wetlands, litter and sediment traps, nutrient filters
Storage:	ponds and 8ML dam
Distribution:	irrigation network, tankers
End Use:	Irrigation and road construction

Reference:

Stormwater and Urban Water Conservation Fund, Round 2 Funding (www.dpi.vic.gov.au)

Municipal Association of Victoria (2006) Victorian Local Government Secrets of Success in Urban Water Management: Case Studies report

Personal communication with Sanjay Manivasagasivam (Infrastructure Engineer) 4 February 2008

PROJECT TITLE: ALTONA GREEN PARK

Location:

Victoria

Project Manager/Applicant:

Hobsons Bay City Council

Project Status:

Constructed 2003

Project Objectives:

- To provide an active recreational area for the public and a residential development that incorporates high environmental standards, chiefly through retention and use of stormwater.

Catchment and Site Characteristics:

- Total catchment area 6.15ha

Estimated Potable Water Savings:

4ML/a

Project Summary:

- Vacant land was converted to sports field area as part of a residential development.
- As a part of this project a WSUD stormwater harvesting system was setup
- Stormwater from residential properties is diverted into a swale.
- Stormwater is also collected from the main road and surface runoff from the ovals.
- Collected stormwater is stored in a 400kL underground tank
- Water is then pumped into an irrigation network for 2 ovals
- Estimated by MUSIC to reduce pollutant loads 83% suspended solids, 71% TP, 55% TN

Costs:

\$250,000 for stormwater use system

Key Points:

Capture: Swales

Treatment: Swales

Storage: underground tank

Distribution: irrigation network

End Use: irrigation – sports grounds

Reference:

www.wsud.melbournewater.com.au

PROJECT TITLE: ALTONA LEISURE CENTRE

Location:

Victoria

Project Manager/Applicant:

Hobsons Bay City Council

Project Status:

Under construction

Project Objectives:

- Incorporate innovative water conservation measures with the redevelopment of the Altona Leisure centre

Catchment and Site Characteristics:

Estimated Potable Water Savings:

3.5 ML/a

Project Summary:

- Potable water will be saved through substitution with stormwater from the Altona Leisure Centre and surrounding landscapes
- Harvested stormwater will be piped into the existing 25m lap pool that will be converted to a tank for storage before being pumped into the centres new swimming pools
- Collected water will be chlorinated and then used to top up the centre's new swimming pools
- By using the old pool as a storage tank that would have been otherwise demolished, reduces the overall environmental impact of the redevelopment by reducing the demolition waste and materials needed for construction
- The project demonstrates the importance of conserving water and innovative measures to the wider leisure and aquatic centre industry and community at a site which traditionally consumes a high amount of water

Costs: \$98,000

Key Points:

Capture: roofwater, stormwater capture method not specified

Treatment: chlorination

Storage: old swimming pool

Distribution: existing swimming pool system

End Use: swimming pool - recreational

Reference:

Stormwater and Urban Water Conservation Fund, Round 3 Funding (www.dpi.vic.gov.au)

PROJECT TITLE: EDINBURGH GARDENS

Location:

Victoria

Project Manager/Applicant:

City of Yarra

Project Status:

Concept Plan developed Nov 2007

Project Objectives:

- Outline opportunities for the capture, treatment and use of stormwater runoff from the North Fitzroy catchment above Edinburgh Gardens

Catchment and Site Characteristics:

- Catchment upstream of planned diversion point 27ha
- Edinburgh Gardens 15ha

Estimated Potable Water Savings:

15 ML/a

Project Summary:

- Inline with state government policy to reduce the use of potable water in public open space, the City of Yarra has developed a landscape water management plan for Edinburgh Gardens which includes alternatives to potable water for irrigation.
- This case study was developed to outline an option for harvesting and treatment of stormwater from the local catchment, and the storage and use of treated stormwater for augmenting the irrigation demand within the Edinburgh Gardens
- The proposed stormwater treatment and use system involves harvesting stormwater from the Fitzroy Main Drain using a diversion weir
- Stormwater is then treated in a stormwater treatment wetland.
- Treated stormwater from the wetland would then be stored within an adjacent underground storage facility
- Storage size is to be 50-100 kL in order to supply approximately 45% of the annual irrigation demand
- Stormwater will then be subjected to UV disinfection and then used for irrigation within the gardens.
- The treatment wetland is predicted to remove the following annual pollutant loads: 10,460kg suspended solids, 18kg TP, 90kg TN.

Costs:

Option not costed

Key Points:

Capture: Diversion of main stormwater drain
Treatment: wetland and UV disinfection
Storage: underground storage facility
Distribution: irrigation network
End Use: irrigation – public open space

Reference:

City of Yarra (2007) Water Sensitive Urban Design Guidelines

PROJECT TITLE: DARLING HARBOUR STORMWATER HARVESTING SYSTEM

Location:
NSW

Project Manager/Applicant:
Sydney Harbour Foreshore Authority

Project Status:
Completed July 2006

Project Objectives:

- Utilise the significant runoff generated from the large impervious area at Darling Harbour

Catchment and Site Characteristics:

- Catchment area / harvested roof area 20,000m²

Estimated Potable Water Savings:

3.6 ML/a

Project Summary:

- In 2002 the Foreshore Authority recognised that the large impervious area such as roofs and paving at Darling Harbour generate significant runoff – a resource that could be harvested, treated and used
- In the initial study phase, 7 stormwater harvesting opportunities were identified in the Darling Harbour precinct storing water in a purpose built 1ML underground tank or within an extended detention zone in the Darling Walk Lake. However high costs related to the storage options resulted in smaller scale opportunities to be pursued.
- Later investigations identified the Entertainment Centre car park as an excellent source of high quality stormwater that could be harvested with little difficulty
- The roof of the car park is rarely used and the stormwater downpipes are readily accessible
- A pilot stormwater harvesting scheme has been constructed
- Stormwater is harvested by diverting stormwater from the downpipes from the car park roof using ECS Peak rain flow diverters
- Harvested stormwater is then stored in 22 off the shelf colourbond steel tanks that are located in unused parking bays on the ground floor
- The tanks combined have a storage capacity of 660kL
- All tanks are interconnected to ensure balance
- There is a direct feed from all tanks into the suction main of a pump set that is connected to the Darling Harbour irrigation network
- A study of the runoff quality prior to the construction of the use system showed that the water quality was suitable for irrigation use without requiring any further treatment

Costs:

Unknown

Key Points:

Capture: Downpipe diversion
Treatment: First flush device
Storage: Multiple above ground, off the shelf tanks
Distribution: Irrigation network
End Use: irrigation

Reference:

Phillips, B, Radcliffe, J and Fisher, M (2007) **Harvesting Stormwater for reuse at Darling Harbour, NSW**, NSW Stormwater Industry Association and Australian Water Association 2007 Annual Conference, Wollongong, NSW
SIA (NSW) (2007) Darling Harbour Stormwater Harvesting System, 2007 SIA Awards for Excellence, Prepared by Cardno Willing and Sydney Harbour Foreshore Authority

PROJECT TITLE: HOMEBUSH BAY WATER RECYCLING

Location:

NSW

Project Manager/Applicant:

Was Sydney Olympic Park Authority

Project Status:

Completed for 2,000 Olympic games

Project Objectives:

- Design and construct a showcase water recycling facility that integrates sewage treatment and stormwater collection that can be used for all non-drinking purposes

Catchment and Site Characteristics:

- Inner city suburban catchment

Estimated Potable Water Savings:

850ML/a combined sewerage and stormwater savings

Project Summary:

- Stormwater runoff from the Homebush Bay area is conveyed to stormwater treatment wetlands
- Treated stormwater is then collected in a 300ML ex-brickpit which can also hold surplus treated effluent from the water reclamation plant
- Water from the water reclamation plant and the brick pit is then given advanced treatment with microfiltration to remove particles including all parasites, viruses and bacteria, and then reverse osmosis to remove salts
- The advanced treatment can treat up to 7ML/day
- A major post treatment storage is located under the plant
- As well as Olympic Park the recycling facilities also serve the adjacent suburb of Newington through a dual reticulation system

Costs:

Key Points:

Capture: Existing stormwater infrastructure

Treatment: wetlands, advanced treatment processes

Storage: 300ML ex-brick pit

Distribution: dual reticulation and irrigation network

End Use: All non-drinking purposes to residential, commercial, and sporting facilities and for the irrigation of sports grounds and public open space

Reference:

ATSE (2004) **Water recycling in Australia** ATSE, Victoria

PROJECT TITLE: CITY OF SALISBURY INTEGRATED WATER MANAGEMENT PLAN

Location:

South Australia

Project Manager/Applicant:

City of Salisbury

Project Status:

Ongoing

Project Objectives:

- Implement Australia's first totally integrated water management plan to efficiently harness and manage systems for rainwater, stormwater, groundwater, recycled wastewater and potable water
- Replace potable and groundwater use for community, industrial, residential and irrigation use with recycled stormwater across the region
- Create an environmentally, economically, and socially sustainable urban water management system
- Reduce ocean outfalls and the pollution loads of the remaining outflows
- Harnessing and naturally treating stormwater along with ASR to provide fit for purpose water to end users
- Reduce reliance on potable water sourced from the River Murray

Catchment and Site Characteristics:

- City of Salisbury covers an area of 161km²

Estimated Potable Water Savings:

Currently 7,500 ML/a

Another 25,000 ML/a planned to be harvested in short term future projects

Project Summary:

- Council has developed a strategic of 20 stormwater harvesting sites or wetlands
- Water flow from the upper reaches of the catchment is regulated in a series of flood control dams, designed to handle a 1 in 100 yr event
- The dams effectively throttle down the flow of water into a series of pipes and open channels planted with reed beds to filter and cleanse the water of nutrients and heavy metals
- The pipes and channels direct water into the strategically placed stormwater harvesting sites and wetlands
- Stormwater is further cleansed in the wetlands and grassed swales which act as self sustaining filtration and water treatment systems
- Treated stormwater is pumped via distribution mains directly into industrial and commercial users with high water dependency, and irrigation Council's sports grounds and public open spaces
- Much of the water is also pumped into the aquifer using ASR technology for use by the industry and the community in drier months
- Water collected by council is sold to end users

Costs:

Capital cost of \$4.5 million for the major Parafield Partnerships Urban Stormwater initiative (>1GL/a of stormwater used for industrial customer)

Key Points:

Capture: pipe diversion
Treatment: wetlands, swales
Storage: ASR, wetlands
Distribution: distribution mains
End Use: industrial, commercial and community use

Reference:

ATSE (2004) **Water recycling in Australia** ATSE, Victoria

City of Salisbury, (2007) **Fact Sheet: The Salisbury Integrated Water Management Plan**, City of Salisbury (www.salisbury.sa.gov.au)

City of Salisbury (unknown) **Stormwater recycling through wetlands in the City of Salisbury, South Australia**, City of Salisbury (www.salisbury.sa.gov.au)

PROJECT TITLE: COTTESLOE PENINSULA GROUNDWATER RESTORATION PROJECT

Location:

Western Australia

Project Manager/Applicant:

Town of Cottesloe

Project Status:

Currently under construction

Project Objectives:

- Reduce the risk of aquifer collapse and seawater intrusion
- Minimise pollutants entering the aquifer by cleaning polluted stormwater
- Achieve more sustainable household and garden water consumption through use of stormwater
- Achieve environmental benefits by removing an estimated 180ML per year of stormwater ocean outfalls
- Assist in a better community understanding of local water resource management and use
- Promote water efficient technology.

Catchment and Site Characteristics:

- Extensive groundwater use in the region

Estimated Potable Water Savings:

None – only topping up the aquifer to replace groundwater consumed

Project Summary:

- The management of stormwater being primarily oriented towards maximising infiltration, a process that is particularly appropriate on the Swan Coastal Plain. It may be noted that residents in Perth are prohibited from discharging stormwater off their properties. Effectively stormwater use occurs via the coastal plain groundwater system
- The project involves the replacement of open sumps with seven new underground sumps and 280 new soakage pits throughout Cottesloe to trap and filter stormwater, and then replenish the Cottesloe groundwater aquifer with the treated stormwater.
- Utilising stormwater to replenish the groundwater enables the closure of 10 stormwater outfall pipes along the coast.
- In addition to these measures, a public education programme will aim to reduce private groundwater use, decrease the installation of new private bores and reduce stormwater pollutants.

Costs:

Cottesloe Project \$2.35 million

Key Points:

Capture: Stormwater sumps and soakage pits
Treatment: Infiltration, geotextile filter
Storage: aquifer
Distribution: groundwater bores
End Use: everything

Reference:

ATSE (2004) **Water recycling in Australia** ATSE, Victoria
See [Cottesloe Peninsula Groundwater Restoration Project](#) fact sheet

PROJECT TITLE: MULGA CREEK CATCHMENT WETLAND DEVELOPMENT, BROKEN HILL

Location:

New South Wales

Project Manager/Applicant:

Broken Hill City Council

Project Status:

Under construction

Project Objectives:

- Improve the quality of stormwater runoff leaving the streets of Broken Hill in the Mulga Creek Catchment by removing pollutants from the water
- Promote environmental education and research with cooperative partnerships
- Capture and store stormwater with the aim of using it for irrigation of parks and ovals
- Provide a public open space to be enjoyed and enhance public amenity

Catchment and Site Characteristics:

- Wetland site covers approximately 2 ha

Estimated Potable Water Savings:

Project Summary:

- Involves the creation of a constructed wetland system capable of holding 8.2ML of water
- The system will capture, filter and store stormwater runoff in a three pond system with 2 intake structures
- In the second stage of the project an aquifer storage and recovery system will be set up, the first of it's kind in NSW

Costs:

\$600,000

Key Points:

Capture: directing stormwater to wetland
Treatment: wetland
Storage: ASR
Distribution: irrigation network
End Use: irrigation

Reference:

Broken Hill City Council (2007) Mulga Creek Catchment Wetland Development Fact Sheet

PROJECT TITLE: DOCKLANDS

Location:

Victoria

Project Manager/Applicant:

VicUrban

Project Status:

Projects ongoing – some completed

Project Objectives:

- Demand management
- Maximise stormwater use for open space irrigation
- Treat stormwater runoff to achieve state guidelines and therefore reduce pollutant loads to the stormwater systems and Port Phillip Bay

Catchment and Site Characteristics:

- Docklands is a major redevelopment of the Victoria Harbour Precinct on the eastern side of Melbourne's CBD
- It covers 200ha and 7km of waterfront
- Area has a mix of residential and commercial medium density and high rise developments
- Multiple projects have been undertaken on site ranging from an individual site scale to regional and precinct scales
- Precinct scale open space areas provide opportunity to integrate stormwater collection, treatment and storage/use facilities within the overall landscape design. With competing uses for these spaces the scale and landscape form of the stormwater management systems needs to carefully consider the other park uses and their potential interaction with the stormwater management systems. Public safety and aesthetic amenity issues are important design considerations requiring site analysis to determine site usage patterns, journeys, site lines, and existing landscape character in order to ensure an appropriate landscape form.

Estimated Potable Water Savings:

Project Summary:

- Docklands Park
 - Docklands Park is a significant green public open space covering 2.7 ha including 3 wetlands.
 - Docklands Park provides insufficient catchment area for stormwater harvesting to meet irrigation demand. However, the adjacent urban catchment provides opportunities for stormwater harvesting, treatment and use.
 - Stormwater from the NAB building roof and forecourt, Harbour Esplanade, Grand Plaza, and a portion of the Bourke St extension are collected for use.
 - The water is directed wither by gravity or pumped to Docklands Park
 - The wetlands in the park function as a stormwater treatment system as well as a modern landscape feature
 - The maximum size of each of the wetlands that could be constructed in the area was 1475m³. Three wetlands with this size can treat approximately 80% of the runoff generated from the overall catchment area of 4.8 ha with 0% impervious area
 - Treated stormwater is stored underground. Three underground storages with a combined capacity of 500kL are situated adjacent to the wetlands
 - Treated stormwater is used for park irrigation
- NAB Forecourt
 - Stormwater from the NAB roof and surrounding courtyard is collected and directed to a constructed wetland situated in the forecourt.
 - The wetland is designed in the shape of an exclamation mark providing a landscape feature and functioning water treatment system.
 - The water enters the full stop, a sedimentation basin, removing coarse sediment.
 - Water then flows to the wetland for treatment before underground storage, and used for irrigation of Docklands Park
- Grand Plaza and Harbour Esplanade
 - The Harbour Esplanade runs along the waterfront south of Telstra Dome, while the Grand Plaza connects the wharf to Harbour Esplanade.
 - Both regions have high impervious areas from the plaza, footpaths and streets.
 - Stormwater flowing from these areas require treatment prior to discharge
 - The existing infrastructure includes a culvert between the tram line and the planned Grand Plaza deck. The culvert provides an opportunity for temporary storage for stormwater runoff.
 - The runoff water is then pumped to the Docklands wetland for treatment
 - Runoff from Harbour Esplanade flows directly to the storage culvert. Grand Plaza runoff will initially pass through gross pollutant traps. The water is then stored in an adjacent underground culvert

- Overflow >3month ARI are discharged into Victoria Harbour
- Bourke and Collins Street Extensions
 - The Bourke St extension along the NAB building will be graded to drain east towards Harbour Esplanade and hence be collected for use

Costs:

Unknown

Key Points:

Capture: Gravity or pumped
Treatment: wetlands, gross pollutants, street trees
Storage: Wetland, underground storage
Distribution: irrigation network
End Use: irrigation

Reference:

City of Melbourne WSUD Guidelines

PROJECT TITLE: QUEEN VICTORIA MARKETS

Location:

Victoria

Project Manager/Applicant:

City of Melbourne

Project Status:

Concept plan

Project Objectives:

- Conserve potable mains water through stormwater use and treat stormwater to Victorian best practice

Catchment and Site Characteristics:

- The markets cover 7ha in the northern part of Melbourne's CBD
- Largest undercover market in Australia
- Some buildings currently have no stormwater connection, with stormwater infiltration the soil and entering the street drainage system
- Plans are under way for the upgrade of the stormwater system within the lower market areas and including WSUD

Estimated Potable Water Savings:

7.5 – 10ML/a

Project Summary:

- Recent water wise initiative have reduced water consumption in recent years
- Redevelopments must be in keeping with the site's heritage character
- Melbourne's first cemetery is situated underneath the market and adjacent car park. Some bodies were exhumed but an estimated 8,000 to 10,000 bodies remain. Clearly, this site must be respected and recognised appropriately in any development. This limits the excavation depth in the car park and potential underground water storages
- The markets roof is 2ha, providing a significant catchment area for stormwater harvesting that requires little treatment aside from a first flush device
- The presently unconnected stormwater areas will require drainage installation. It is proposed that a system similar to rocla ecotanks be used (basically large diameter concrete pipes with high level weirs to store water, overflows spill directly into the drainage system)
- The additional storage will supplement toilet flushing and wash down water, thereby increasing supply reliability of the water collected from the roof of the sheds
- The stormwater infrastructure upgrade and car park redevelopment provides opportunities to treat the stormwater at source. The shallow nature of bioretention systems will also not disturb the burial site
- The treated stormwater can then be collected in the underground storage for additional toilet water supply

Costs:

Key Points:

Capture: roofwater harvesting, bioretention
Treatment: first flush diverter, bioretention
Storage: ecotanks (pipe storage), toilet header tanks
Distribution: Toilet systems wash down system
End Use: toilets and wash down water

Reference:

City of Melbourne WSUD Guidelines

PROJECT TITLE: REGENT GARDENS

Location:

South Australia

Project Manager/Applicant:

Department of Environment and Natural Resources

Project Status:

Completed 1995

Project Objectives:

- No site runoff to enter existing stormwater system due to lack of capacity

Catchment and Site Characteristics:

- Precinct occupies 72ha, residential homes and 10.6ha of public reserves

Estimated Potable Water Savings:

Project Summary:

- Peak runoff from the development site was mitigated using stormwater detention basins and wetlands
- The project developed conjunctive wetland ponds and aquifer storage and recovery within the main reserve of the development
- A well was constructed with a gravity diversion from the downstream end of the wetlands
- A controlled pump system is connected to the well, and fitted to the local reserve irrigation network
- The wetland and gross pollutant traps are used to treat the water before entering the ASR system

Costs:

Approximate Capital : \$220,000

Annual Operating and maintenance \$5,500

Key Points:

Capture: gravity

Treatment: GPT, wetland

Storage: ASR

Distribution: irrigation network

End Use: irrigation

Reference:

Emmett, AJ, Clarke, S and Howles, S (1996) Conjunctive wetland/aquifer storage and recovery at regent Gardens residential development, Northfield, South Australia. Desalination **106**: 407-410

PROJECT TITLE: CITY OVAL DRAINAGE RETENTION SYSTEM BOX HILL PROJECT

Location:

Victoria

Project Manager/Applicant:

City of Whitehorse

Project Status:

Under construction

Project Objectives:

- Address the under capacity of a local stormwater drain without having to replace it at a significant cost
- Maintain function of the oval for length of project
- Allow collection of stormwater which can be used for various purposes and help reduce reliance on the reticulated water systems

Catchment and Site Characteristics:

-

Estimated Potable Water Savings:

12.5 ML/a

Project Summary:

- The project has been designed to divert, capture, store and use stormwater at Box Hill City Oval from an existing stormwater drain that runs under the oval
- Water from the catchment above the reserves will be diverted into four large interconnected underground storage tanks with a total capacity of 1ML
- The tanks are filled with filter material
- The collected stormwater is initially treated by a GPT and then is treated through a bioretention sand filter.
- The captured water is then pumped into a wet well system mounted with submersible pumps for use on oval irrigation
- A stand pipe is also available as a supply for Council tankers for mobile tree watering, drain cleaning, council garden beds and street sweeping

Costs:

\$740,000

Key Points:

Capture: diversion from existing pipe
Treatment: GPT, sand filter
Storage: underground tanks
Distribution: irrigation system, tankers
End Use: irrigation

Reference:

City of Whitehorse (2007) Council's water saving project at Bolton reserve (website article) www.whitehorse.vic.gov.au
Stormwater and Urban Water Conservation Fund, Round 3 Funding (www.dpi.vic.gov.au)

PROJECT TITLE: BEECHWORTH RECREATION RESERVES STRATEGY

Location:

Victoria

Project Manager/Applicant:

Indigo Shire Council

Project Status:

Project Objectives:

- Enable substitution of potable water with treated stormwater and wastewater

Catchment and Site Characteristics:

- New subdivision

Estimated Potable Water Savings:

9ML/a for stormwater use

11ML for combined wastewater and stormwater use

Project Summary:

- The project has is constructing a retention basin with the installation of a reticulation system to provide for stormwater and wastewater use from a new subdivision
- Captured stormwater will be used to irrigate a golf course, sports fields and school oval.
- Stormwater treatment facility – not specified as to what techniques

Costs:

Estimated capital \$721,000

Key Points:

Capture: passive drainage designed for subdivision

Treatment: not defined

Storage: retention basin

Distribution: irrigation network

End Use: irrigation – golf course, sports fields

Reference:

Stormwater and Urban Water Conservation Fund, Round 3 Funding (www.dpi.vic.gov.au)

PROJECT TITLE: WODONGA'S SUSTAINABLE SPORTS GROUND

Location:

Victoria

Project Manager/Applicant:

City of Wodonga

Project Status:

Project Objectives:

- Develop a consistent availability of water for irrigation especially during dry periods to keep sports grounds available throughout the year

Catchment and Site Characteristics:

- Use facility based at Wodonga racecourse
- New subdivisions drainage has been designed to tie in with the use project

Estimated Potable Water Savings:

90ML/a

Project Summary:

- An existing stormwater facility will be enlarged under the Project to establish treatment wetlands and provide reticulation infrastructure for irrigation of community sporting grounds at the Wodonga racecourse
- Stormwater will be captured from new and existing residential areas
- The existing storage facility within the racecourse already collects stormwater from urban kerb and channel runoff, however this water was not used for irrigation

Costs:

\$870,000 (not including new subdivision costs)

Key Points:

Capture: diversion from existing stormwater system
Treatment: wetlands
Storage: wetlands
Distribution: irrigation network
End Use: irrigation – sporting grounds

Reference:

Stormwater and Urban Water Conservation Fund, Round 3 Funding (www.dpi.vic.gov.au)

PROJECT TITLE: CRANBOURNE TURF CLUB IRRIGATION

Location:

Victoria

Project Manager/Applicant:

Racing Victoria

Project Status:

Completed 2006

Project Objectives:

- Demonstrate and investigate drought proofing techniques and the use for treated stormwater on turf race tracks

Catchment and Site Characteristics:

- Catchment area 8.3ha including car park area

Estimated Potable Water Savings:

30ML/a

Project Summary:

- Stormwater runoff is captured from the car park and catchment area upstream
- Stormwater is delivered to a constructed 25ML irrigation storage dam via 300mm pipes at the training centre and turf club
- The roof of the Turf Club collects a further 5ML/a of water
- The storage dam is sealed and lined with two 250mm layers of compacted select clay-rich earth liner material and specialised geotextile fabric in limited areas
- When available track irrigation will be undertaken using 100% stormwater
- Stormwater supplies will be supplemented with treated effluent water from an adjacent pipeline

Costs:

Capital \$800,000

Key Points:

Capture: roofwater diversion, stormwater diversion

Treatment: None specified

Storage: 25ML clay lined dam

Distribution: Irrigation network

End Use: Irrigation – race course

Reference:

Stormwater and Urban Water Conservation Fund, Round 3 Funding (www.dpi.vic.gov.au)

PROJECT TITLE: BENDIGO HARNESS RACING TRACK WATER HARVESTING

Location:

Victoria

Project Manager/Applicant:

Harness Racing Victoria

Project Status:

Completed June 2007

Project Objectives:

- Reduce potable use for irrigation through the harvesting of stormwater and application of more efficient methods

Catchment and Site Characteristics:

- Stormwater harvested from the main and inner tracks, and runoff from adjacent permeable roof and paved surfaces

Estimated Potable Water Savings:

15ML/a

Project Summary:

- Stormwater is to be diverted, harvested and stored for track watering and maintenance at Bendigo Harness Racing Club
- A storage retention dam was constructed with a piped reticulation system to distribute the stormwater for irrigation

Costs:

Capital \$412,000

Key Points:

Capture: diversion
Treatment: none
Storage: retention dam
Distribution: irrigation network
End Use: irrigation – race course

Reference:

Stormwater and Urban Water Conservation Fund, Round 3 Funding (www.dpi.vic.gov.au)

PROJECT TITLE: NEW BROMPTON ESTATE

Location:

South Australia

Project Manager/Applicant:

City of Charles Sturt

Project Status:

Completed 1991

Project Objectives:

- Substitute the use of potable water with treated stormwater for irrigation of public open space

Catchment and Site Characteristics:

- Reserve size 2250m²
- Catchment consists of 15 houses surrounding the reserve

Estimated Potable Water Savings:

Project Summary:

- A small reserve is surrounded by 15 houses
- Roof runoff from the houses is directed via PVC pipes to a gravel trench located around 3 sides of the reserve
- The trench conveys the water to a central point where it enters a bore via 9 standpipes and is then transferred to a storage in the Tertiary aquifer
- The inlet of each standpipe has a mesh bucket lined with geotextile in the base which requires maintenance quarterly
- The standpipe system is not recommended for use by the author – other methods are better
- In summer water is retrieved from the aquifer for irrigating the reserve

Costs:

Key Points:

Capture: house roof
Treatment: gravel trench, geotextile filter
Storage: ASR
Distribution: irrigation network
End Use: irrigation – public open space

Reference:

Argue (2005) Water Sensitive Urban Design: Basic Procedures for Source Control of Stormwater, UniSA Urban Water Resources Centre, Adelaide, South Australia

PROJECT TITLE: PARFITT SQUARE

Location:

South Australia

Project Manager/Applicant:

City of Charles Sturt

Project Status:

Completed 1997

Project Objectives:

- Control runoff for 1 in 100 yr event
- Collect and store runoff for irrigation use in summer months

Catchment and Site Characteristics:

- Parfitt Square is a 0.6ha recreational reserve
- The catchment is 1ha consisting of residential land use

Estimated Potable Water Savings:

2ML/a

Project Summary:

- Stormwater runoff from the developed catchment passes to the northern side of Parfitt Square
- A stormwater treatment train has been incorporated into the design of the reserve
- All stormwater runoff generated in the upstream catchment is collected at 2 gutter entry pits which feed flow directly to a 30m sediment trap adjacent the northern car park.
- Overflow from the sediment trap passes to a gravel based reed bed where sediment is retained with a load of 1 tonne each year for 100 years.
- Stormwater then runs through another gravel filled trench leading to the aquifer recharge area at the southern end of the reserve
- Geotextile is wrapped around the entries of the four recharge bores
- Roof runoff from houses located on the eastern edge of the reserve is treated using a first flush diverter and then flows directly into the trench leading into the recharge area
- The water in the aquifer has a relatively high salinity for use for irrigation, however the stormwater has a shandy effect that reduces the salinity to levels suitable for irrigation use on the reserve

Costs:

Key Points:

Capture: gutter entry pits

Treatment: treatment train – sediment trap, reed bed, underground gravel filled trench and geotextile filter

Storage: ASR

Distribution: irrigation network

End Use: Irrigation – public open space

Reference:

Argue (2005) Water Sensitive Urban Design: Basic Procedures for Source Control of Stormwater, UniSA Urban Water Resources Centre, Adelaide, South Australia

Argue and Pezzaniti (1999) Catchment greening using stormwater in Adelaide, South Australia, Water Science and Technology 39(2): 177-183

PROJECT TITLE: MAWSON LAKES

Location:

South Australia

Project Manager/Applicant:

Recycled water system now managed by SA Water

Project Status:

Online 2005

Project Objectives:

- To create a sense of belonging, provide carefully planned community facilities, offer real housing choice, give investment protection, be responsive to global and local environment issues and to also meet the aesthetic and recreational demands of a community
- To have a recycled water supply system to provide at least 50% of household water and all irrigation water for public open space

Catchment and Site Characteristics:

- Initial development site 620ha Has since been expanded
- Catchment area harvested 810ha
- Land uses include residential, commercial and industrial

Estimated Potable Water Savings:

- 487 ML/a from onsite stormwater harvesting – 80% of the catchment yield
- Additional 128ML/a from a separate local stormwater treatment wetland
- Additional 506 ML/a from wastewater use

Project Summary:

- Traditional stormwater system collects the water
- Stormwater is then passed through gross pollutant traps and settling basins before entering stormwater treatment wetlands. Wetland covers 2.8ha with 9 day detention time
- Water is then pumped to the filtration plant. The filtered water is discharged to the reticulation storage tank for chlorination and distribution with the reclaimed wastewater
- Flows surplus to reticulation requirements are injected into the tertiary aquifer in an ASR operation
- Water recovered from the aquifer is refiltered and transferred to the reticulation storage tank

Costs:

Capital cost \$10.5million for completed recycled water scheme (including wastewater use component). Represents approx \$3,000 per house.

Annual operation and maintenance costs approx \$470,000 for entire scheme

Key Points:

Capture: traditional stormwater system

Treatment: GPTs, settling basins, treatment wetlands, filtration, chlorination

Storage: distribution storage tank and/or ASR

Distribution: dual reticulation – purple pipe

End Use: irrigation of lawns, parks and gardens (including vegetables and flowers), flushing toilets, washing cars, filling ornamental ponds and water features

Reference:

Marks, R and Eddleston, F (2000) Meeting the Challenges in Urban Water Recycling – Mawson Lakes, South Australia in Water Recycling Australia, PJ Dillion (ed), CSIRO and AWA

PROJECT TITLE: BARRY BROTHERS WATER USE

Location: Victoria

Project Manager/Applicant:

City of Port Phillip / Barry Brothers

Project Status:

Operating since 2003, project expansion ongoing

Project Objectives:

- Use water collected from service pits that is normally disposed of

Catchment and Site Characteristics:

- Variable between each pit

Estimated Potable Water Savings:

Approx 12ML/a collected and treated, only 6ML/a used for irrigation due to limited storage capacity

Project Summary:

- Barry Brothers is a private business contracted by Telstra and CitiPower to collect and dispose of the water collected in telecommunication and electrical roadside service pits
- Barry Brothers built a water recycling plant in Port Melbourne to enable collected water to be used.
- The water is treated to class C standard and used for irrigation
- Four tanks on site can hold 80kL in total. Because of limited storage capacity the system is not operating to its full potential. In wetter months excess water is treated and used for street sweeping
- Sediment collected during the treatment process is sent to landfill and excess water is sent to the sewer
- The treatment plant treats an average of 400kL of water each month
- Plans are being developed to expand the system and extend the pipeline to other reserves to allow more water to be recycled through the existing plant

Costs:

Capital \$100,000

Key Points:

Capture: Pumped out of service pits
Treatment: method not specified – to Class C
Storage: Above ground tanks
Distribution: irrigation network
End Use: Irrigation, street sweeping

Reference:

MAV (2006)



Urban Water Security Research Alliance

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