MANAGING URBAN STORMWATER

Harvesting and Reuse

Department of **Environment and Conservation** NSW

stormwater
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Cover photo of stormwater harvesting and reuse at Sydney Olympic Park,
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Foreword

The recent drought and concerns about climate change have all highlighted the need to manage our water resources more sustainably. Expanding the use of stormwater runoff to add to our water supply and reduce water pollution are important objectives for the NSW Government. Stormwater is now recognised as a valuable resource, rather than a nuisance to be disposed of quickly, especially in large urban centres.

Over recent years, stormwater harvesting and reuse have emerged as a new field of sustainable water management. Harvesting and reusing stormwater offer both a potential alternative water supply for non-drinking uses and a means to further reduce stormwater pollution in our waterways. Stormwater harvesting complements other approaches to sustainable urban water management, including rainwater tanks, greywater systems, effluent reuse and demand management.

The NSW Government recognises the many benefits that can accrue from harvesting stormwater. Through the Government's Stormwater Trust, we have already provided over $4 million for ten pilot projects that together are saving up to 13 million litres of water annually. This has been Australia's most comprehensive stormwater harvesting funding program and many of these projects are profiled in this document.

Additional funding for stormwater harvesting will be made available from mid-2006 through the NSW Government's $80 million Urban Sustainability Fund, part of the Iemma Government's $439 million City and Country Environment Restoration Program.

The pilot projects that have already been funded have taught us much about what goes to make a stormwater harvesting scheme successful. In an Australian first, this document combines these lessons with ideas and principles from the fields of stormwater, wastewater and water supply management to provide specific guidance on developing successful stormwater harvesting schemes. It aims to encourage projects that will lead to more sustainable urban water management, while also managing the health and environmental risks associated with stormwater reuse.

Managing urban stormwater: harvesting and reuse provides a sound basis for implementing operational stormwater harvesting schemes more widely. It is also an invaluable part of the Government's Metropolitan Water Plan which aims to utilise all cost-effective means to help meet the demand for water resources as Sydney grows, while sustaining the health of our rivers.

I encourage all local councils, water managers, developers and planners to use this document and help realise the full potential of stormwater harvesting and reuse schemes.

Bob Debus
Minister for the Environment

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Several people and organisations kindly supplied photographs for use in this report:

Cover: Stormwater treatment at Sydney Olympic Park (J Dahlenburg/wsud.org)

Contents: Kogarah Town Square (J Dahlenburg/wsud.org)

Section 1 opener: Taronga Zoo stormwater treatment plant and Sydney Harbour (H Pantenburg/Taronga Zoo)

Sections 2 & 3 openers: Water ponding at Sydney Olympic Park (J Dahlenburg/wsud.org)

Section 4 opener: Fenced constructed wetland at Camden (J Dahlenburg/wsud.org)

Section 5 opener: Stormwater planning at Hornsby Council (K Walters/DEC)

Section 7 opener: Weed control in stormwater reuse system at Archers Creek, Ryde (M Sharpin/DEC)

Section 8 opener: Hornsby stormwater harvesting and reuse scheme (J Dahlenburg/wsud.org)

References opener: Stormwater treatment at Victoria Park (J Dahlenburg/wsud.org)

Appendices opener: Water-sensitive urban design at Victoria Park (J Dahlenburg/wsud.org)

Contents

1. Introduction

1.1 Water in the urban environment

Water is an integral part of urban life. In our homes, we use water for drinking, washing and watering our gardens. Away from home, we swim and fish in water, and sail on water. At the beach or paddling a canoe on a river, we appreciate good quality water. We value water for its usefulness, its recreational benefits and its place in the landscape and environment.

Urbanisation changes the way water flows through a catchment, and this can have a range of adverse impacts on the water environment, including:

- poor water quality and degraded aquatic ecosystem health within rivers and creeks from the disposal of stormwater and wastewater
- changes to the pattern of flow in streams and rivers
- increased frequency and magnitude of flooding
- demand for potable water exceeding the sustainable supply, and impacting on the availability of water for users.

These are significant issues facing urban water managers and urban communities, although there are many potential solutions.

One option receiving increasing attention is water recycling and reuse. Water for reuse in urban areas can be sourced from rainwater, stormwater, greywater and effluent from sewage treatment plants (STPs).

Water reuse projects can achieve multiple benefits, including:

- reduced demand for mains drinking water
- reduced pollution loads to waterways
- reduced wastewater flows (where effluent and greywater are reused)
- reduced stormwater flows (where stormwater and rainwater are reused).

Recognising all of the potential benefits is a key to the economic and environmental viability of many reuse projects.

1.2 Harvesting stormwater for reuse

The capturing or harvesting of urban stormwater for reuse can contribute to water conservation, water quality and streamflow objectives. It complements other approaches to sustainable urban water management such as demand management, rainwater tanks, and the reuse of effluent and greywater.

Stormwater harvesting and reuse can be defined as the collection, treatment, storage and use of stormwater run-off from urban areas. It differs from rainwater harvesting as the run-off is collected from drains or creeks, rather than roofs. The characteristics of stormwater harvesting and reuse schemes vary considerably between projects, but most schemes would have the following elements in common:

- collection – stormwater is collected from a drain, creek or pond
- storage – stormwater is temporarily held in dams or tanks to balance supply and demand. Storages can be on-line (constructed on the creek or drain) or off-line (constructed some distance from the creek or drain)
- treatment – captured water is treated to reduce pathogen and pollution levels, and hence the risks to public health and the environment, or to meet any additional requirements of end-users
- distribution – the treated stormwater is distributed to the area of use.

Some components of a scheme may serve multiple purposes, such as a grass swale that collects and treats stormwater while forming a feature in the urban landscape.

Stormwater harvesting and reuse is a relatively new form of water reuse compared to rainwater tanks and the reuse of STP effluent. It is, however, increasingly recognised as a potential option for meeting the water demands and other objectives of many projects and sites. Harvested stormwater has commonly been used for irrigating public parks and golf courses, and other non-potable uses are possible.

1.3 The purpose and scope of this document

This document is part of a series of publications from the Department of Environment and Conservation NSW (DEC) under the *Managing urban stormwater* theme which provide guidance on different aspects of managing stormwater in the urban environment.

As noted above, urban stormwater harvesting and reuse is a relatively new field of water management and most of the projects constructed to date have been pilot projects. The main aim of this document is therefore to provide guidance on key considerations for future stormwater harvesting and reuse projects, based on experience gained from early stormwater harvesting projects. The most important considerations are:

- planning – assessing the context of a project within a broader strategy of integrated urban water cycle management and risk assessment
- project design – particularly treating stormwater to address risks to public health and the environment, and meeting any additional end-use requirements
- operations, maintenance and monitoring – ensuring that potential impacts to public health and the environment are managed appropriately and the project remains sustainable.

The elements typically used in stormwater harvesting and reuse projects are also found elsewhere in the water industry, such as in wastewater management. A successful harvesting and reuse project will select, design and adapt elements from these other contexts and integrate them into a sustainable system with multiple objectives and benefits.

Experience to date has shown that no two stormwater harvesting projects are exactly the same – there is no single approach to developing these projects, and any guidance needs to provide for this in its approach.

A successful stormwater harvesting and reuse scheme needs specialist input from a number of areas: stormwater management, water supply management, environmental management and public health. One of the secondary aims of this document is therefore to give specialists from these areas insights into key aspects of disciplines other than their own.

This guidance was prepared to help stormwater harvesting become a more ‘mainstream’ water management discipline. It also aims to encourage wider appreciation of the factors that can maximise the potential benefits of stormwater harvesting while minimising the associated risks.

Stormwater harvesting is closely related to rainwater reuse, as they are both sourced from rainfall. A discussion of rainwater and stormwater reuse is provided in section 2. Guidance on using rainwater tanks has not been included in this document, as existing comprehensive guidelines are available, including enHealth (2004), NSW Health (2004) and Melbourne Water (2005).

This document does not address urban stormwater harvesting as a raw water source for large-scale potable water supply schemes. Relevant information about these schemes can be obtained from the *Australian drinking water guidelines* (NHMRC & NRMMC 2004a).

1.4 Structure of this document

Section 2 provides a brief overview of stormwater harvesting and reuse, including potential applications, advantages and limitations

Section 3 summarises statutory requirements for a stormwater harvesting and reuse project in New South Wales

Section 4 discusses the key considerations for managing public health and environmental risks in stormwater harvesting and reuse projects

Section 5 presents an overview of planning a stormwater harvesting and reuse project, both in existing urban areas and new urban developments

Sections 6 and 7 outline key considerations for the design and operation of stormwater harvesting and reuse schemes

Section 8 contains case studies of stormwater harvesting and reuse projects.

Appendices provide detailed information to support the planning, design, operation and maintenance of stormwater reuse schemes. Appendix A contains the key considerations from sections 5 to 7 – these can be used as a project checklist.

2. Overview of stormwater harvesting

2.1 Stormwater harvesting, treatment and reuse

This section looks at some of the applications for treated and reused stormwater. Some of the potential benefits and limitations associated with non-potable applications are described and pointers provided on what makes a scheme successful.

This section also compares stormwater reuse, rainwater tanks and effluent reuse and looks at the willingness of communities to accept and support stormwater reuse.

2.2 Potential applications

Stormwater harvesting and reuse schemes can be developed for existing urban areas or new developments and are mainly suitable for non-potable purposes such as:

- residential uses
- irrigating public areas
- industrial uses
- ornamental ponds and water features
- aquifer storage and recovery.

This report does not cover potential uses for stormwater reuse in growing crops, such as in market gardens, many of which are located on the urban fringe, or in aquaculture.

2.2.1 Residential uses

Stormwater in residential areas could be harvested and used for several purposes that would significantly reduce household demand for mains water, such as:

- toilet flushing
- garden watering
- car washing.

Toilet flushing has a relatively constant demand throughout the year and typically accounts for around 15% of internal household water use. Garden watering consumes up to 30% of total household water, depending on the premises and season. Car washing is normally a relatively small component of residential water use compared to toilet flushing or garden watering.

In new urban areas, a scheme for harvesting, reticulating and reusing stormwater for non-potable residential uses could help a proposed development meet its BASIX (building sustainability index) water-savings targets. The water savings targets are required under the Building Sustainability Index, BASIX, a state environmental planning policy (NSW Government 2004).

Stormwater used for these purposes could expose the general public to potential health risks from pathogens, usually arising from animal wastes, and would therefore need to be treated to ensure a low risk to public health.

2.2.2 Irrigation

To date, harvested stormwater has been mainly used to irrigate public reserves and playing fields. It is used to grow and maintain grass surfaces on playing fields, golf courses and in other public open spaces, and to establish and grow ornamental plants in public gardens.

Typical annual irrigation demand for open areas ranges between 3 and 8 ML/ha, depending on the local climate, the type of vegetation being irrigated and the type of irrigation system used.

The type of irrigation system will also help determine the degree to which the stormwater needs to be treated before reuse in order to reduce health risks, and may also affect whether public access needs to be controlled or restricted during irrigation.

The irrigation methods commonly used in urban areas are:

- sprinkler or spray irrigation – the most widely used technique for irrigating large areas
- drip irrigation – often used for garden areas
- subsurface irrigation using perforated pipes – which can be used to irrigate small or large areas.

2.2.3 Industrial and commercial uses

Various processing and manufacturing industries have a regular and significant demand for water, making them well-suited for stormwater reuse. Typical uses would include washdown, cooling tower make-up or process water. Treated stormwater could also be used on construction and mining sites for applications such as dust suppression and vehicle washing. In commercial premises, stormwater could be reused for toilet flushing and vehicle washing.

The degree of treatment required depends on the proposed use, particularly the level of public exposure. Additional treatment may be required for specific industrial uses, with little or no extra treatment required for low-grade uses such as washdown and dust suppression.


K Walters/DEC

Irrigation with stormwater at Greenway Park, Cherrybrook

2.2.4 Ornamental ponds and water features

Water is commonly used in the landscape design of residential and commercial developments. These features can consume a considerable volume of water through evaporation or seepage. Stormwater can be used as make-up water to maintain design levels where the public has no direct contact with the water. The stormwater would need to be low in pathogens to reduce public health risks and low in nutrients to prevent algal growth.

2.2.5 Aquifer storage and recovery

Aquifer storage and recovery (ASR) is the planned infiltration or injection of water into an aquifer during times when water is available, and the subsequent recovery of the water when it is needed. ASR can also increase the yield of the aquifer or protect it from seawater intrusion. Before recharge, the stormwater needs to be treated to prevent the aquifer from becoming clogged with particulate or organic material, or contaminated by other pollutants. ASR is not common in New South Wales, but is used elsewhere in Australia where geologic conditions near urban areas are more suitable, such as in Adelaide.

2.3 Potential benefits and limitations

2.3.1 Potential benefits

The main benefits that can be gained from a successful stormwater reuse scheme are reductions in:

- demand for mains water
- stormwater volumes, flows and the frequency of run-off
- stormwater pollution loads to downstream waterways.

The extent of the benefits from a particular stormwater harvesting and reuse scheme depends on a range of factors, including:

- the local climate – particularly rainfall
- catchment land uses – which influence run-off quality and quantity
- the condition of the sewerage system – which affects sewer overflows to stormwater
- the demand for reuse water – in particular the flow rates and any seasonal variations
- the design of the scheme – particularly the flow diverted to the scheme and the storage volume provided.

Reduced demand for mains water

Stormwater reuse can substitute in full or in part for existing mains water uses. The volume of stormwater run-off from Australian capital cities (including Sydney) is about equal to the amount of potable water used (Environment Australia 2002).

More than 50% of high quality water piped to urban areas is used for lower quality purposes, such as garden watering and toilet flushing. There is potential therefore for more stormwater to be collected, stored and reused for non-potable purposes. As an example, stormwater harvesting could meet 10–25% of Adelaide’s water needs (Kellogg, Brown & Root 2004). However, as stormwater is also needed to provide flows for urban creeks and rivers, total stormwater harvesting is not an appropriate goal.

Lower stormwater volumes

Urban development typically has major impacts on the volume, frequency and quality of run-off, and has associated ecosystem impacts. For example, it can:

- double annual run-off volumes
- reduce infiltration
- increase peak flows by up to ten-fold
- significantly increase the frequency of run-off.

Stormwater harvesting can reduce the volume of water flowing into the drainage system and so reduce stream erosion and minimise the impacts of urbanisation on aquatic ecosystems. In new urban developments, harvesting stormwater can reduce the need for, and capacity of, on-site detention measures.

Lower pollution loads

Urbanisation of a catchment commonly results in up to a four-fold increase in stormwater pollutant loads to local waterways. A stormwater harvesting and reuse scheme can reduce these loads by:

- abstracting a proportion of the polluted stormwater within a drain or waterway for reuse
- trapping pollutants in on-line storages, where the treated stormwater flows back to the waterway rather than being reused
- returning surplus treated stormwater to receiving waters, further reducing pollutant loadings.

Indicative outcomes

The actual outcomes from a stormwater harvesting and reuse scheme depend on the specifics of the scheme and its catchment. Table 2.1 indicates the potential outcomes that could be achieved from schemes in New South Wales, based on moderate and large on-line storages and an irrigation demand (WBM 2004, 2005).

The noted peak flow reductions for rare events, e.g. 100-year average recurrence interval (ARI), are low. This is because stormwater harvesting and reuse schemes focus on more frequent events (i.e. below the three-month ARI event). This is discussed further in section 6.

Table 2.1 Indicative outcomes from stormwater harvesting projects

Indicator	Indicative outcome	
	Moderate storage	**Large storage**
Mains water demand reduction	2–35%	5–50%
Annual stormwater run-off volume reduction	2–20%	2–40%
100-year ARI peak flow reduction	Negligible	Negligible
2-year ARI peak flow reduction	Negligible	1–2%
3-month ARI peak flow reduction	0–1%	1–2%
Suspended solids annual load reductions	15–35%	60–90%

Note: ARI – average recurrence interval

2.3.2 Potential limitations

The potential limitations and disadvantages to stormwater harvesting and reuse schemes depend largely on the nature of the scheme and the local environment. The major limitations are:

- variable rainfall patterns
- environmental impact of storages
- potential health risks
- high relative unit costs of treated stormwater.

Variable rainfall patterns

Variable rainfall is the main limitation for harvesting schemes, as this influences the reliability of stormwater flows from a catchment. The extent of this variability depends on local climatic conditions. For example, Sydney has an average of 130 rain days in a year, around half of which are likely to generate significant run-off for harvesting and reuse. Between-year variability also occurs, which is partly related to longer-term cycles such as the El Niño Southern Oscillation Index, and possible longer-term changes in rainfall due to climate change.

Variable rainfall patterns can affect the viability of stormwater reuse schemes by:

- increasing the required storage volume, resulting in larger land area requirements for above-ground storages – in the case studies in this report (see section 8), the average storage volume per unit of catchment area was 86 kL/ha, equivalent to one olympic-sized swimming pool per 23 hectares of catchment
- increasing the need for back-up water supplies and/or demand management when demand cannot be met from harvested stormwater
- causing considerable fluctuations in the water level in storages, due to the variability in streamflow and demand, particularly for irrigation schemes. This may reduce the aesthetic appearance of an above-ground storage – especially where it doubles as an urban lake or other landscape feature – with denuded banks and possible algal blooms and turbid water.

The required storage volume increases for a given reliability of supply as the demand becomes more variable (e.g. for irrigation) or when otherwise poorly matched to the availability of stormwater. The ideal system is therefore one where the stormwater supply closely matches the pattern of demand.

Environmental impact of storages and extraction

A storage constructed directly on a drain or creek normally consists of a dam wall or weir to retain streamflows. Planning for such storages would need to consider the potential impacts on the environment as well as on people, and would need to address various statutory requirements in New South Wales (discussed in section 3).

The environmental impacts of such storages can include:

- acting as a potential barrier to the passage of fish and other aquatic fauna (which often need to move freely upstream or downstream to grow, reproduce or feed)
- trapping coarse sediment, which not only reduces the capacity of the storage over time, but also results in downstream bank erosion where the sediment transport capacity of the stream exceeds the supply (a well-known phenomenon in fluvial geomorphology)
- increasing the potential for upstream flooding – this can also apply to diversion structures (e.g. weirs) constructed for off-line storage

- providing potential habitat for mosquitoes and associated mosquito-borne diseases
- posing a risk to human safety, especially to children.

Extracting stormwater from a watercourse may reduce streamflows to below pre-urbanisation levels. For on-line storage, this may occur during periods of low flow or where storage capacity and demand are large relative to inflows. Over-extraction of flows may impact on downstream aquatic ecosystems by reducing the available aquatic habitat, interfering with natural flow regimes to streams or wetlands.

This is normally only a problem where the storage is very large or where demand for water is high (Fletcher et al. 2006).

Potential health risks

Pathogens in stormwater for reuse can pose public health risks. These risks can be reduced by treating and disinfecting the harvested stormwater and/or limiting public access for some applications.

Higher unit costs of stormwater

Treated stormwater tends to have a higher unit or levelised cost (see glossary) than the retail cost of mains water (see section 8.2.3). However, this type of cost-effectiveness analysis does not take into account the multiple environmental benefits of stormwater harvesting schemes, including reduced downstream pollution loads and flows.

Figtree Place, Newcastle

Figtree Place, in inner suburban Newcastle, presents an innovative example of integrated stormwater management in a residential and commercial setting.

The site, consisting of 27 residential units, employs rainwater tanks, infiltration trenches and a central basin in which treated stormwater enters an unconfined aquifer.

During the planning phase of the development, it was determined that the stormwater harvested from the site should meet:

- 50% of in-house needs for hot water and toilet flushing
- 100% of domestic irrigation needs
- 100% of the bus-washing demand.

The main features of the development include:

- underground rainwater tanks, with capacities ranging from 9 to 15 kL, fitted with 'first flush' devices (i.e. to discard the first part of inflow carrying sediment, leaves, etc.). Each tank services between four and eight homes.
- recharge trenches on 19 of the home sites, each trench measuring 750 mm deep by 1000 mm wide, and containing gravel 'sausages' enclosed in geofabric. These trenches receive overflow from the rainwater tanks and help to recharge groundwater
- diversion of the run-off from impervious areas to the central detention basin for recharging of groundwater
- increasing the degree of flood protection for the site to the 50-year ARI level
- use of groundwater for garden watering and bus washing.

These measures achieved internal residential water savings of 45% by using treated water in hot water systems and flushing toilets, with total water savings anticipated to be 60%. For further details, see Coombes et al. (2000).

2.4 Characteristics of successful schemes

A successful stormwater harvesting and reuse scheme is one that:

- realises its full potential benefits
- addresses public health and environmental risks
- is both cost-effective and sustainable
- has the support of key stakeholders.

Some of the key characteristics of a successful stormwater harvesting and reuse scheme are:

- the project replaces an existing mains water use and is designed to reduce stormwater flows and pollution loads – that is, the project is designed to meet multiple objectives
- the project has clearly defined and quantitative objectives, consistent with those for the management of the catchment
- public health and safety risks are managed appropriately
- the end uses have relatively low water-quality requirements, minimising treatment costs
- the level of treatment is appropriate not just for meeting the needs of the end use, but also for addressing public health and environmental risks
- the storage capacity is designed to achieve 'reasonable' reliability of supply
- the scheme is located close to the end use, minimising distribution costs (e.g. a golf course located adjacent to a creek)
- procedures are in place for on-going operation, maintenance, monitoring and reporting.

While no two stormwater harvesting schemes are exactly the same, these points above can be used as a checklist for all schemes to varying degrees.

Another key consideration for a successful stormwater harvesting project is having all stakeholders in the planning, design and operation of a scheme recognise that a reuse scheme is a type of water supply scheme, not solely a form of stormwater management. This is important because the public health risks from reuse schemes are higher than in conventional stormwater management.

Consequently, stormwater reuse schemes need a more sophisticated management focus than other stormwater activities, especially in the operation, maintenance, monitoring and reporting. These issues are discussed further in section 7.

2.5 Stormwater harvesting and rainwater tanks

Stormwater harvesting schemes and the systematic installation of rainwater tanks across a catchment can have broadly similar benefits in reducing pollution loads, downstream stormwater flows and demand for mains water. However, there are distinct differences in costs, stakeholders, maintenance and health risks between these approaches – each has potential advantages and disadvantages.

Table 2.2 indicates the relative benefits and limitations of stormwater harvesting and wide-scale rainwater tank usage. The comparison demonstrates that neither alternative is clearly preferred – decisions about using rainwater tanks or stormwater harvesting should be made on a case-by-case basis, to meet specific project or catchment objectives, and should be based on the views of key stakeholders.

Combined rainwater and stormwater collection and reuse schemes have been implemented successfully for medium-density developments, in which reticulation costs are relatively low; see panels on Figtree Place, Newcastle (page 11) and Kogarah Town Square (page 15).

In a combined stormwater/rainwater scheme, and from a risk management perspective, the water treatment objectives for stormwater reuse should be adopted whether the source waters are combined or if the stormwater stream if managed separately to the rainwater. The references noted in section 1 can be used to guide development of the rainwater tank component of such schemes.

Treated stormwater from a stormwater harvesting and reuse scheme could provide an alternative non-potable water source to rainwater tanks to meet the requirements of BASIX for new developments in New South Wales (as noted in section 2.2.1). Conversely, where rainwater tanks are installed to meet BASIX requirements, less stormwater will be available for harvesting and reuse.

Table 2.2 Indicative potential benefits and limitations of stormwater

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	Reuse 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 run-off from roads and other paved areas is collected	Limited reduction in pollution loads, as relatively clean roof run-off is collected

Kogarah Town Square

Kogarah Town Square was redeveloped in 2003 as part of Kogarah Council's shift towards sustainable development. The site contains 193 residential apartments, 4500 m^2 of retail and commercial space, a public building, an underground carpark and both public and private gardens.

Water-sensitive urban design concepts were incorporated into the original design, ensuring the capture, recycling and reuse of all stormwater from the site for irrigation, toilet flushing, car washing and the town square water feature.

The reuse system recognises the difference between 'clean' and 'dirty' stormwater.

The 'dirty' run-off from the square passes through a gross pollutant trap into a storage tank and is used for garden irrigation. The design uses the landscape to filter the water, so that excess nutrients and fine particles are retained by the soil. The 'clean' stormwater (predominantly from roof surfaces) is retained in a storage tank, and passes through a screen filter and disinfection unit prior to use for higher level needs.

The system saves up to 8 ML of mains water annually, representing a 50% reduction in water use for the site.

For further details, refer to Salan (2002) and Kogarah Council (2004).


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2.6 Stormwater and effluent reuse

Some water reuse projects can use stormwater as well as effluent from STPs or leachate from waste disposal facilities. This document focuses on stormwater harvesting and reuse – DEC (2004) provides guidance on effluent reuse.

In general, the design criteria relating to effluent reuse will be more stringent than those for stormwater reuse and should be adopted for combined schemes in place of guidance in this document. The design needs to consider the different characteristics of stormwater and effluent. In particular, stormwater supply is more variable in quality, quantity and reliability, and pollution levels are usually lower than in treated effluent.

Some reuse schemes combine stormwater and effluent (by 'blending') to reduce effluent salinity levels. The panel about Sydney Olympic Park provides an example of a combined stormwater and effluent reuse project.

Sydney Olympic Park

The Water Reclamation and Management Scheme at Sydney Olympic Park represents a large-scale approach to recycling non-potable water. Established in 2000, the scheme aims to provide all water required for toilet flushing, irrigation and other residential uses in the park and the nearby suburb of Newington. The scheme conserves approximately 850 megalitres (ML) of mains water per year.

Stormwater is captured in two storages – the Brickpit Reservoir (located in the old quarry), having a 300 ML capacity, and a series of freshwater wetlands constructed as part of the Haslams Creek area remediation. Treatment through the wetlands reduces sediment and nutrient loads by up to 90%. Stormwater from both storages is combined with reclaimed water 'mined' from a trunk sewer, filtered via continuous microfiltration and disinfected prior to use. A dual reticulation system distributes the water to the park and to Newington homes.

In addition to conserving water, implementation of the scheme has allowed for the annual diversion of approximately 550 ML of sewage normally discharged through ocean outfalls.


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The scheme, with a capital cost of $15 million, provides recycled water to consumers at a rate of $0.83 per kL. While this is lower than mains water charges, it does not reflect the true cost of recycled water supply.

For more information, see SOPA (2004a, 2004b).

2.7 Community acceptance of treated stormwater

Community acceptance and use of treated stormwater is a key factor in a successful scheme. Many of the existing schemes, particularly those referred to later in this document, have irrigation of public areas as the end use. However, research suggests that there is growing support for extending the use of treated stormwater for domestic purposes, including clothes washing, toilet flushing and garden irrigation.

In a study investigating social acceptability of treated stormwater in Perth, Melbourne and Sydney, Mitchell et al. (2006) found that:

- acceptance was highest among respondents for either household scale or large (centralised scale) systems, rather than neighbourhood/cluster schemes operated by a body corporate or similar entity
- respondents were more accepting of using rainwater than stormwater for garden watering
- the acceptance of treated stormwater was greater than that of treated wastewater.

More recently, stormwater harvesting and reuse has been successfully introduced as part of the water-sensitive urban design of several developments (see panels). The initial findings from these developments suggest a high degree of satisfaction and acceptance by residents of treated stormwater for use within a residential environment (Coombes et al. 2000).

3. Statutory requirements

3.1 Planning

The statutory approvals required for stormwater harvesting and reuse projects vary between states. This section deals with the requirements that may apply in New South Wales. The information was current at the time of publication; however, statutory requirements and the roles of government agencies can change over time – proponents should check that this information is current during the planning stage of their project.

Stormwater harvesting schemes would normally be subject to the requirements of the *Environmental Planning and Assessment Act 1979* (EP&A Act). The EP&A Act sets out the requirements for environmental impact assessment for development consent purposes.

Development consent is an approval for development issued by a ‘consent authority’, normally the local council but sometimes the Minister for Planning. Environmental planning instruments will determine if development consent is required for a development proposed for a certain zone. Therefore, depending on the provisions in the relevant environmental planning instruments, constructing a stormwater harvesting and reuse scheme may require development consent.

Development proposals that require development consent are subject to the requirements of Part 3A or 4 of the EP&A Act. Part 3A specifies the assessment and approval process for major infrastructure and other major projects while Part 4 specifies the process for other proposals requiring development consent. These Parts of the EP&A Act consider development applications to be ‘integrated development’ where certain licences or approvals are required from bodies other than a consent authority. Applicants must inform the consent authority of any licences, additional approvals or permits required from state agencies other than development consent before lodging their applications. Councils are then required to consult with the relevant state agency and obtain requirements in relation to the development.

Activities not covered by planning or development control processes, and thus not requiring development consent, fall under Part 5 of the EP&A Act. Such ‘exempt’ activities include installations of public utilities undertaken by local councils and government agencies. A review of environmental factors (REF) may be required in these circumstances.

3.2 Environmental and natural resource management

3.2.1 Environment protection licences

The *Protection of the Environment Operations Act 1997* is the principal legislation governing the protection, restoration and enhancement of the environment in New South Wales. Part 3.1 of the Act requires environment protection licences to be issued for scheduled activities that may cause pollution. Stormwater harvesting schemes do not require such licensing.

3.2.2 Water extraction

The *Water Management Act 2000* provides the statutory framework for water extraction from rivers, lakes and estuaries. The Act's definition of 'river' includes any watercourse, including an artificially improved channel, but not a piped drain. The definition of 'lake' includes any body of natural or artificial still water, including a wetland. In an urban context, the Act would apply to any river, creek, (open) drainage channel, lake or pond, but not to schemes that harvest stormwater from a drainage pipe.

Stormwater harvesting schemes proposed for construction on a 'river' normally require:

- a water access licence
- a water use approval
- a water supply work approval.

Applications for these licences and approvals should be made to the Department of Natural Resources and must be issued before water can be extracted from a river.

New water access licences for commercial purposes are generally not being granted, to stop unsustainable over-allocation of water. In particular, this applies to areas covered by a gazetted water-sharing plan. An existing access licence can be purchased on the water market, subject to dealing (trading) rules. A water utility may apply for a special purpose licence, although the amount of water available may depend on the rules of the water-sharing plans.

An approval to use water is required before river water may be used at a particular location, such as for irrigation or town water supply. A stormwater harvesting scheme granted development consent under Part 4 of the EP&A Act does not require a water use approval.

A water supply work approval is required for water management works associated with water use, including to:

- extract water from a river or lake
- store water taken from a river or lake (in off-line storages)
- convey water extracted from a river or lake to another location
- retain water in a river (via a weir or in-river dam).

3.2.3 Impacts on fish habitats

Components of a stormwater harvesting project that involve works in a watercourse are likely to require a permit from the Department of Primary Industries under the *Fisheries Management Act 1994.* Further details can be obtained from *Policy and guidelines – aquatic habitat management and fish conservation* (NSW Fisheries, 1999).

3.2.4 Impacts on rivers and foreshores

A permit under the *Rivers and Foreshores Improvement Act 1948* may be required for projects undertaken in or adjacent to a stream, river, lake or lagoon. Depending on the location of the project, the permits are to be obtained from the Department of Natural Resources or the NSW Maritime Authority. The Act does not apply to works on piped stormwater drainage systems.

3.2.5 Impacts on threatened species

The *Threatened Species Conservation Act 1995* integrates the conservation of threatened species and communities into the processes for planning and development control under the EP&A Act. The Minister for the Environment can certify environmental planning instruments if satisfied that they will bring an overall improvement or maintenance in biodiversity values. A separate threatened species assessment may not be needed for development applications in areas that have certified environmental planning instruments.

Where a development is proposed in an area for which the environmental planning instrument has not been certified, the EP&A Act sets out factors to be considered in deciding whether there is likely to be a significant effect on threatened species, populations or ecological communities and if a species impact statement is required. Where there is likely to be a significant effect, the consent authority must seek the concurrence of DEC.

3.2.6 Clearing of native vegetation

The *Native Vegetation Act 2003* applies to the clearing of native vegetation and certain regrowth vegetation. The Act applies primarily to rural areas and not to the Sydney metropolitan area, Newcastle, areas with certain residential land use zonings, or national parks, conservation areas and state forests. Approvals are required from catchment management authorities for clearing native vegetation in areas subject to the Act.

3.2.7 Impacts on Aboriginal cultural heritage

The *National Parks and Wildlife Act 1974* protects all Aboriginal objects and Aboriginal places in NSW. A consent under the Act must be obtained from DEC for activities that are likely to destroy, damage or deface an Aboriginal object or Aboriginal place.

3.3 Other requirements

3.3.1 Dam safety

The requirements of the *Dams Safety Act 1978*, as administered by the Dam Safety Committee, may apply to storages for stormwater harvesting schemes depending on the height of the dam wall and the associated hazard rating (Dam Safety Committee 1998, 2002). The hazard rating (consequence categories) is related to the population at risk of a dam failure and the severity of the associated damage and loss.

3.3.2 Plumbing requirements

The plumbing requirements for distribution systems associated with stormwater harvesting and reuse schemes are discussed in section 6.

4. Risk management

4.1 Background

Risk management is playing an increasingly important role in the water industry. The Australian drinking water guidelines (NHMRC & NRMMC 2004a) apply a risk management approach to the production of drinking water in Australia. Another relevant example is the publication *Guidelines for managing risk in recreational water* (NHMRC 2005).

The draft national guidelines for water recycling (NRMMC & EPHC 2005) include a risk-based framework for managing the quality and use of recycled water. This is based on the framework in the Australian drinking water guidelines. The draft water recycling guidelines note that the sustainable use of recycled water should be based on the following three principles:

- the protection of public and environmental health is paramount and should never be compromised
- ongoing protection of public and environmental health depends of the implementation of a preventive risk management approach
- application of control measures and water quality requirements should be commensurate with the source of recycled water and the intended uses.

The panel below summarises the approach to risk management used in the Australian drinking water guidelines and adopted in this document. Further information on risk management can be obtained from AS/NZS 4360:2004 *Risk management* (Standards Australia 2004) and related documents.

Ideally, risks for a stormwater harvesting and reuse project should be assessed during the project's planning phase. This will enable many significant hazards to be managed during the project's design. If risk assessment and management are left to the operational phase of a project, the costs of effective mitigation may be considerably higher than if they were considered during the planning phase.

Further information on risk management is provided in appendix B.

Risk management

The current edition of the Australian drinking water guidelines emphasises the importance of taking a preventive management approach to drinking water quality, in which risks are identified and managed proactively, rather than simply reacting to when problems arise.

There are three basic steps in taking a preventive approach. The first step is to look systematically at all the potential hazards to the water supply from the catchment to the consumer's tap (i.e. what might happen and how).

Once the hazards are identified, the next step is to assess the risk from each hazard by estimating the likelihood that the event will happen and what the consequences would be if it did. The final stage is to ensure that existing preventive measures are sufficient to control the hazards, and to improve or replace such measures if necessary.

Source: NHMRC & NRMMC (2004a)

4.2 Potential hazards

There are a range of potential public health, public safety and environmental hazards from stormwater harvesting and reuse. Table 4.1 summarises the most common of these (see also appendix B). The public safety risks are primarily related to schemes where open storages are used.

Additional hazards relating to scheme operations and occupational health and safety are also likely – these are not considered in detail in this section (refer to section 7.3 for information on occupational health and safety).

4.3 Risk management framework

It is important that stormwater harvesting and reuse schemes are developed and operated within a risk management context.

The draft national guidelines for water recycling include a comprehensive risk-based framework for public health and environmental risks associated with wastewater recycling and greywater reuse. This framework can be used in the planning, development and operation of a stormwater harvesting and reuse scheme. A future version of these guidelines (due in 2008) will address stormwater harvesting specifically.

The framework incorporates a preventive risk management approach, including elements of hazard analysis and critical control point (HACCP) assessment, ISO 9001 (Quality management) and AS/NZS 4360 (Risk management), and it applies them in the context of recycled water supply.

A summary of the framework is provided in table 4.2, with further details provided in appendix B. The elements in this framework are similar to those adopted in the Australian

Table 4.1 Common potential hazards associated with stormwater harvesting and reuse

Area	Hazard
Public health	Microorganisms (pathogens) in water: • bacteria • viruses • protozoa • helminths Chemical toxicants in water: • inorganic chemicals (e.g. metals, nutrients) • organic chemicals (e.g. pesticides, hydrocarbons)
Public safety	Water storages (above ground): • drowning • embankment failure/overtopping
Environmental	Over-extraction of stormwater flows Storage constructed on natural watercourses Flooding above any diversion weir Surface water pollution by run-off (irrigation schemes) Groundwater pollution (irrigation schemes) Soil contamination (irrigation schemes)

drinking water guidelines. A related approach has been used in Queensland for water recycling (EPA Queensland 2005a).

The framework in table 4.2 recognises that successful risk management requires appropriate scheme planning, design and operations. As the monitoring of treated stormwater is not continuous and there is normally a period of time (hours or days) between sampling and the availability of monitoring results, monitoring should not be used as a primary risk management activity – the focus of monitoring should be primarily on validating the effectiveness of the preventive approaches to managing water quality.

The framework applies to schemes of all sizes and complexity, the main difference in application being the extent to which the elements are applied. The extent of risk management for a project should be appropriate to the project's risks. Hence a large stormwater harvesting and reuse scheme with significant public contact (exposure) to treated stormwater warrants a comprehensive risk assessment. Smaller schemes with controlled public access (i.e. lower exposure risk) warrant a less comprehensive risk assessment.

The approach taken in this document is to provide guidance on appropriate public health and environmental risk management activities for stormwater harvesting and reuse schemes that meet the nominated threshold criteria noted in table 4.3 and follow nominated design and operational practices. Management practices suitable for sub-threshold schemes are noted in tables 4.4 and 4.5 and described in sections 5 to 7. Public safety, occupational health and safety and operational risks should be assessed separately for each scheme. The basis for the thresholds in table 4.3 is provided in appendix B.

This default approach is intended to provide guidance on suitable risk management activities to achieve low public health and environmental risks from the scheme's operations. This approach is particularly suitable for small schemes, particularly where the application has relatively low public exposure such as irrigation. Most stormwater harvesting and reuse schemes to date are relatively small-scale compared with many effluent reuse schemes, and this is likely to continue for the foreseeable future.

Table 4.2 Risk management framework for recycled water quality and use

Element	Description
1	Commitment to the responsible use and management of recycled water quality
2	Assessment of the recycled water system
3	Preventive measures for recycled water management
4	Operational procedures and process control
5	Verification of recycled water quality and environmental sustainability
6	Management of incidents and emergencies
7	Employee awareness and training
8	Community involvement and awareness
9	Validation, research and development
10	Documentation and reporting
11	Evaluation and audit
12	Review and continual improvement

Source: NRMMC & EPHC (2005)

Environmental risks from a well-designed and oprerated stormwater reuse scheme are generally low. Further, the health risks from stormwater reuse are generally lower than for wastewater reuse for the same application. However, stormwater reuse does carry some health risks and these need to be managed appropriately. All recycled water schemes need to be appropriately designed and managed to minimise risks – for example, a poorly operated stormwater harvesting scheme may present greater health risks than a well-operated effluent reuse scheme.

These thresholds are not intended to represent a threshold between viable and non-viable schemes. The intention is to distinguish between schemes that can readily achieve low public health and environmental risks and those where further investigation is appropriate.

Table 4.3 Thresholds for use of default risk management approach

Parameter	**Threshold criteria – all schemes**
Catchment land use	Residential/commercial (i.e. no significant industrial areas)
Sewer overflows in the catchment	Low frequency and volumes
Stormwater reuse application	• Residential non-potable (small scale) • Irrigation of public open spaces • Industrial uses • Water feature • Irrigation of non-food crops • Aquifer storage and recovery
Storage	Constructed either off-line or on-line on a constructed drain
Extraction	Flow in watercourse after extraction is greater than the estimated pre-urbanisation flow. Stormwater is reused in the catchment from which it was extracted
Stormwater quality	Turbidity levels are low or moderate
	Threshold criteria – irrigation schemes
Salinity levels in stormwater	Low/medium
Groundwater	Not in an area where groundwater is vulnerable
Location of irrigation area	More than 1 km from a town water supply bore
Slope – sprinkler irrigation	< 6%
Slope – trickle or microspray irrigation	< 10%
Landform	crests, convex slopes and plains
Surface rock outcrop	Nil
Soil salinity (0–70 cm)	< 2 dS/m
Soil salinity (70–100 cm)	< 4 dS/m
Depth to top of seasonal high water table	> 3 m
Depth to bedrock or hardpan	> 1 m
Soil saturated hydraulic conductivity (0–100 cm)	20–80 mm/h
Available soil water capacity	> 100 mm/m
Emerson soil aggregate test (0–100 cm)	Class 4, 5, 6, 7

Where a scheme does not meet some or all of the threshold criteria or different management practices are proposed, a risk assessment should be carried out. It should focus on the area exceeding the threshold or the different management practice. This may result in additional management actions being developed.

The scheme's developer should check that the management measures are appropriate for the circumstances of the particular scheme, recognising that all schemes have some unique features.

Further information is provided in appendix B, including a generic risk assessment for sub-threshold schemes.

Table 4.4 General management measures for default risk management approach

Area	Management measures
Planning	• Identify any point sources of pollution and industrial land uses within the catchment • Identify sewer overflow characteristics within the catchment • Involve scheme's proposed operator in the scheme's planning
Design	• Involve scheme's proposed operator in the scheme's design • Limit stormwater extraction rates • Use plumbing controls and signage
Operations	• Ensure organisational commitment, including continuous improvement • Ensure appropriately qualified scheme operators • Manage upstream catchment • Follow appropriate scheme operations and maintenance • Implement workplace procedures • Establish and follow incident response procedures • Monitoring, reporting and record keeping • Prepare and implement scheme management plan

Table 4.5 Specific management measures for default risk management approach

Application	Access restrictions	Stormwater quality criteria	Specific operational practices
Residential (non-potable)	Nil	Level 1	Above-ground storage design and management Additional plumbing controls
Irrigation of open spaces	Nil	Level 2	Irrigation scheme design and operational controls
	Controlled public access or subsurface irrigation	Level 3	
Industrial	Nil	Level 2	
	Controlled public access	Level 3	
Ornamental waterbodies	Nil	Level 2	
	Controlled public access	Level 3	
Aquifer storage and recovery	Not applicable	Level 3	ASR scheme operational controls


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5. Planning considerations

5.1 Planning process

Key considerations in the planning process

The planning process should aim to:

- identify all risks to public health, safety and the environment
- identify all of the upstream catchment characteristics likely to present public health or environmental risks to stormwater reuse
- involve the organisation(s) responsible for operating the scheme, and other key stakeholders
- identify all site constraints and regulatory requirements
- evaluate possible arrangements for a stormwater harvesting and reuse scheme, including evaluating costs and benefits.

Stormwater harvesting and reuse schemes can be implemented either in existing urban areas or as part of a new urban development. The project's context will therefore influence the nature of the planning process.

The process summarised below could be used in part for preparing a plan for integrated water cycle management in an existing urban area or as part of the master planning for a new urban development. The basic steps are common to both situations, but the details of each step may differ. The planning process is based on the assumption that a decision has been made to proceed with a stormwater harvesting and reuse scheme to at least the planning stage.

Also, the planning process is likely to be iterative, requiring several rounds of review in earlier stages as new information arises and negotiations progress with stakeholders (including end users) that may alter the objectives and/or available options.

The complexity of the planning process for stormwater harvesting schemes should match the size and nature of the project and the associated levels of public health and environmental risks. For example, a small scheme to harvest stormwater for irrigating a playing field would require less risk assessment than a major scheme to treat and reticulate harvested stormwater to a new development area.

During the project's planning stage, a risk management strategy should be developed. This should, in particular, identify public health and environmental hazards and an appropriate mix of controls to be implemented during the design and operational phases.

Key stakeholders should be consulted throughout the planning process, particularly during the setting of project objectives. Their engagement in the scheme from the planning stage will:

- provide opportunities for educating the community and the proponents
- allow for any concerns or misconceptions to be identified and addressed early in the scheme
- build user confidence in the scheme, resulting in greater use of treated stormwater as an alternative to mains water.

Additionally, providing feedback mechanisms to gain community opinions throughout the design, construction and operation phases may help to secure greater community acceptance for the project and any future schemes.

The five steps discussed below for stormwater harvesting and reuse schemes are broadly similar to other planning processes, but they differ in the specific details relevant to stormwater harvesting and reuse schemes:

1. identify the project objectives
2. assess the site and catchment
3. identify potential options
4. evaluate options
5. recommend an option.

5.1.1 Identify the project objectives

In developing reuse schemes for a site, broader catchment or regional objectives are important (see section 2.3). These could involve specified reductions in:

- mains (potable) water use
- stormwater flow rates and/or volumes
- stormwater pollution loads
- the effective (connected) impervious area of the catchment.

Organisational objectives, government policies and environmental planning instruments may also provide a strategic context for the project. The most common project objectives will relate to:

- managing public health and safety risks
- managing environmental risks
- meeting the requirements of the end user, primarily relating to water quality, quantity and reliability of supply
- protecting or enhancing visual amenity or aesthetics.

This step should determine the relative importance of reliability of supply and reductions in mains water use. A scheme aiming for a high reliability of supply will generate a relatively low yield (resulting in a smaller reduction in mains use). Put another way, less harvested water would be used than if the design sought to maximise reuse volumes by withdrawing stormwater to keep water levels in storage low, while keeping the capacity to store new inflows high.

5.1.2 Assess the site and catchment

This step identifies and assesses the potential constraints and opportunities of the proposed project site. Potential constraints may include:

- topography
- land use
- adjacent land uses (including potential land-use conflicts)
- watercourse characteristics (e.g. tidal watercourses are normally inappropriate for stormwater harvesting)
- vegetation and other sensitive ecosystems (potential biodiversity impacts)
- soil characteristics, such as salinity or acid sulfate – refer to DEC (2004) for further details


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- existing water management infrastructure
- statutory or regulatory constraints.

This step should identify opportunities for reusing treated stormwater, as well as suitable locations for storages. Other aspects of the end-user's operations may also be important, such as future development plans or land-use changes that may affect longer-term water use patterns.

The quality of stormwater for a reuse project is affected by the characteristics of the scheme's catchment. For example:

- the risk of chemical pollution in a catchment increases with the extent and nature of industrial uses and paved roads, particularly those with high traffic volumes
- the risk of pathogen contamination increases where catchments have multiple sewer overflows or high loadings of animal wastes.

The impact of such diffuse pollution sources can be gauged by investigating water quality during wet and dry weather, or by referring to existing water quality databases.

Similarly, the scheme should investigate the impacts on water quality from any point sources of pollution, such as sewage treatment plants and landfills. The hazard assessment for the scheme (see section 5.1.4) may need to consider both diffuse and point sources of pollution – for example, significant sewer overflows may pose a significant hazard for a scheme involving residential use for garden watering.

The level of the site and catchment investigation required should match the size and scale of the development and its potential impacts (i.e. larger developments having a greater impact would require greater site investigation). As noted for effluent reuse schemes (DEC 2004), a staged approach to site investigations can be adopted to minimise costs. This involves an initial screening level assessment using readily available information to identify major constraints and opportunities, then focusing efforts on any identified constraints.

5.1.3 Identify potential options

This step identifies various possible layouts for a scheme to meet the project's objectives. As noted in section 2, different stormwater harvesting projects can have several elements in common. However, the arrangement and sizing of these elements tends to be specific to each project; for example, on-line and off-line storages could be considered, as well as different treatment techniques depending on end uses and catchment water quality.

This step should assess the influence of different sizes for key elements such as storages. This step is likely to involve modelling the outcomes from various options, identifying the degree to which each option meets the adopted project objectives. This could be iterative, modelling the influence of a number of key aspects of the project (such as different storage volumes against predicted outcomes), and may include modelling of:

- water balance
- stormwater pollution and environmental flows
- stormwater peak flows and flood levels.

Water balance modelling

The water balance will determine the relationship between storage capacity, reuse demand and reliability of supply or frequency of stormwater discharges for various scenarios. If the demand pattern is known, the required storage capacity can be estimated for varying levels of supply reliability and discharge frequency. Information from section 5.1.2 is used as an input to the modelling. The outputs are then compared to the water management objectives for the project. Water balance modelling can also be used to assess variations in water levels, a consideration where fluctuations in open storages may have aesthetic, environmental and operational impacts.

Stormwater pollution and environmental flow modelling

Modelling of stormwater pollution loads from the catchment, and the reduction achieved through the stormwater harvesting and reuse scheme, should be conducted for each option. The stormwater pollution load reductions to waterways that can be achieved by a scheme include:

- the ‘loss’ of pollution due to the reuse of the extracted stormwater
- pollutant retention in on-line storages
- reduced loads in any stormwater that is treated by a scheme, but which is returned to the stormwater system because it is not needed for reuse,

This modelling usually employs an extended timeframe (e.g. 10 years) with daily or shorter time steps. It can also be used to assess the impacts of the scheme on downstream streamflows – see Engineers Australia (2005) for further details of this form of modelling.

Stormwater peak flow and flood level modelling

The third form of modelling involves estimating peak flows in the system for a range of average recurrence intervals (ARI), commonly including the 100-year ARI flood. Flood levels in the vicinity of the scheme can then be estimated, using hydraulic modelling, to assess the impact of an option on upstream flood levels (Institution of Engineers Australia 1987). This modelling can also assess the benefits of the scheme in reducing downstream flood flows.

5.1.4 Evaluate options

The various options identified in section 5.1.3 should be evaluated, taking into account social, economic and environmental considerations. The evaluation is likely to consider the factors noted in table 5.1.

The evaluation of options should primarily assess how well each option meets the project’s objectives. It is likely that during this process trade-offs between objectives may need to be assessed as, for example, it may not be cost-effective to meet all objectives.

There is no widely used evaluation technique for water recycling schemes such as stormwater harvesting (Hatt et al. 2004, Kellogg Brown & Root 2004, McAlister 1999). This may be partially due to the difficulty in quantifying many of the costs and benefits of such schemes, and where some of the costs and benefits can be attributed to parties not directly involved in the proposed scheme.

Possible evaluation techniques include:

- economic evaluation:
    - cost-benefit analysis
    - cost-effectiveness analysis
- triple bottom-line analysis
- multiple criteria analysis.

Economic evaluation: cost-benefit analysis

Cost-benefit analysis quantifies in monetary terms all the major costs and benefits of project options. The outcomes for a range of options are therefore translated into comparable terms to facilitate evaluation and decision making. The technique can also makes explicit allowance for the many costs and benefits which cannot be valued. In both cost-benefit and cost-effectiveness analysis, all unquantifiable benefits and costs should be described.

Cost-benefit analysis is a more comprehensive technique than cost-effectiveness analysis and is normally the preferred technique wherever feasible (NSW Treasury 1999). An approach that can be adopted to cost-benefit analysis is described in NSW Treasury (1999). This approach involves quantifying the benefits and costs over the project life, with a 20-year analysis period recommended for consistency. The costs and benefits are expressed in net present value terms, using a 7 per cent discount rate.

A potential difficulty in using cost-benefit analysis for stormwater harvesting and reuse proposals is that some benefits can be difficult to quantify. Further, the analysis is often not warranted for small reuse projects.

While capital costs for projects are relatively easy to estimate, maintenance costs (which are important in the life-cycle cost of a project) are often more difficult.

Appendix D provides some guidance on estimating maintenance costs for stormwater treatment measures.

Table 5.1 Potential option evaluation considerations

Area	Evaluation consideration
Social	• risks to human health and safety • aesthetic benefits/impacts of storages • any improvements to the condition of community assets (i.e. sports fields) and other amenity improvements. • any flooding impacts caused by weirs (this may also be a social, economic and/or environmental factor)
Economic	• capital costs (e.g. project management, investigation, design, construction and any land acquisition) • recurrent costs (e.g. operating, power, maintenance, asset renewal and monitoring) • any savings in mains (potable) water costs • any income received from the sale of the treated stormwater • any income benefits for end users (e.g. golf course remains green and attractive to golfers) • any savings in fertiliser application
Environmental	• benefits of reduced stormwater pollution and downstream flows • benefits in reduced mains water consumption • potential impacts of on-line storages or diversions for off-line storages • environmental risks (e.g. potential impacts of irrigation on surface water quality, groundwater and soils) • potential impacts of the scheme on endangered ecological communities, populations and species • energy use and any associated greenhouse gas production

Economic evaluation: cost-effectiveness analysis

Where the main benefits of a project are not readily measurable in monetary terms (using either actual or proxy values), it may not always be possible to apply cost-benefit analysis. An alternative approach is to use cost-effectiveness analysis to compare the costs of each option, assuming the benefits of each option are broadly similar. Where the benefits of each option differ, cost-effectiveness analysis is less useful than cost-benefit analysis, where costs and benefits of different kinds of options are more readily comparable (NSW Treasury 1999).

The approach to cost-effectiveness analysis described by NSW Treasury (1999) quantifies the present value of project costs over the project life, using a 20-year analysis period and a 7 per cent discount rate.

An alternative approach to estimating project costs for cost-effectiveness analysis is life-cycle costing (Standards Australia 1999, NSW Treasury 2004), which is a process to determine the sum of all the costs associated with all or part of an asset, including acquisition, installation, operation, maintenance, refurbishment and disposal. Taylor (2003) provides further advice on life-cycle costing for stormwater projects.

A simplified approach to life cycle-costing is to calculate the net present value of a project’s capital and operating costs, using the 20-year analysis period and 7 per cent discount rate noted above.

A related approach is levelised costing, defined as the net present value of the project’s costs over the analysis period divided by total volume of water supplied or pollutant removed (IPART 1996). The 20-year analysis period and 7% discount rate noted above can be used for these calculations. Levelised costs are expressed in cost per kilolitre or cost per kilogram of pollutant removed.

A disadvantage of the levelised cost approach is that it associates the project’s costs with a single objective (e.g. water supply volumes), whereas most stormwater harvesting schemes satisfy multiple objectives that cannot readily be accounted for using this approach. When the outcomes from different options are the same (e.g. the same volume of water reused), levelised cost calculations are not warranted, as the comparison does not need to be based on unit costs – life cycle costing can be used. Life cycle or levelised costs can also be used in triple-bottom-line and multi-criteria analysis.

Triple-bottom-line analysis

An alternative and often more comprehensive approach to assessing costs and benefits in a sustainability context is triple-bottom-line (TBL) assessment. This method provides for the equal consideration of environmental, social and economic elements associated with a given scheme proposal (see table 5.1).

While the obvious benefits of this approach lie with the potential to undertake a balanced assessment of project options, the considerable investment of time required for detailed investigations suggests that TBL assessment is best suited to large-scale proposals. Taylor (2005a) generated comprehensive guidelines on the application of this approach for stormwater management measures, and explains the preferred use of multi-criteria analysis in evaluating multiple objectives.

Multi-criteria analysis

Multi-criteria analysis or evaluation provides a decision-support framework that can be used to undertake a triple bottom-line assessment of project options. This technique requires that proposals be evaluated against predetermined criteria, with the most favourable option identified through comparing relative weightings or rankings arising from this evaluation. While complicated, this approach allows for an in-depth assessment of the multiple parameters and objectives normally associated with a stormwater harvesting and reuse scheme. Further information on undertaking a multi-criteria analysis can be found in Proctor & Qureshi (2005).

5.1.5 Recommend an option

This step identifies a recommended option, based on the evaluation of options. The options evaluation report should include a risk management strategy identifying actions to reduce risks (including to public health and the environment) during the design and operation of a scheme.

The selected option may then be subject to more-detailed conceptual design and analysis to confirm its feasibility and suitability. This may include preparing a conceptual layout that indicates the size and location of the proposed facilities for stormwater collection, treatment, storage and distribution.

Water-sensitive urban design at Kogarah Town Square

5.2 Considerations for schemes in existing urban areas

The decision to implement a stormwater harvesting and reuse system in an existing urban area should ideally be made in the context of a regional or catchment-based plan or strategy for integrated urban water cycle management.

Such a plan would seek to integrate all streams of the urban water cycle – not just stormwater, but also potable water and wastewater – towards multiple objectives such as water demand, pollution loads, environmental flows and flooding.

A stormwater harvesting scheme could be developed in the context of a water utility's integrated water cycle management plan (DEUS 2004) or water savings plan (DEUS 2005).

In existing urban areas, option evaluation of a scheme may be more straightforward than in new urban areas, as the scheme's proponent would also usually be the scheme's operator. The economic analysis can therefore be based on both the capital costs and the operating costs to the proponent, which can be integrated through an analysis such as life-cycle costing (Taylor 2005b).

5.3 Considerations for schemes in urban developments

For stormwater harvesting schemes in new urban developments, key project objectives are likely to be established by council, and possibly by the water supply authority and/or the Department of Planning. Such a scheme needs to be considered early in the processes of master planning and development approval. It should also be an integral part of a site's water cycle master planning, accounting for water supply, sewerage and stormwater objectives. This integrated approach should achieve the optimal water cycle balance for the development, for example by addressing competing demands for non-potable water uses between treated stormwater and effluent (e.g. dual reticulation). It can also allow for the scheme to take into account any flood mitigation benefits when assessing on-site detention requirements.

In new developments, it is important to consider the interests of the developer, the council and the scheme's operator (if this is not the council) by assessing the costs and benefits to these stakeholders separately. The assessment should consider the capital costs to the developer and the recurrent costs to the scheme's operator (e.g. council). This is a different emphasis to the life-cycle costing approach, which is useful when the proponent is also the operator.

Councils would probably refer a development application for a stormwater harvesting and reuse scheme to the Department of Health for comment. It would therefore be useful for the proponent to discuss the project with that department during the development phase.

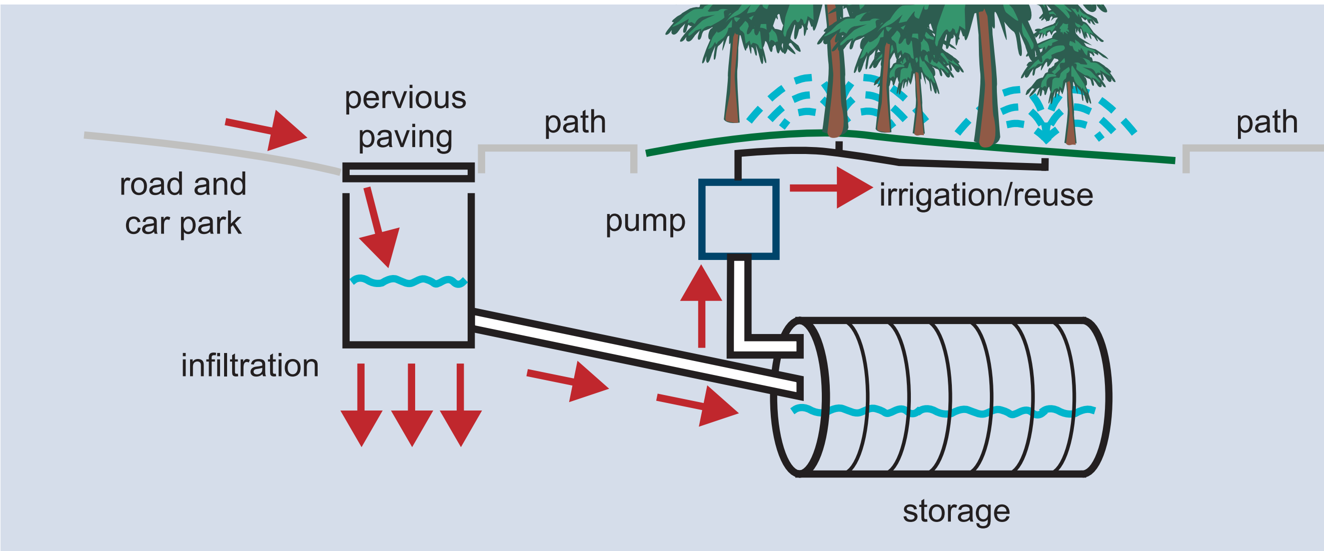
The likely issues that a council may want included in a development application involving a stormwater harvesting and reuse scheme include:

- anticipated benefits and impacts associated with scheme construction and operation (including social, environmental and economic aspects)
- consideration of environmental impacts during construction and operation phases through the preparation of an environmental management plan (EMP)
- compatibility of the proposed scheme with council's objectives, plans or strategies, including any relevant strategic water management plan or strategy
- how public health and safety risks are addressed

- management arrangements for the scheme
- what (if any) risks and/or financial obligations would be transferred to council if it operates the scheme (e.g. operations, maintenance, monitoring and reporting costs)
- compatibility of the proposed plan with surrounding land uses (compliance with zoning requirements)
- a ‘scheme management plan’, as described in section 7.

The development consent for a stormwater reuse scheme may include conditions requiring:

- appropriate management arrangements to be in place, if council is not the scheme’s operator (e.g. a golf course operated by a club or private company)
- implementation of an EMP to manage construction impacts on the environment
- the scheme management plan to be implemented
- regular reviews and updating of the management plan as required
- reporting of monitoring results (including any exceedances) and implementing any corrective actions.



6. Design considerations

6.1 Design overview

Key considerations in the design process

The design process should aim to:

- design the reuse scheme for ease of operations and maintenance
- incorporate elements in the design intended to address public health and environmental risks, to complement operational risk management activities
- cost-effectively meet the project's objectives identified during project planning.

6.1.1 Arrangement of project elements

Various combinations of elements can be used in a stormwater harvesting and reuse scheme, depending on the nature of the site and the end uses. The design process needs to consider the following components:

- collection
- storage
- treatment
- distribution.

The design process should also consider construction, operations and maintenance issues.

As noted in section 2, there is no fixed arrangement for project elements. For example, a storage may be located before, after or between treatment facilities. Depending on the design of the scheme, water may be transferred between these elements by gravity flow or pumping. The elements should be arranged to suit the characteristics of the site and of the specific application. Examples of two possible arrangements are shown in figure 6.1.

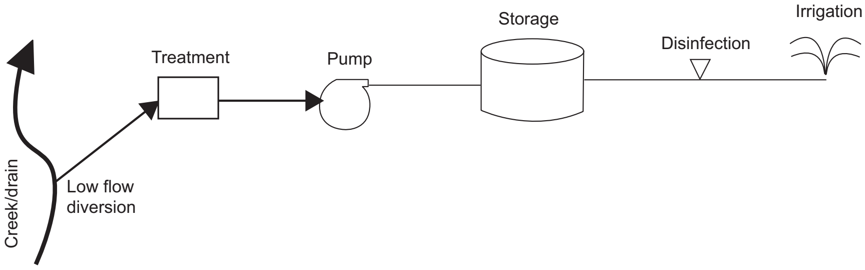


Figure 6.1 (a) **Schematic of an example harvesting scheme with off-line storage**

Figure 6.1 (b) **Schematic of an example harvesting scheme with on-line storage**

6.1.2 Approach to design

As with the planning process discussed in the last chapter, the design of a stormwater harvesting and reuse scheme is likely to be iterative, particularly to optimise the project's costs. As the end-use requirements essentially dictate the collection, storage and treatment elements of a scheme, the initial design is likely to follow the opposite direction of water flow:

- identify the end-use requirements relating to water quality and quantity, including reliability of supply
- for an irrigation scheme, prepare a preliminary design of the irrigation system to estimate the irrigation demand and the peak flow
- assess the water balance for sizing the storage to meet the end-use demand
- design the collection system for off-line storage so that it collects sufficient stormwater to meet the storage volume requirements – this can be estimated through a relationship between average annual volume and diversion flow rates
- design the treatment system based on the diversion flow rate if treatment is provided before the storage, or to the distribution flow rate if treatment occurs after the storage.

It is also important that the scheme is designed to consider the ease of operation and maintenance (see section 7). It is therefore useful for maintenance personnel to be involved in the design process. The project should also be designed to cost-effectively address the project's objectives determined during the planing phase (section 5).

As noted in section 5, a risk management strategy should be prepared during the planning stage to identify risk issues for the project design to address.


K Walters/DEC

Stormwater pump at Greenway Park stormwater reuse scheme, Cherrybrook

6.2 Collection

Key considerations in the collection of stormwater for reuse

The design of the collection system should ensure that:

- sufficient stormwater is collected for transfer to storage to meet the end-use volume requirements
- the extraction does not compromise downstream aquatic ecosystems
- collection can be stopped if stormwater is contaminated by an incident within the catchment
- the risk of upstream flooding impacts is minimised.

This component of a scheme collects or diverts stormwater into the harvesting scheme from an urban creek, stormwater drain or overland flow. The nature of the collection arrangements depends on whether the storage is constructed on a drainage system (on-line) or away from the drainage system (off-line). These arrangements are discussed further in section 6.3.

Where on-line storage is used, there is no collection system, as stormwater flows directly into the storage. Stormwater can be directed to the storage by drains or swales.

For schemes with off-line storages, water is usually collected by a diversion weir constructed on a stormwater drain or urban creek. The weir diverts low flows into the scheme while enabling high flows to bypass the system. These schemes should also include a bypass facility to return stormwater to the drain when the storage is full. Where a scheme draws stormwater from larger watercourses, lakes or ponds, stormwater can be collected by installing a well with a submersible pump and associated rising main.

In new urban developments, stormwater can be collected through water-sensitive design elements such as swales and biofilters. These elements also provide a degree of stormwater treatment.

The design of the diversion weir should ensure that an adequate volume of stormwater would be diverted to meet the planned water demand and reliability of supply. The weirs are usually designed to divert flows below a specific average recurrence interval (ARI) peak flow into the scheme, with higher flows overtopping the weir. Usually it is the low ARI storm events that are diverted (e.g. 3-month ARI), as such low flows provide the bulk of the annual yield and account for the greater proportion of the pollution load.

The relationship between annual run-off volume and peak flow is site-specific and distinctly non-linear. Figure 6.2 from Wong et al. (2000) illustrates that 90–97% of the mean annual run-off from Australian urban catchments occurs at flows lower than the 3-month ARI peak flow. This relationship is indicative only, and a site-specific relationship should be developed for particular projects.

Figure 6.2 also highlights a distinct ‘point of diminishing returns’ in the relationship between diversion flow rate and the percentage of average annual run-off volume diverted. Diversion flows of 6-month to 1-year ARI are likely to divert nearly all (over 98%) of the annual run-off volume. The implication for the design of diversion structures is that the diversion of infrequent, high-ARI flows is unlikely to be cost-effective.

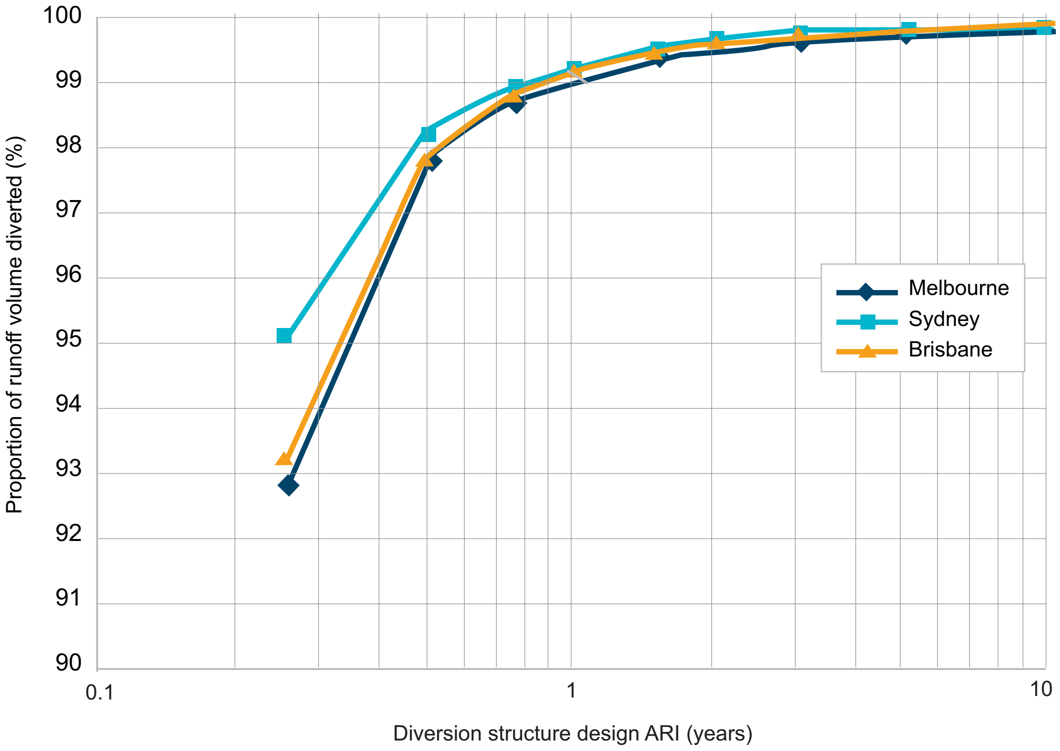


Figure 6.2 **Relationship between diversion structure flow and run-off volume**

Source: after Wong et al. 2000

Similarly, where water is pumped from a creek, the benefits of selecting a pump with a rate greater than the 3-month ARI flow would only be marginal.

The project design should assess the extraction volume compared to the needs of the downstream receiving environment and any downstream users to prevent over-extraction. For example, a 90% reduction in annual runoff volume may result in over-extraction relative to environmental flows, and a design diversion flow of 1-month ARI or less may be more appropriate. This needs to be assessed on a case-by-case basis as, for example, a high extraction could be compensated for by significant stormwater inflows downstream of a harvesting scheme.

6.3 Storage

Key considerations in the storage of stormwater

The design should aim to:

- store sufficient water to balance supply and demand, and meet reliability of supply objectives
- design above-ground storages to minimise mosquito habitat (virus control), risks to public safety and risks to water quality (e.g. eutrophication), and address dam safety issues.

6.3.1 Storage volume

Storage in stormwater harvesting and reuse schemes needs to balance the variability between stormwater inflow and demand. Demand variability can be significant, especially in the case of irrigation, and may be the inverse of stormwater availability because demand would decrease during periods of rainfall.

The primary function of a storage is to balance inflows and demand to achieve a desired reliability of supply. There is a complex relationship between storage volume, annual run-off volume, the demand for treated stormwater and the yield from a scheme. For example:

- if the storage size is increased for a given demand, the yield increases, as does the reliability of supply – there is less likelihood of the storage being empty
- if the demand increases for a given storage size, the yield increases although the reliability of supply decreases – the storage is empty or nearly empty more often, increasing the capture of inflows
- where the demand represents a high proportion of the mean annual run-off and a high degree of reliability is required, a significant storage volume will be needed.

These interactions highlight the importance of water balance modelling for sizing storages (discussed further in appendix C). The size of storages can be optimised when the pattern of demand is similar to that of stormwater supply. To keep storages to a reasonable size, the design could include a top-up facility, usually from mains water (if appropriate or permissible), or altered operating rules to ration or restrict demand in certain periods.

Storages may be constructed specifically for stormwater reuse or a scheme could utilise an existing storage, such as an urban lake. Alternatively, a harvesting scheme could use a storage created as part of a broader stormwater management scheme, such as a constructed wetland or pond for stormwater treatment. This would involve adding volume for reuse at the design stage of the wetland or pond.

While most storages for stormwater harvesting projects are above ground, alternatives include underground storages in tanks or injection into aquifers (known as aquifer storage and recovery or ASR). ASR is used widely in South Australia (Kellogg Brown & Root 2004) and is very space and cost-efficient. Dillon & Pavelic (1996), EPA SA (2005) and Dillon & Molloy (2006) provide further information on ASR.

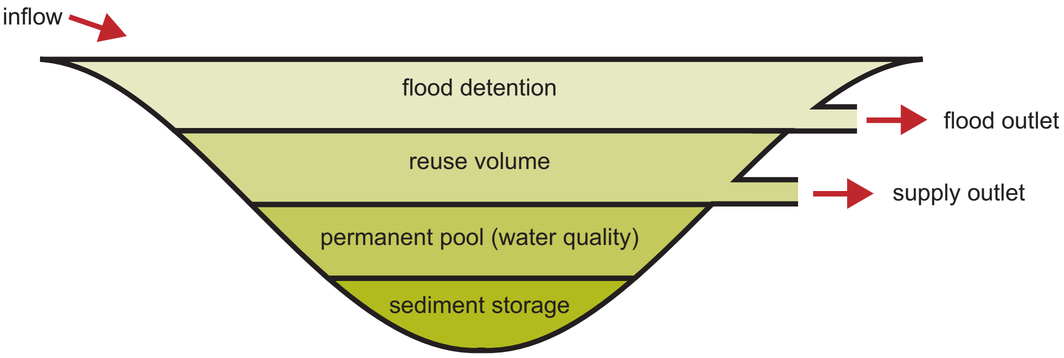
There are three main issues associated with the design of stormwater storages:

- function – single or multi-purpose
- capacity – meeting a specific reliability of supply
- location – on-line or off-line, surface or aquifer, centralised or distributed.

Storages, particularly those above ground, may also have other functions, including:

- flood mitigation
- visual amenity
- pollution load reduction
- habitat
- fire-fighting supplies.

Figure 6.3 Schematic diagram of a multi-purpose above-ground storage



While multiple objectives may be desirable, the scheme may not be able to satisfy all objectives all of the time, requiring some compromises to be made. For example, significant fluctuations in the water levels of open storages may hinder the growth of fringing macrophytes needed for effective water quality control, habitat, visual appeal and access control, requiring some trade-off between these objectives.

The various storage volumes for a multi-purpose project can be derived through water balance, water quality and flood modelling, as described in section 5.

6.3.2 Design of storages

The design of a storage should take the following constraints into account:

- location
- storage type
- water quality in storage
- human health and safety risks
- operations and maintenance
- spillway design and dam safety.

Location

Storage in stormwater harvesting and reuse schemes can be on-line and off-line. There are both advantages and disadvantages with each type (see table 6.1). Some of the potential disadvantages can be addressed through good design. Off-line systems are likely to be the most appropriate for schemes on natural watercourses.

Storage types

Open storages and above-ground or underground tanks are normally used in stormwater harvesting and reuse schemes. Each has particular advantages and disadvantages that should be considered during the planning and design phases (see table 6.2).

Table 6.1 Comparison of on-line and off-line storages

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 reuse 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

Water quality in storages

Water quality considerations apply to varying degrees to both on-line and off-line storages, as well as to open and covered (e.g. underground) storages. These considerations are most critical when treatment levels other than disinfection are low and when the demand is small relative to the storage volume.

Elevated nutrient loadings, particularly of phosphorus, can result in eutrophication of an open storage in which cyanobacteria (also called blue-green algae) can bloom and anaerobic conditions develop. The risk of eutrophication is higher if the water is stored for long periods and nutrients are not removed or reduced by the treatment process.

Table 6.2 Potential advantages and disadvantages of storage types

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

Stormwater storage at Pennant Hills Park stormwater reuse scheme

To minimise the risk of cyanobacterial blooms in open storages, Melbourne Water (2005) recommends that detention times should not exceed those noted in table 6.3 at the summer water temperatures indicated. This is based on the assumption that sufficient nutrients are available for algal growth and there is no light limitation due to elevated turbidity levels.

During the water balance modelling for the project, the residence time of water in the storages should be checked against these guidelines. If the residence times will exceed those indicated, consider options for minimising the likelihood of blue-green algal blooms, such as nutrient removal before storage or altering the diversion/demand operating rules.

Anaerobic conditions can develop in all storages, especially where elevated loads of organic matter occur with inadequate aeration. This is because the bacteria that break down organic matter consume the available dissolved oxygen faster than it can be replenished from the atmosphere. This may be a greater problem in underground tanks than in open storages. Management options include reducing the loads of organic matter before storage by installing a gross pollutant trap and not operating the scheme during periods of limited demand and long retention times (e.g. winter).

Table 6.3 Detention times to reduce the risk of algal blooms

Detention time[1] (days)	Average daily temperature (ºC)
50	15
30	20
20	25

Note: 1 20th percentile

Open storages can be attractive to waterbirds, which contribute faecal matter containing pathogens, thus increasing public health risks. This is of particular concern where the treated stormwater is intended for residential uses, as low pathogen levels are required due to the high public exposure. To minimise attractiveness to waterbirds, the storage should be designed with relatively steep side slopes and no fringing macrophytes planted. The storage should also be fenced for public safety and to minimise faecal inputs from animals. This arrangement should be considered as an additional barrier for addressing health risks for schemes with residential uses of treated stormwater.

Turkey's-nest dam, Bexley golf course

Human health and safety risks

The layout of above-ground storages and associated stormwater treatment measures should consider public health and safety issues. These relate principally to side slopes and storage depths. The side slope affects the ease with which somebody can clamber out should they fall in, and from this viewpoint the slope should be shallow when adjacent to areas of deep water.

However, shallow side slopes may encourage disease-carrying mosquitoes to breed and so from this perspective steep slopes or vertical sides with handrails should be used. Ultimately, the design of the edge treatments needs to balance public safety and public health risks against environmental and aesthetic values.

Prominent warning signs should be considered for storages containing stormwater for reuse where public access is available. Warnings could read 'Recycled water storage – do not drink. No swimming, wading or boating'. Signs should be designed to AS 1319 and could also use supplementary symbols.

The design also needs to consider the extent of fluctuations in water levels within the storage, as this will influence the edge design.

The design of open storages is discussed further in *Managing urban stormwater: treatment techniques* (DEC 2006) and Melbourne Water (2005).

K Walters/DEC

Warning sign at Bexley golf course

Sedimentation

Sediment levels in raw and treated urban stormwater are higher than those in mains water. It is important that the design allows for accumulated sediment to be removed, which is likely to involve dewatering of the storage. This also applies to storage tanks where sedimentation of fine particles will occur.

Spillway design

Above-ground storages should be provided with a spillway to safely convey a design flood flow. This design flow is commonly the 100-year average recurrence interval (ARI) event or higher. Further advice can be sought from the Dam Safety Committee (NSW) (2004).

6.4 Treatment

Key considerations in the treatment of stormwater

The stormwater treatment system should be based on:

- adopting stormwater quality criteria that:
    - minimise public health risks for the adopted public access arrangements
    - minimise environmental risks
    - meet any additional end-use requirements
- designing appropriate stormwater treatment techniques to meet the adopted objectives.

6.4.1 Treatment overview

The treatment arrangements for a stormwater harvesting and reuse scheme should relate closely to the project's objectives, in particular by:

- addressing public health and environmental risks
- meeting any additional end-use requirements.

Stormwater quality can affect the performance of a reuse scheme in several ways, and these need to be considered at the design stage. For example, a scheme may need to include disinfection, but disinfection may be affected by turbidity. Associated with this is the need to reduce sediment so that it does not block the distribution system, including the sprays for any irrigation component. These aspects are discussed later in this section.

Where stormwater reuse is part of a larger stormwater project that, for example, includes protecting receiving water quality, only the reuse component of the treatable volume needs to be subject to these water quality considerations.

Thus, the design of a treatment system for a stormwater harvesting and reuse scheme needs to consider both:

- stormwater quality criteria, and
- treatment techniques to meet these objectives.

6.4.2 Stormwater quality criteria

Stormwater quality criteria for public health risk management

National guidelines for water recycling that include stormwater reuse are due in 2008. As an interim measure, table 6.4 presents default stormwater quality criteria for managing public health risks for various applications. Different criteria apply depending on the access arrangements for some applications (refer to table 4.4), with more stringent criteria applying (i.e. lower levels of pathogens) where the potential for human contact and ingestion of water is higher.

These criteria are suitable for schemes below the thresholds noted in table 4.3. A health risk assessment should be prepared for larger schemes with high public exposure, such as medium to large dual reticulation schemes for residential purposes (refer to Department of Health and Aging & enHealth Council 2002, and EPA Queensland 2005a for guidance). This risk assessment may find that the stormwater quality criteria in table 6.4 are appropriate for the scheme.

The stormwater quality criteria in table 6.4 have an associated statistical descriptor; for example *E. coli* objective is the median value. These values should be based on the analysis of monitoring data conducted over a 12-month period. Section 7 provides monitoring guidance.

Other aspects of water quality relevant to public health considerations noted in table 6.4 are turbidity and pH. High turbidity levels can shield pathogens from disinfection, which may result in less-efficient disinfection or higher disinfection requirements (Health Canada 2003). When pH levels are lower than 6.5, plumbing features can be corroded. At higher levels (e.g. above 8), the efficiency of chlorine disinfection is impaired.

Stormwater quality criteria for environmental risk management

Stormwater harvesting and reuse projects that are below the threshold criteria noted in table 4.3 and are operated in accordance with the guidance in section 7 are expected to have low environmental risks related to water quality. Specific stormwater quality criteria for environmental risk management are therefore not required for these schemes. Specific investigations and possible additional treatment may be required for schemes where the raw stormwater quality is likely to be poorer than from sub-threshold schemes – this may apply in catchments with industrial land uses or significant sewer overflows.

Table 6.4 Stormwater quality criteria for public health risk management

Level	Criteria[1]	Applications
Level 1	*E. coli* <1 cfu/100 mL Turbidity ≤ 2 NTU[2] pH 6.5–8.5 1 mg/L Cl_2 residual after 30 minutes or equivalent level of pathogen reduction	Reticulated non-potable residential uses (e.g. garden watering, toilet flushing, car washing)
Level 2	*E. coli* <10 cfu/100 mL Turbidity ≤ 2 NTU[2] pH 6.5–8.5 1 mg/L Cl_2 residual after 30 minutes or equivalent level of pathogen reduction	Spray or drip irrigation of open spaces, parks and sportsgrounds (no access controls) Industrial uses – dust suppression, construction site use (human exposure possible) Ornamental waterbodies (no access controls) Fire-fighting
Level 3	*E. coli* <1000 cfu/100 mL pH 6.5–8.5	Spray or drip irrigation (controlled access) or subsurface irrigation of open spaces, parks and sportsgrounds Industrial uses – 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

Source: derived from NSW RWCC (1993), DEC (2004), ANZECC & ARMCANZ (2000)

Operational stormwater quality criteria

Urban stormwater contains elevated levels of gross pollutants, including litter and coarse sediment (Engineers Australia 2005). These are likely to present a hazard to most stormwater harvesting and reuse schemes through their potential impacts on pump operations, the efficiency of treatment measures and the operations of the distribution system. A high degree of gross pollutant removal should be achieved for flows up to the scheme's collection flow.

Additional stormwater quality criteria for specific applications

Residential uses

The *NSW Guidelines for urban and residential use of reclaimed water* (NSW RWCC 1993) note the need to consider a number of characteristics in non-potable reticulated water, such as:

- salt
- nutrients
- heavy metals
- pesticides.

These apply equally to stormwater reuse, because garden watering is a key use of non-potable water and it is important to prevent impacts on soils or groundwater.

Irrigation

Irrigation with stormwater has different water quality requirements to irrigation with treated effluent. The levels of pollutants in stormwater are normally much lower than in effluent (see appendix C). Further, effluent reuse schemes typically have higher application rates (higher hydraulic loadings) because they aim primarily to dispose of effluent, whereas stormwater schemes may have multiple objectives. For these reasons, the environmental consequences of poor design or operation are likely to be more severe in an effluent irrigation scheme than in a stormwater irrigation scheme.

As noted above, urban stormwater is characterised by high loads of suspended solids, sand and grit. This can cause excessive wear and clogging of pumps and control equipment, and may block irrigation sprays. The specific treatment level required would depend on the design of the irrigation systems. For irrigating playing fields and golf courses, suspended solids levels below 50 mg/L are unlikely to result in operational problems. Limiting particle sizes to smaller than approximately 0.5–1.0 mm may avoid operational problems in conventional spray irrigation schemes. Specific information should be obtained from the irrigation scheme designer and/or equipment supplier.

High nutrient levels can cause operational problems for irrigation schemes through biofilms clogging irrigation equipment. ANZECC & ARMCANZ (2000) provides trigger values for agricultural irrigation that could be used for stormwater irrigation. These are presented in table 6.5.

Table 6.5 Trigger values for nutrients in irrigation water

Element	Long term (up to 100 years)	Short term (up to 20 years)
Total phosphorus (mg/L)	0.05	0.8–12[1]
Total nitrogen (mg/L)	5.00	25.0–125[1]

1 Requires site-specific assessment (refer to ANZECC & ARMCANZ 2000)

The phosphorus levels noted in appendix C are higher than the long-term trigger values in table 6.5 but are lower than the short-term values. Hence there is potential for long-term operational impacts where stormwater is irrigated without actions to reduce phosphorus concentrations. The nitrogen levels are lower than the long-term trigger levels.

Industrial uses

Additional stormwater quality objectives for industrial uses will depend on the nature of the use. Advice should be sought from the operator of particular industrial premises. Potential water quality concerns for industrial uses are noted in table 6.6.

Aquifer storage and recovery

Guidance on treatment objectives for aquifer storage and recovery can be obtained from Dillon & Pavelic (1996), and information about design and operations from EPA SA (2005) and Dillon & Molloy (2006).

6.4.3 Treatment techniques

The treatment arrangements for a stormwater reuse project should relate to the adopted stormwater quality criteria for the project.

Where a project has a single objective of stormwater harvesting and reuse, the treatment processes need to address the relevant public health and environmental risks, and any additional end-use requirements. For example, a small scheme irrigating a golf course with controlled public access may only need sediment removal by an efficient gross pollutant trap and disinfection.

Where reuse is only one of several project objectives, more conventional stormwater treatment measures (such as constructed wetlands for nutrient removal) may also be required in order to reduce pollution loads to design levels.

Water quality should be monitored during the planning and design phase for harvesting schemes where the upstream catchment has:

- point sources of pollution
- significant sewer overflows
- non-residential land uses, such as industrial areas
- roads with high traffic volumes.

The monitoring results will provide input into the project's risk assessment and design. A degree of redundancy or 'over design' is likely to be appropriate for these schemes, particularly for pathogen removal, due to the higher public health risks.

Table 6.6 Potential stormwater quality concerns for industrial uses

Quality	Potential problem
Pathogen levels	Health risks to public and workers
Chemical quality (e.g. ammonia, calcium, magnesium, silica, iron)	Corrosion of pipes and machinery, scale formation, foaming etc.
Physical quality (e.g. suspended solids)	Solids deposition, fouling, blockages
Nutrients (e.g. phosphorus, nitrogen)	Slime formation, microbial growth

Source: EPA Victoria (2003)

Stormwater treatment – contaminants

Stormwater for harvesting and reuse is likely to need pre-treatment to remove gross pollutants, including litter, organic matter and coarse sediment before it enters a storage or downstream treatment measures. Several types of proprietary and non-proprietary gross pollutant traps are available which could be used for this purpose.

As the level of gross pollutants in stormwater and the efficiency of gross pollutant traps are variable, the scheme should be designed on a contingency basis such that the scheme's operation is not compromised by the presence of gross pollutants. Pumps should be capable of pumping sand and grit, and subsequent stormwater treatment measures and storages should be able to accommodate some sediment inputs.

Table 6.7 shows indicative concentrations for pollutant retention and outflow from a range of stormwater treatment measures. The outflow concentrations have been based on the average stormwater concentrations contained in tables C.1 and C.3 (appendix C) for a residential catchment. Outflow concentrations will depend on inflow concentrations, with higher outflow levels expected in industrial catchments or those with high sewer overflows. The relationships also assume that there is no significant loss of volume through the treatment measure that might affect the concentration of a parameter.

Table 6.7 Indicative levels of pollution retention and outflow concentrations for different stormwater treatment measures

Stormwater treatment measure	Suspended solids	Total phosphorus	Total nitrogen	Turbidity	*E. coli*
Retention					
GPT	0–70%	0–30%	0–15%	0–70%	Negligible
Swale	55–75%	25–35%	5–10%	44–77%	Negligible
Sand filter	60–90%	40–70%	30–50%	55–90%	–25–95% (up to 1.5 log)
Bioretention system	70–90%	50–80%	30–50%	55–90%	–58–90% (up to 1 log)
Pond	50–75%	25–45%	10–20%	35–88%	40–98% (0.5–2 log)
Wetland	50–90%	35–65%	15–30%	10–70%	–5–99% (up to 2 log)
Outflow*					
GPT	42–140	0.18–0.25	1.7–2.0	18–60	9,000
Swale	35–63	0.16–0.18	1.8–1.9	14–34	9,000
Sand filter	14–56	0.08–0.15	1.0–1.4	6–93	500–11,000
Bioretention system	14–42	0.05–0.13	1.0–1.4	6–93	900–15,000
Pond	35–70	0.14–0.19	1.6–1.8	7–81	200–5,000
Wetland	11–67	0.09–0.16	1.4–1.7	19–53	100–9,000

* concentrations in mg/L except for turbidity (NTU) and *E. coli* (cfu/100 mL)

Source of retention data: DEC (2006), Fletcher et al. (2004), Victorian Stormwater Committee (1999).

The actual reduction in concentration achieved by a particular stormwater treatment measure will depend on its design and the inflow characteristics, both for flow and water quality. Information on the design of non-proprietary stormwater treatment measures can be obtained from DEC (2006) and Melbourne Water (2005).

The indicative results presented in table 6.7 highlight that stormwater treatment using conventional treatment measures can achieve the following levels of treatment:

- suspended solids concentrations of less than 50 mg/L – this is important for the design of irrigation systems
- reduced turbidity levels, but not to the levels of 2–5 NTU required for maximising disinfection
- reduced total phosphorus levels, although rarely to the long-term trigger value for irrigation systems shown in table 6.5 (no reduction is needed to meet the short-term trigger level or for the average total nitrogen level).

Stormwater treatment – pathogens

Treatment techniques for reducing pathogen levels suitable for use in a stormwater harvesting and reuse scheme fall into two broad categories:

- stormwater treatment measures – constructed wetlands, ponds, sand filters etc.
- water treatment techniques – disinfection using chlorine, iodine, UV radiation and ozone; membrane filtration etc.

Treatment to reduce the concentration of pathogens in stormwater should be undertaken at or close to where treated stormwater is used, normally downstream of the storage and at the start of any stormwater distribution system. Disinfection upstream of a storage is normally not effective as pathogen levels may increase in storage (e.g. waterbirds may add faecal matter to above-ground storages).

Stormwater treatment measures

Conventional stormwater treatment measures can achieve some degree of disinfection, as noted in table 6.7. However, the reductions are highly variable and at best can achieve the level 3 *E. coli* criteria noted in table 6.4. Overall, there will be difficulties in consistently achieving target pathogen levels for urban applications of treated stormwater using only conventional stormwater treatment measures.

The variability in pathogen removal efficiency of conventional stormwater measures is compounded by variability in the quality of stormwater inflows. The expected variation in pathogen levels in treated stormwater is a significant issue for public health risk management, as many of the health impacts are acute and related to a single exposure.

The use of stormwater treatment measures alone for reducing pathogen levels should be considered only when:

- a low level of treatment is required (e.g. level 3 criteria from table 6.4)
- site-specific monitoring has indicated that pathogen levels (as measured by indicator bacteria) are relatively low
- the treatment measures are conservatively designed.

The land area required for conventional treatment measures such as wetlands should also be considered. The scheme should also provide for the installation of disinfection equipment should monitoring indicate that the system is not meeting the stormwater quality criteria reliably.

Further information on the relative effectiveness of stormwater treatment measures and treatment technologies for reducing pathogen levels in stormwater can be found in Perdeck et al. (2003).

Water treatment techniques

The most commonly used disinfection technology for urban stormwater is UV radiation – see the case studies in section 8, and Hatt et al. (2004). In these cases, the relatively small flows and ease of using UV at small facilities made this option feasible. As these schemes did not reticulate treated water for residential uses, there was no need for residual disinfection. Disinfection by ozone has also been used at some stormwater treatment facilities.

Chlorination is the most common disinfection technique for water supply schemes (NHMRC & NRMMC 2004a) which tend to be larger than typical stormwater schemes and where residual disinfection is important. Chlorination would be appropriate for residual disinfection where a scheme reticulates stormwater for residential uses. However, the chemical reactions in chlorine disinfection create by-products which may present other public health or environmental risks. This is discussed further in Department of Health and Aging & enHealth Council (2002) and NHMRC & NRMMC (2004a).

Table 6.8 presents typical reductions in *E. coli* levels that could be expected using common disinfection techniques. The actual disinfection efficiency however would depend on factors like the design of the process, the operating rules (e.g. the dosing rates) and the inflow characteristics. The resulting indicative outflow *E. coli* levels for all technologies are <1 to 90 cfu/100 mL based on the average levels in stormwater from residential areas noted in table C.1 (appendix C).

A further discussion on disinfection technologies is provided in the Australian drinking water guidelines (NHMRC & NRMMC) 2004a and EPA Victoria (2002). Guidance on the design of disinfection systems can be obtained from Water Environment Federation (1996) and American Water Works Association (1999).

As noted earlier, turbidity levels influence the effectiveness of treatment technologies. The EPA Victoria (2002) recommend that pre-disinfection median turbidity levels should be:

- < 10 NTU for chlorination and microfiltration
- < 5 NTU for ozone and UV
- < 2 NTU for any disinfection method where the reuse application demands a significant reduction in pathogens (e.g. *E. coli* to less than 10 cfu/100 mL).

This approach is based on the need to ensure high disinfection efficiency when low pathogen levels are required, and relaxing this requirement when pathogen requirements are less stringent. This guidance is based on effluent disinfection; however, it could also be used conservatively for stormwater disinfection.

Table 6.8 Indicative effectiveness of disinfection technologies

Technology	*E. coli* reductions – log	*E. coli* reductions (%)
UV light	2 to > 4	99 to >99.99
Chlorination	2 to 6	99 to 99.9999
Ozonation	2 to 6	99 to 99.9999

Source: NRMMC & EPHC (2005)

From table 6.7, turbidity levels less than 10 NTU can be achieved by appropriate, well-designed measures. However, achieving turbidity levels less than 2 NTU through stormwater treatment alone is likely to be difficult. Some additional turbidity reduction is likely to occur in storages having relatively long retention times, particularly tanks or underground storages.

A suggested approach to optimise disinfection efficiency is to pre-treat according to the stormwater quality criteria for the indicator pathogen *(E. coli)*. This approach involves:

- for *E. coli* levels below 10 cfu/100 ml (level 1 or 2) – provide pre-treatment using a conventional water or wastewater technology (e.g. filtration) or extended storage in tanks to achieve median turbidity levels of less than 2 NTU
- for *E. coli* levels above 10 cfu/100 mL (level 3) – provide well-designed conventional stormwater treatment as disinfection pre-treatment. *E. coli* levels should be monitored intensively during commissioning to ensure that turbidity is not reducing disinfection. If disinfection is affected, alter the disinfection process (e.g. incrementally increase the dose of chlorine for chlorine disinfection) or provide additional pre-treatment to reduce turbidity.

Overall, disinfection technologies can be expected to achieve the target pathogen levels for urban applications of treated stormwater with a relatively high degree of reliability. While wastewater and potable water disinfection is well known, stormwater disinfection is a relatively new field.

Although turbidity may affect disinfection, the concentration of viable pathogens associated with particulate matter in stormwater may be relatively small when compared to wastewater (Water Environment Federation 1996). Thus wastewater needs to be pre-treated (e.g. by filtration) to achieve high disinfection efficiencies. Consequently high turbidity levels may be less of a concern for stormwater disinfection relative to wastewater disinfection.

This uncertainty highlights the importance of monitoring water quality during the commissioning and operational phases of a scheme to ensure that adequate disinfection is achieved or modifications made to the disinfection arrangements.

It is also important to acknowledge that the reduction in the level of one type of pathogen (e.g. *E. coli*) achieved by a specific disinfection technique may not apply to other types of pathogens (e.g. other bacteria, viruses and protozoa). This is discussed further in NHMRC & NRMMC (2004a).


K Walters/DEC

UV disinfection unit at Greenway Park stormwater reuse scheme, Cherrybrook

6.5 Distribution

Key considerations in the distribution of treated stormwater

The system for distributing treated stormwater should be designed to:

- minimise the potential for contaminant inputs downstream of the final treatment facilities
- minimise the potential for public exposure to treated stormwater and ensure there is no potential for cross-connection with mains water distribution networks or confusion with mains water supplies.

It is important that distribution schemes minimise the potential for contaminant inputs between the final treatment facility (e.g. disinfection) and the end use. This is usually achieved by using a piped distribution system.

There is a risk that treated stormwater contained in a piped distribution system could be mistaken for mains water, with the potential for accidental cross-connection. This is particularly important for schemes that use mains water as a supplementary water supply or for dual reticulation schemes for residential uses. To minimise these risks, the distribution system should be designed on the basis of:

- no cross-connection of the stormwater distribution system into the mains water system
- where mains water is used as make-up water, a backflow prevention device (e.g. an air gap) should be installed in the mains water supply before it enters the stormwater reuse scheme. The stormwater distribution scheme should also be operated at lower pressure than the mains water system, if practical
- underground and above-ground pipes in a stormwater distribution system should be colour-coded (e.g. purple) for schemes where there is public access, mains water back-up or dual reticulation. Identification tape should be installed on top of the underground pipes warning that the pipe contains recycled/reclaimed water and that it is not suitable for drinking
- hose taps for dual reticulation schemes should be have a removable handle and have a connection different to that used for mains water supply. Signs should be provided reading, for example, 'Recycled water – not for drinking'. The sign could also include relevant symbols indicating that the supply is not for drinking purposes. For sign design, refer to AS 1319 (Standards Australia 1994).

If a harvesting and reuse scheme is operated on private property and there is no regular public access, appropriate signage for site workers and any infrequent visitors should be provided. Other special signage requirements may be needed in some circumstances.

Detailed information on the design of the distribution system's plumbing is contained in the following documents (or more recent versions):

- for reticulated systems for residential uses:
  - *NSW Guidelines for urban and residential use of reclaimed water* (NSW Recycled Water Coordination Committee, 1993)
  - *NSW Code of practice for plumbing and drainage* (CUPDR, 1999)
  - *AS/NZS 3500: 2003 Plumbing and drainage* (Standards Australia 2003)
- for other uses:
  - *National Water Quality Management Strategy – Guidelines for sewerage systems: use of reclaimed water* (ARMCANZ et al. 2000).

6.6 Irrigation systems

Key considerations in the irrigation of treated stormwater

A system for irrigating with treated stormwater should be designed to:

- minimise run-off, groundwater pollution and soil contamination
- minimise spray to areas outside the control zone where access control is adopted to reduce public health risks.

6.6.1 Background

Irrigation with stormwater is a relatively new activity compared to irrigation using treated effluent. However there is a significant overlap between these applications. This section provides an overview of the issues to be considered in stormwater irrigation and highlights the differences in irrigating with stormwater or effluent. General information on the design of effluent irrigation schemes can be found in DEC (2004).

The main differences arise from the different pollutant levels in stormwater and effluent (as noted in appendix C). In general, contaminant levels in stormwater are lower than those in secondary treated municipal effluent, with the exception of some metals. DEC (2004) can be adapted to account for these differences.

6.6.2 Application rates

Designing the irrigation scheme's application rate is important for minimising surface run-off, groundwater impacts and impacts on soils. The application rates should consider the site's characteristics (particularly soils) and the irrigated vegetation. DEC (2004) provides guidance on water balance calculations for effluent irrigation schemes, which can also be used for stormwater irrigation. This provides input into the scheme's water balance described in section 5. The loading rate calculations for nutrients, organic matter and salinity in DEC (2004) are normally not required for stormwater irrigation.

The soil infiltration rate is an important consideration in the type of irrigation method used and in the way it is operated. Stormwater should be applied uniformly and at a rate less than the nominal infiltration rate to avoid surface run-off.

6.6.3 Buffer zones and irrigation scheme design

Spraying with stormwater may transmit pathogens through aerosols and mists from the spray water. Where stormwater has been treated to a relatively high level (e.g. level 2 in table 6.4), public health risks associated with irrigation sprays are low. However all spray irrigation systems should be designed to minimise off-site spray drift, as this may present a nuisance to neighbours.

Where a lower level of treatment is provided (e.g. level 3), greater management of irrigation water to reduce public exposure is required. This can be achieved either by using subsurface irrigation or by having buffer zones between the irrigation scheme's wetted perimeter and the nearest point of public access (e.g. road or private property).

DEC (2004) notes that the width of a buffer zone would depend on a range of factors, including the type of irrigation equipment used, slope, wind direction and vegetation present. The preferred approach is to carry out a site-specific study to determine a suitable width. Alternatively, the design could use an indicative buffer zone of 30 metres for drip or trickle irrigation schemes and 50 metres for spray irrigation (excluding high-pressure sprays). To help define buffer zones, low-flow sprinklers or 180° inward throw sprinklers can be used. Irrigation control systems can also include anemometers, which monitor wind direction and speed, to trigger an irrigation system cut-off under high wind conditions where excessive spray drift is likely.

In public access areas, facilities such as drinking water fountains, swimming pools and picnic tables should be placed outside the area irrigated by treated stormwater or be protected from drift and direct spraying.

Signage should be provided at all public access points to stormwater irrigation areas, warning not to drink the water. Additional signage will be needed to warn the public where access controls apply.

6.7 Construction

Key considerations in the construction of a stormwater reuse scheme

In constructing a system for using treated stormwater:

- construct the scheme to minimise water, air and noise pollution and waste generation
- protect any valuable vegetation during construction.

The design of a stormwater reuse project needs to consider the potential environmental impacts from both the operation and construction of the scheme. Construction may cause water, air or noise pollution, and generate waste, and may also damage soils and vegetation. These impacts maybe minimised by preparing an environmental management plan, the implementation of which should be monitored during construction. This will enable practices to be modified or the plan to be updated to address any observed implementation issues.

The construction of a scheme should be in accordance with:

- relevant legislation and guidelines
- relevant development consent conditions
- any environmental management plan that may have been submitted with the development application.

Jute matting prevents bank erosion – wetland reconstruction, Strathfield

Guidance of particular relevance includes Landcom (2004) for water quality management, and any council guidelines or requirements for preserving trees or other vegetation during construction. Particular attention needs to be paid to the construction of on-line storages, where flows within the drain or stream on which the storage is being built need to be diverted around the construction site (refer to Landcom 2004).

7. Operational considerations

7.1 Background

The planning and design phases of a stormwater harvesting and reuse scheme play a key role in managing risk, cost-effectiveness and sustainability. However, the operational phase is equally important in achieving the scheme's anticipated outcomes, particularly from a risk management perspective.

The operation and maintenance of stormwater harvesting and reuse schemes are similar to those of other recycled water reuse schemes and, to varying degrees, to other areas of water supply and stormwater management. Consequently, guidance on the operation and maintenance of stormwater reuse systems can draw on the available information from these other types of recycled water schemes (see DEC 2004, ARMCANZ et al. 2000, EPA Queensland 2005a, EPA Victoria 2003).

This section provides an overview of the issues to be considered in stormwater irrigation, highlighting the differences relative to effluent irrigation, and it provides references to additional relevant information.

7.2 Organisational responsibilities

Key considerations for an organisation operating a stormwater harvesting and reuse scheme

A stormwater harvesting and reuse scheme's operator should ensure that:

- the organisation is committed to the appropriate management of the scheme
- appropriately qualified staff operate the scheme
- the scheme's management is committed to refining the scheme's operations.

7.2.1 Organisational commitment

It is important that the organisation responsible for managing a stormwater harvesting and reuse scheme is committed to the appropriate operation of the scheme. This forms the foundation for all operational activities, as the organisation should be willing to commit appropriate funds and other resources to the scheme's operations.

The degree of management effort and commitment for a stormwater harvesting and reuse scheme should be commensurate with the scale of the scheme and the risks associated with the scheme's operation. For example, a large scheme with significant public exposure to treated stormwater should attract considerable management effort.

In many stormwater harvesting and reuse schemes, the scheme's operator is also the scheme's developer. This makes achieving organisational commitment relatively easy. However, different parts of the organisation may have been involved – a design department may have developed the scheme and the maintenance department may have responsibility for the scheme's day-to-day operation. Often these departments have separate management and budgets. The group responsible for operational management should become involved in the design phase to ensure that the scheme is cost-effective to operate and that a budget is provided for operations. Senior management should resolve any disagreements about responsibility and resourcing before committing to the scheme.

As stormwater harvesting schemes are often not cost-effective when compared solely with potable water costs, many schemes are funded by grants from external bodies (e.g. state and federal governments). In these circumstances, the organisation or department that would be responsible for management should also be involved in the decision to apply for the grant and the development of the project. As for internally funded schemes, agreement with the scheme's managers should be reached during the planning phase.

Stormwater harvesting and reuse schemes can also be constructed as part of a new urban or commercial development project. In these circumstances, the developer is responsible for the design and construction of the scheme, which is then transferred to a separate organisation for operation. This operator may be a council, water utility, golf course, body corporate or other organisation with the ability to resource the scheme's operations. The scheme's proposed operator should be involved in the project's development and agree to the scheme's design.

To provide a framework for the sustainable management of a scheme, the developer and operator should develop a written agreement during the project's development phase. This agreement should focus on the roles and responsibilities of both parties and ensure that all elements of the risk management framework are clearly attributed to one or both parties. Under these circumstances, the developer should prepare a scheme management plan for the scheme's operator. The preparation of such an agreement should be a condition of the development consent for the scheme – there are significant potential risks if the scheme's operator is not aware of their roles and responsibilities.

A similar arrangement on agreed roles and responsibilities should be developed in circumstances where one organisation collects, treats or distributes the stormwater for reuse by another organisation. Guidance on the content of such agreements can be obtained from EPA Queensland (2005b), EPA Victoria (2003) and ARMCANZ et al. (2000).

7.2.2 Qualified staff

This document has emphasised that there can be significant public health and environmental risks from the operation of stormwater harvesting and reuse schemes. Accordingly, it is important that only appropriately qualified staff manage and operate the scheme. Depending on the scheme, plumbers, electricians and specialist technicians may all be involved in operations. These staff should be suitably qualified and appropriately trained in relevant aspects of the scheme's operations and should follow the scheme's operational procedures.

If an organisation does not have the capacity to operate part or the entire scheme, it is important that any contractors used for scheme operations are suitably qualified and knowledgeable about the scheme's operational procedures and protocols.

The operator should also maintain details of training programs delivered, any training needs analysis undertaken and training records for employees and contractors.

7.2.3 Continuous improvement

The management team responsible for a stormwater harvesting and reuse scheme should be committed to the continuous improvement of the scheme's operations. This is likely to involve:

- reviewing monitoring results and assessing what, if any, corrective actions are required
- preparing and implementing a plan to address identified problems
- auditing the operation of the scheme to identify any areas where procedures are not being followed
- based on the audit results, reviewing procedures and/or retraining staff
- regularly reviewing the operations of the scheme to assess whether there have been any changes to public health or environmental hazards
- revising the risk assessment and altering the operations as required.

7.3 Operations

Key considerations for scheme operations

In operating a stormwater harvesting and reuse scheme:

- scheme commissioning should be carried out before starting routine operations
- catchment managers should identify and respond to incidents affecting the quality of stormwater entering a scheme
- appropriate incident response procedures should be in place
- appropriate equipment and materials should be used
- occupational health and safety procedures should be followed, including procedures related to working with recycled water
- appropriate records should be maintained.

7.3.1 Commissioning

The operation of all equipment and the scheme as a whole should be tested during the commissioning phase. After equipment testing, the scheme should operate normally for a certain period for quality assurance purposes – NSW RWCC (1993) recommends one month. During this time, the scheme would operate normally, although all treated stormwater would be diverted and not applied to its end use. More frequent monitoring should be carried out during this commissioning phase (see section 7.5) and action taken to address any identified problems.

The commissioning phase is particularly important for stormwater harvesting and reuse schemes, as this is a relatively new approach to water management and there is a degree of uncertainty associated with the performance of aspects of scheme design (e.g. disinfection).

7.3.2 Catchment management

Managing stormwater quality from a harvesting scheme's catchment is an important preventive measure for addressing health and environmental risks. Appropriate catchment management activities for a stormwater harvesting and reuse scheme include:

- auditing and educating staff in any commercial and industrial premises within the catchment, focusing on those presenting the most risk of stormwater pollution
- abating sewer overflows.

These activities should be carried out by or on behalf of the scheme's operator.

Information on catchment management for potable source water quality protection can be found in the Australian drinking water guidelines (NHMRC & NRMMC 2004a) – while this guidance is specifically for potable water supplies, aspects are relevant for stormwater harvesting and reuse, particularly for a scheme with residential uses.

7.3.3 Chemicals

Some chemicals used in stormwater harvesting and reuse schemes may adversely affect the quality of treated stormwater or the receiving environment (e.g. chlorine for disinfection). These chemicals should be evaluated for potential contamination and impact on the integrity of the scheme (e.g. their corrosion potential). All chemicals used in treatment processes should be securely stored and bunded (as appropriate) to avoid spills or leakage to waters.

7.3.4 Incident response

Incidents or emergencies that may compromise the operation of a scheme and hence present public health or environmental risks should be responded to in a considered way. By their nature, most incidents and emergencies are difficult to predict, in terms of their nature and timing, and a contingency planning approach to management is therefore required.

Types of incidents that could influence a stormwater harvesting and reuse scheme include:

- a chemical spill or sewer overflow in the catchment upstream of the scheme
- power failure
- failure of part of the treatment system (e.g. disinfection)
- electrical or mechanical equipment failure (e.g. pumps)
- vandalism or operator error
- algal blooms in storages
- flooding.

The incident response should follow established procedures and communicate the details to relevant stakeholders.

The project's risk analysis should assess the likelihood of foreseeable incidents or emergencies and their consequences. For serious incidents, it should identify responses in an incident and emergency response plan. Operational staff should receive training in following the plan and the plan should be tested regularly.

The scheme's operator should develop a communications procedure as part of such a plan. Depending on the nature of the scheme and the incident, the procedure should nominate a person to communicate information to any end-users of the treated stormwater, as well as the relevant council and health authorities. The notification would summarise the nature of the incident and the actions to be taken. Following the incident, when the scheme's operations have returned to normal, all parties initially notified should be advised.

As part of the incident response arrangements, the scheme's operator should arrange with the council and DEC to be notified of any major chemical spills within the catchment, and with the water supply authority to be notified of any sewer overflows.

In the case of spills or sewer overflows within the catchment or algal blooms in the storage, the operator should consider suspending operations of the scheme.

7.3.5 Occupational health and safety

Employers are responsible for the health and safety of employees, and the operator of a stormwater harvesting and reuse scheme must provide a safe working environment, including:

- ensuring that employees are not placed at risk through exposure to stormwater
- providing adequate training so that employees can work safely and responsibly
- providing well-documented work and emergency procedures, and ensuring that employees are trained in using them
- conducting regular educational and training programs to ensure up-to-date knowledge for employees
- providing employees with appropriate protective equipment, such as impervious gloves and footwear, protective masks, hats and clothing that will reduce their risk of exposure to the stormwater
- ensuring the effective and safe operation of all equipment
- ensuring maintenance of all equipment
- ensuring that employees develop and maintain good personal hygiene
- providing, where appropriate, medical assessments of employees.

It may also be useful for owners/operators of these systems to prepare safe work method statements to identify potential hazards, risk levels and controls to be implemented.

There are potential health risks to workers on stormwater harvesting and reuse schemes, which should be managed during operations. Appropriate actions may include:

- training for workers (staff and any contractors) on the public health risks and appropriate risk management activities
- immunisation for workers
- no consumption of treated stormwater – mains water should be provided for drinking
- installation of a washbasin using mains water at worker amenities
- no eating, drinking or smoking while working with treated stormwater until after hand washing with soap and mains water
- prompt cleaning with antiseptic and dressing of any wounds
- using appropriate personal protective equipment
- avoiding high exposure to treated stormwater – for example, minimising access to irrigation areas during irrigation.

7.3.6 Controlling access

As noted in sections 4 and 6, controlling access is an effective risk management strategy commonly adopted for recycled water schemes. For irrigation schemes, this normally involves restricting public access during irrigation and for a withholding period after irrigation until the application area is dry. The length of this period depends on the application rate, soil conditions and climate, and is commonly 1–4 hours in temperate areas. These access restrictions do not apply to operations staff (refer to previous section on occupational health and safety). Access control is usually achieved by fencing and may be complemented by scheduling irrigation to occur at night.

7.3.7 Operating irrigation schemes

The application of the correct amount of treated stormwater can be controlled through manual or automated techniques. For example, the soil moisture deficit can be simply computed using monthly average evapotranspiration and actual rainfall events. Irrigation is then applied according to the size of the deficit (see section 6). The irrigator will need to know how much water is being delivered by their irrigation system over a given area. At a more sophisticated level, soil moisture monitors can be used to determine when irrigation is needed. These can be linked to a computer system.

Both methods are likely to give false results under certain circumstances and other controls must be put in place to mitigate these. For example, regular checks of soil moisture in the topsoil should be made before an irrigation event to ensure that the soil is dry and needs irrigating, and after the event to check that watering has been adequate but not excessive.

Anemometers, used to determine wind speed and direction, may be used to predict the direction and extent of spray drift and can also trigger the irrigation system to cut out under high wind conditions. Wind-activated systems may also be used to start the irrigation when conditions become suitable. The wind speed at which the system cuts out can be determined by considering the proximity to public or sensitive areas, the wind direction, the height of sprayers and droplet size, and the type of irrigation system used.


K Walters/DEC

Irrigation controller at Greenway Park stormwater reuse scheme, Cherrybrook

7.4 Maintenance

Key considerations for scheme maintenance

In maintaining a stormwater harvesting and reuse scheme:

- the scheme should be inspected and maintained regularly
- asset management practices should be followed.

7.4.1 Inspections

Regular inspections of a scheme are needed to identify any defects or additional maintenance required. The inspections may need to include:

- storages for the presence of cyanobacteria, particularly during warmer months

- spillways and creeks downstream of any on-line storage after a major storm for any erosion
- stormwater treatment systems
- distributions systems for faults (e.g. broken pipes)
- irrigation areas for signs of erosion, under-watering, waterlogging or surface run-off.

7.4.2 Scheme maintenance

Appropriate maintenance of stormwater harvesting and reuse schemes is important to ensure that the scheme continues to meet its design objectives in the long term and does not present public health or environmental risks.

The actual maintenance requirements will depend on the nature of the scheme. Maintenance may include measures relating to each element of a scheme, as shown in table 7.1. To help ensure that the scheme is operated and maintained appropriately, a management plan (which includes operations and maintenance) should be prepared for all schemes (see section 7.5).

Guidance on maintenance can be obtained from:

- *Managing urban stormwater: treatment techniques* (DEC 2006)
- *Operations and maintenance manual for water pumping stations* (Water Directorate, 2004a)
- *Operations and maintenance manual for water supply service reservoirs* (Water Directorate, 2004b)
- *Operations and maintenance manual for water reticulation* (Water Directorate 2003a)
- *Operations and maintenance manual for chlorination installations* (Water Directorate 2003b).

Given that sediments removed from storages are likely to be highly contaminated, it is important to ensure that they are disposed of to an appropriate waste management facility.

Table 7.1 Indicative maintenance activities

Element	Actions required
Collection	• cleaning any blockages of or damage to diversion structures (e.g. weirs) • maintenance of any pumps and rising mains
Treatment	• removal of sediment and other pollutants from stormwater treatment measures • mowing and weed control for vegetated treatment systems (e.g. swales) • regular inspection and maintenance of disinfection equipment in accordance with manufacturer's instructions, including removal of any sludge
Storage	• removal of accumulated sediment • ensuring the integrity of any fences around open storages • ensuring the structural integrity of on-line storages (e.g. downstream erosion) – an inspection of storages may be appropriate after major storm events
Distribution systems	• cleaning of any screens and filters in irrigation systems • maintenance of pumps and rising mains • fixing any pipe leaks or breakages

7.4.3 Asset management


K Walters/DEC

All elements of a stormwater harvesting and reuse scheme have a nominal design or replacement life. Some elements such as concrete pipes may have a 100–150 year life, while pumps may only have a 10-year life. Appropriate asset management should be carried out for the scheme to ensure programmed replacement of elements under an associated financial plan.

Guidance on asset management can be obtained from the *International infrastructure management manual* (IPWEA, 2006).

7.5 Monitoring and reporting

Key considerations for monitoring and reporting

In monitoring and reporting on a stormwater harvesting and reuse scheme:

- water quality should be monitored during the scheme's commissioning and operational phases
- monitoring results should be reported to internal and external stakeholders
- monitoring records should be maintained for an appropriate period.

7.5.1 Monitoring

Monitoring program

Monitoring programs should be developed to ensure that public health and environmental hazards are monitored to provide sufficient data to manage the relative risk each poses. Those components that play a critical role in the scheme's risk management will require more intensive monitoring than low-risk components.

Monitoring is costly and it is therefore important to design a monitoring program that gives sound information at an affordable cost. Several guidelines and standards are available on sampling techniques (e.g. ANZECC & ARMCANZ 2000, Standards Australia 1998).

The following monitoring recommendations are a guide only and provide a basis for tailoring a monitoring program to an individual scheme. It is important that any monitoring program is site-specific and takes account of the above considerations. In particular, the frequency (how often) and intensity (number of samples) of monitoring will depend on the type and scale of the scheme, sensitivity of the site and trends identified in any previous monitoring.

In an irrigation scheme using stormwater, the key component to be monitored is the quality of the treated stormwater. Monitoring of soil characteristics is less important in such a scheme than it is in effluent irrigation because of the generally lower contaminant levels of stormwater. Where stormwater salinity levels are high, DEC (2004) provides guidance on appropriate soil monitoring.

Environmental monitoring is also not usually important for a stormwater irrigation scheme. This form of monitoring commonly assesses water quality or aquatic ecosystem health upstream and downstream of a scheme to identify any impacts the scheme may be having on water quality. As harvesting schemes commonly draw stormwater from drains or creeks any runoff from the irrigation scheme is likely to have similar or lower contaminant levels than the receiving waterway, and downstream impacts are therefore unlikely.

Monitoring of the volume of treated stormwater and any mains water used can provide useful information for optimising the operation of a scheme. This would use metering or a combination of power usage records and pump characteristics where treated stormwater is pumped within the scheme.

Commissioning stage monitoring

During the commissioning of a stormwater harvesting and reuse scheme, treated water quality should be monitored frequently and regularly. Monitoring should aim to assess the degree to which the treatment system meets the scheme's stormwater quality criteria, as part of a validation process. EPA Queensland (2005a) suggests that 20 samples be taken for validation, with sampling occurring on different days and at different times during the day. During commissioning, the treated stormwater would not normally be reused.

Operational monitoring for public health

There are currently no specific national or NSW monitoring guidelines for verifying stormwater reuse schemes to protect public health under operational conditions. National guidelines for water recycling including stormwater reuse are due in 2008, and these will include guidance on monitoring.

Until then, the most appropriate monitoring guidance available relates to the reuse of reclaimed wastewater (effluent) from sewage treatment plants, where the public health risks are probably greater than they are for treated stormwater (and are therefore conservative). Table 7.2 provides interim guidance on the frequency of stormwater quality monitoring for assessing the effectiveness of a scheme against criteria to manage public health risks in the urban environment (see table 6.4).

G Dunkerley/DEC

Stormwater quality monitoring near Wagga Wagga

The required frequency of monitoring for treated water quality should be assessed when preparing the monitoring plan. This should be a risk-based assessment, considering the likelihood of significant variability in water quality and the consequences of poor water quality. For example, a risk assessment for a small scheme irrigating a playing field with controlled public access where UV disinfection is used may result in a sampling frequency similar to that shown in table 7.1 for the scheme's first year of operation. If the scheme's performance was found to be satisfactory, a reduced monitoring frequency could be adopted. If the scheme's performance deteriorates, corrective actions should be taken and the monitoring frequency reduced until the system has re-stabilised.

As noted in section 6, the stormwater quality criteria against which monitoring results are to be compared are the median values from annual monitoring, thus half of all results could be expected to exceed this value. It is important to determine, however, whether action is needed, rather than simply waiting to see if the next results are any better. It is useful to set trigger levels above which another sample should be taken immediately. Should this sample also exceed the trigger level, operations of the scheme could be suspended until corrective action occurs and monitoring results are below trigger levels. A trigger value 50% above the adopted *E. coli* stormwater quality criteria could be adopted (EPA Queensland 2005a).

Operational monitoring for irrigation schemes

Table 7.3 suggests a basic monitoring regime for treated stormwater used for irrigation purposes, based on values for low-strength effluent (DEC 2004), in addition to monitoring for public health (above). More-frequent and/or targeted analysis should be undertaken if any of these parameters exceed recommended trigger levels. A risk-based assessment of monitoring frequency could also be carried out for irrigation water quality monitoring, as noted above.

Table 7.2 Interim guidance on treated stormwater quality monitoring for public health

Stormwater quality criteria	Monitoring frequency
Level 1[1]	*E. coli* – five days in every week turbidity – continuous pH – weekly Cl_2 – daily (for chlorine disinfection systems)
Level 2[2]	*E. coli* – weekly pH – weekly turbidity – continuous Cl_2 – daily (for chlorine disinfection systems)
Level 3[2]	*E. coli* – weekly pH – monthly Cl_2 – daily (for chlorine disinfection systems)

Notes:

1 derived from NSW RWCC (1993) and ANZECC & ARMCANZ (2000) 2 derived from DEC (2004),

7.5.2 Reporting

Monitoring results and other scheme performance information should be routinely reported to key internal and external stakeholders (e.g. the consent authority), and this would normally be annually. This would enable the operator and the consent authority to assess the ongoing performance of the scheme, in particular by comparing monitoring results to the scheme's stormwater quality criteria. The report should identify appropriate follow-up actions needed where systems are not performing adequately.

7.5.3 Record keeping

It is recommended that all monitoring results be retained for a suitable period. A number of factors can influence how long monitoring records should be retained.

The minimum storage period would be whatever is required to meet any relevant regulatory or development consent requirements and to satisfy auditing needs. This assumes that once results have been reported to the relevant regulator or provided to the external auditor, any actions that may be required will have been completed and further storage would not be necessary. The managers of the system should determine data storage for longer periods.

Other relevant considerations may be the need to track treatment system performance over time, monitor the performance of new technology, or maintain data on microbiological or chemical contaminants that may be of value for future projects.

Table 7.3 Interim guidance on treated stormwater quality monitoring for irrigation

Constituent	Monitoring frequency
Suspended solids	Quarterly
Total phosphorus	Biannually
Total nitrogen	Biannually
Conductivity/total dissolved solids	Quarterly

7.6 Scheme management plan

Key considerations for a scheme management plan

A management plan should be prepared for all stormwater harvesting and reuse projects, outlining:

- roles
- responsibilities
- procedures for the scheme's operations.

The scheme management plan should be reviewed regularly and after any major incident.

The proponent of a stormwater reuse scheme should prepare a management plan for the scheme and the site during the planning phase. The plan should highlight the roles and responsibilities of relevant parties and provide a framework for the appropriate operation of the scheme. The plan should be made available to all staff involved in the scheme's operations.

The content and extent of the management plan will vary depending on the nature and scale of the scheme, but could include the information shown in table 7.4.

Various sources provide guidance on water management planning for recycled water. This information can be modified to suit stormwater and applications other than irrigation:

- New South Wales – site management plan (DEC 2004, ARMCANZ et al. 2000)
- Queensland – recycled water management plan (EPA Queensland 2005a)
- Victoria – environment improvement plan (EPA Victoria 2003)
- South Australia – irrigation management plan (EPA SA 1999).

As part of the operator's commitment to continuous improvement, the management plan for the scheme should be reviewed regularly (e.g. every three to five years and after any major incident) and updated as required.

K Walter/DEC

Checking the stormwater irrigation system at Greenway Park, Cherrybrook

Table 7.4 Indicative contents of a scheme management plan

Section	Contents
Background information	• Statutory requirements • Relevant permits or approvals • Description and flow diagram or map of the scheme, including the location of public warning signs and all underground pipes • Treatment objectives (against which monitoring data is compared)
Roles and responsibilities	• How responsibilities are shared between treated stormwater suppliers and end users (if applicable) • Responsibilities of any third parties (e.g. councils)
Operational information	• Information on operating plant and equipment • Information on operating the irrigation scheme (if applicable), such as loading rates, access restrictions, irrigation timing • Procedures for responding to non-compliance with scheme objectives (e.g. water quality criteria) • Occupational health and safety procedures, including any associated safe work methods for operations • Qualifications of personnel involved in the scheme's operations
Maintenance information	• Inspection schedules • Maintenance requirements • Safe work methods for maintenance • Asset management procedures
Incident response/ contingency actions	• Incident response protocols • Incident communications procedures • List of key stakeholders with current contact details
Monitoring information	• Operational monitoring requirements, including sampling methods • Reporting procedures

8. Case studies

8.1 Background

8.1.1 Project profiles

A number of stormwater harvesting and reuse projects operate in NSW. A selection of these are profiled in this section. For each project, these case studies provide:

- objectives
- description
- costs
- monitoring results, where available.

Most of these projects were funded or partly funded by the NSW Government through its Stormwater Trust between 1998 and 2003. The profiles were derived from project documentation, site inspections, and interviews with project managers ('design' data), but where no information was available, estimates were made from other sources ('estimated' outcomes).

The estimated yields were based on average irrigation rates per unit or irrigated area for the irrigation projects. The pollutant load reduction estimates were based on:

- the average stormwater concentrations in table C.3 (appendix C)
- irrigation volumes
- any additional load reductions achieved by on-line storages and overflows from storages.

The 12 projects profiled in detail are:

- Barnwell Park Golf Course, Five Dock
- Sydney Smith Park, Westmead
- Bexley Municipal Golf Course, Bexley
- Black Beach foreshore park, Kiama
- Manly stormwater and reuse project, Manly
- Powells Creek Park, North Strathfield
- Hawkesbury water reuse project, Richmond
- Scope Creek, Cranebrook
- Solander Park, Erskineville
- Taronga Zoo, Mosman
- Riverside Park, Chipping Norton
- Hornsby Shire Council nursery and parks depot, Hornsby.

A further case study at the Prince Henry Development, Little Bay, is included as an example of reuse associated with a new urban development. However, as this project was incomplete at the time of publication, this profile contains less information than the others. Additional stormwater harvesting projects are described in Hatt et al. (2004).

8.1.2 Project costs

Recurrent costs have been listed for each case study where cost information was available. The total recurrent costs listed include the following:

- annual maintenance of the system
- electricity costs
- disinfection costs (where applicable)
- irregular costs (where applicable – including pump replacement, replacement of sand filter media, dredging of sedimentation ponds, etc.)
- monitoring costs.

Life-cycle costs have been calculated for all projects where cost data was available, using the simplified method described in section 5.1.4.

8.2 Comments on case studies

To provide a context for the case study summaries, the following paragraphs aim to:

- summarise the nature of the projects
- compare common characteristics
- evaluate project outcomes.

These comments apply to all of the case studies excepting Prince Henry Development, Little Bay (incomplete). Considerations for future projects are summarised in appendix A.

8.2.1 Nature of the projects

There are clear differences between the objectives of a trial or demonstration project and an operational project. The latter should have quantitative objectives established during the planning stage as part of a broader integrated urban water cycle management strategy.

Rather than aiming to achieve a specified flow or pollutant reduction target, the reuse projects profiled here were predominantly pilot projects, to promote the concept of stormwater reuse, or demonstration projects showing how a particular stormwater treatment technique could be used. None of the projects were identified as part of an integrated water cycle management strategy, in which a reuse project is part of a larger series of water management measures aiming to meet specific quantified objectives.

8.2.2 Common characteristics

While all schemes include common elements of collection, storage, treatment and distribution, they differ in their details. The type of reuse in these case studies is predominantly the irrigation of public open space and sporting fields.

Disinfection was incorporated in the treatment process in only two of the twelve profiled projects. As noted in section 6, disinfection should be considered for schemes where treated stormwater is to be used in publicly accessible areas.

Most of the projects have only limited resources allocated for on-going water quality monitoring, while in some projects there is no monitoring. The limited water quality data available for these projects indicates that faecal coliform levels for some schemes are generally higher than those suggested as criteria in table 6.4 for uncontrolled public access (using the conversion between faecal coliform and *E. coli* levels in appendix C).

None of the projects incorporate specific controls on public access during and following irrigation, although it is likely that the two golf course projects are closed to the public during irrigation.

The treatment processes for most projects used conventional stormwater treatment measures designed to achieve typical stormwater quality objectives for protecting receiving waters. Most of these systems were not designed specifically to meet stormwater quality criteria for irrigation.

The case studies note the total project capital costs provided by the project managers. Data for operating costs was not available for the projects, and so was estimated using the approach noted in section 8.1. It was therefore not possible to accurately derive the long-term cost-effectiveness of all projects.

This document highlights the importance of restricting access because of relatively low stormwater quality, designing schemes to meet specific stormwater quality criteria, and assessing both capital and operating costs.

8.2.3 Evaluation of project outcomes

The outcomes from these case studies are summarised below for the following parameters:

- unit cost of treated stormwater
- water quality benefit unit costs
- total project costs
- storage volumes.

There are limitations with using unit cost approaches as these allocate all project costs to either the volume of treated water used, or the pollutant reduction achieved. This can overlook the multiple benefits achieved by the projects. However this approach is commonly used in the water industry, particularly for comparing alternative water supply schemes (potable or recycled).

An alternative approach would compare the costs of another project or combination of projects that achieve the same outcomes as the case studies, rather than evaluating the case study’s costs against a single objective.

Further, the project costs given for the case studies may not represent the cost of designing similar projects today. This is because the case studies were developed before the guidance in this document was available, and accordingly, some costs would be higher, and others lower.

Cost of treated water

The levelised unit costs are summarised in figure 8.1 for all projects except the Hawkesbury water reuse project and Prince Henry Development (Little Bay), for which no cost data was available. Unit costs are presented for water savings and total phosphorus reductions (as an indicator of pollutant removal). No total phosphorus (TP) data was available for the Taronga Zoo and Hornsby nursery schemes. These costs were calculated using the approach described in section 5.1.4.

The levelised cost relates to the reuse water volume and the total phosphorus loads individually. As noted in section 5, the levelised cost indicator cannot readily attribute costs to multiple objectives or evaluation parameters. Therefore the data indicates

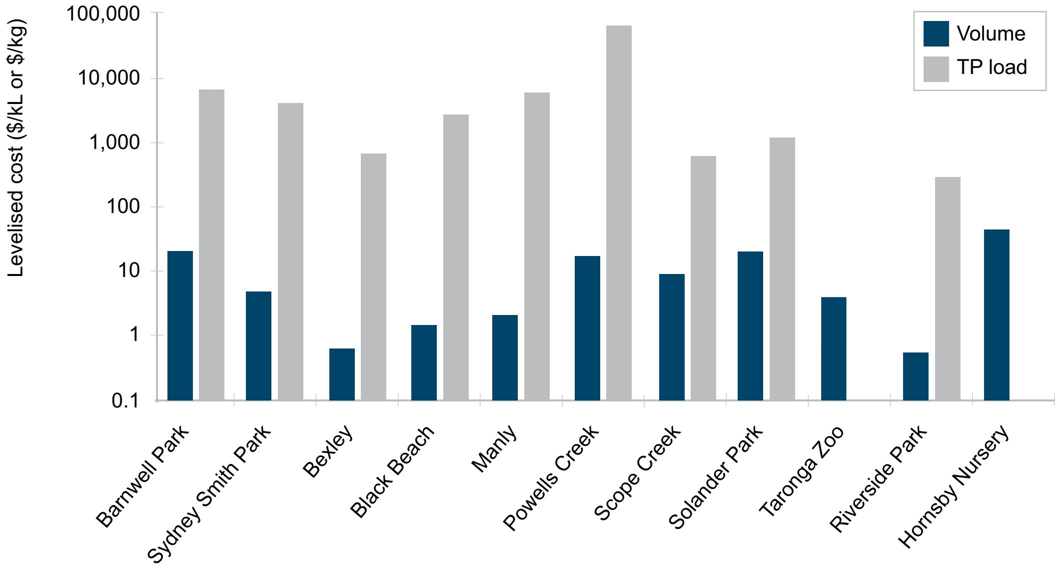


Figure 8.1 **Levelised unit costs for case studies**

relative, rather than absolute, differences in cost-effectiveness between projects.

The broad range of values between the case studies reflects the diversity of project scales and design criteria. The average levelised cost of treated stormwater in the projects was $10.80/kL, ranging from $0.52 to $42.00/kL. This average value is higher than the mains water prices in the Sydney Greater Metropolitan Area in 2005–06 (see table 8.1). However, this figure does not account for the additional water quality benefits from the projects, highlighting a limitation of the levelised cost approach.

Water quality benefits

The estimated average cost of total phosphorus removal from these case studies was $9000/kg/year, ranging from $300 to $63,000/kg/year.

Comparing these stormwater pollution trapping costs against a benchmark is more difficult than comparing water costs, as unit costs from conventional stormwater treatment measures are not readily available and are likely to be relatively variable. The following unit costs were derived from the cost data for pollutant retention, capital and operations for a hypothetical constructed wetland in Sydney, using data from Fletcher et al. (2004):

- suspended solids: $2/kg
- total phosphorus: $2000/kg
- total nitrogen: $500/kg.

The average levelised costs for the case studies in figure 8.1 are higher than those for

Table 8.1 **Unit prices for mains water in the Sydney, Central Coast and Newcastle areas, 2005–06**

Water authority	Price ($/kL)	Notes
Sydney Water	1.20 (Tier 1) 1.48 (Tier 2)	Tier 1 consumption is up to 1.096 kL per day
Hunter Water	1.09 (Tier 1) 1.03 (Tier 2)	Tier 1 consumption is up to 2.74 kL per day
Gosford/Wyong Councils	0.925	

Source: IPART determinations

the wetland. This higher cost is expected, as most of these projects included conventional stormwater treatment measures, as well as additional reuse-related items.

Again, just as the cost of treated stormwater does not account for the benefits of pollutant removal, the cost of pollutant removal does not account for the benefits of water reuse.

Total project costs

Figure 8.2 indicates the capital costs against reuse volumes for these projects. While there is considerable variability in costs ($R^2 = 0.37$), the capital cost for most small projects (less than 10 ML/year) is around $500,000, with larger projects having a lower unit cost. Initial project establishment costs for treatment, collection and storage apply for smaller projects generating small reuse volumes. These costs increase more slowly with higher reuse volumes – there is an economy of scale for larger projects. Kellogg Brown & Root (2004) report a similar trend for stormwater harvesting schemes in Adelaide. Although data is limited, economies of scale are also likely for operating and maintenance costs.

Cost-effectiveness

It is apparent that the cost-effectiveness of some projects is relatively low, as described by their levelised costs (while acknowledging the limitations of this approach). The stormwater treatment costs significantly affect the cost of these projects. Project cost-effectiveness will be enhanced by following the steps in section 6.4 when designing treatment arrangements. This involves adopting targeted stormwater quality criteria and designing the treatment system to meet these.

Storage volumes

Figure 8.3 indicates the unit storage volumes (kL/ha) for the sites. The volumes are highly variable, ranging from 0.2 to 344 kL/ha, averaging 86 kL/ha. The highest volumes were

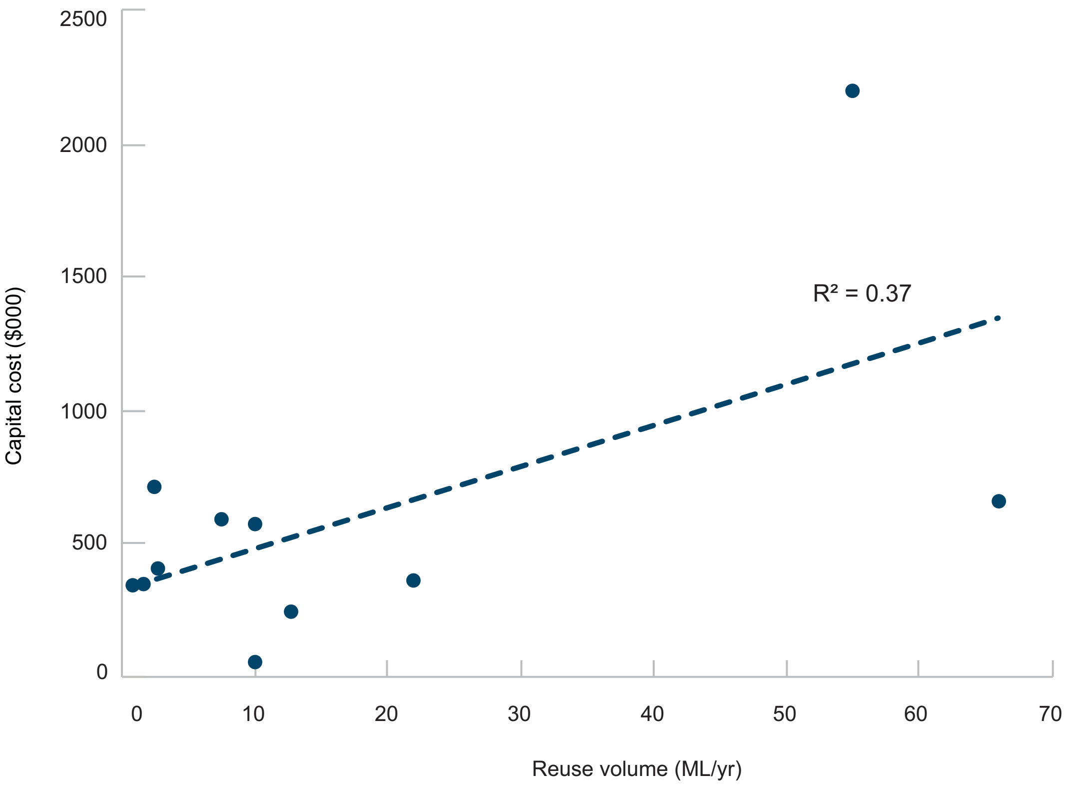


Figure 8.2 **Project costs for case studies**

at Chipping Norton (where the reuse scheme was an addition to an existing wetland scheme) and at the Hornsby Shire nursery.

The proportion of average annual catchment runoff volumes reused in these case studies is illustrated in Figure 8.4. The percentage utilisation is highly variable, ranging from 1% to 83% (average 27%). The highest utilisation was at Manly, Powells Creek and Richmond (which has large storage volumes).

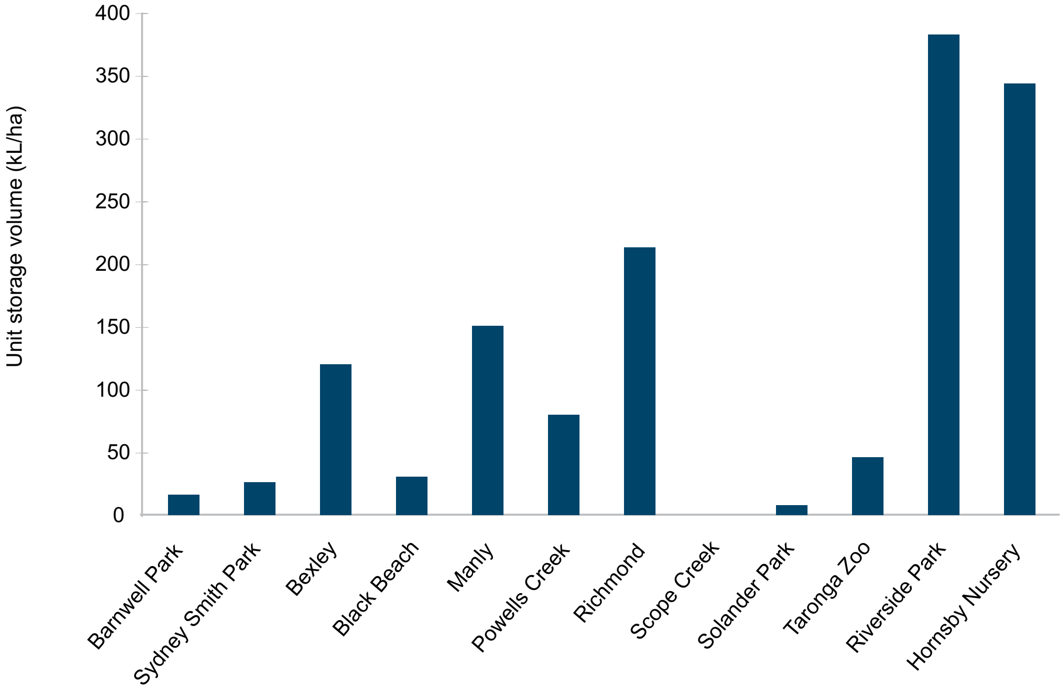


Figure 8.3 **Unit storage volumes for case studies**

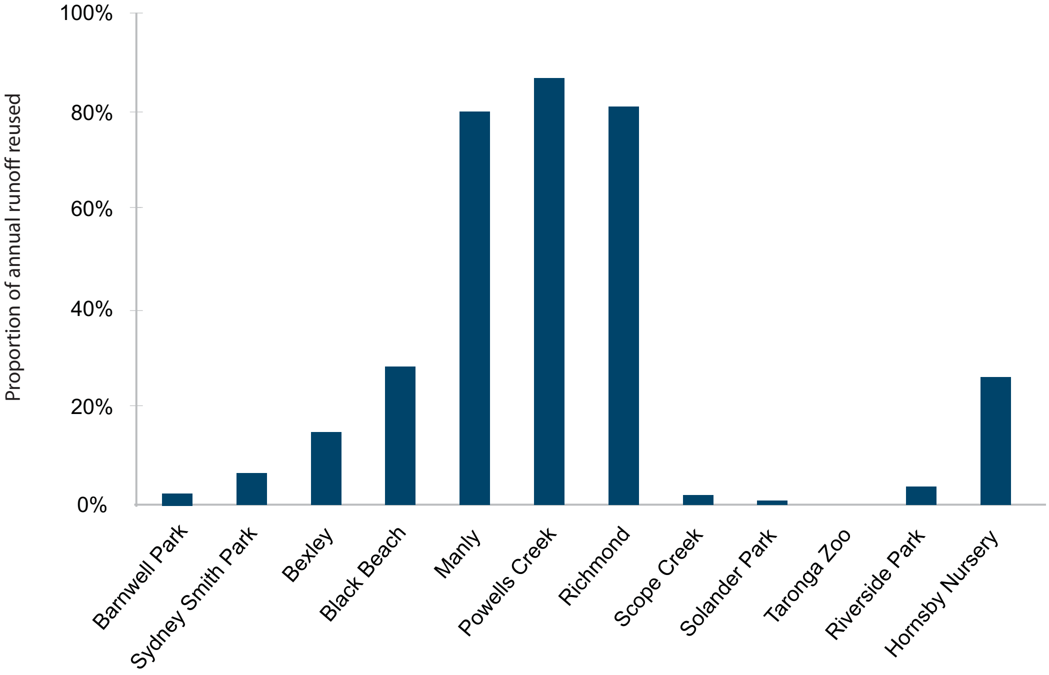


Figure 8.4 **Run-off volume use for case studies**

This variability in the storage and annual run-off volumes highlights the need to model water balances at the planning and design stages, as these volumes depend heavily on catchment characteristics and the demand for treated stormwater.

8.3 Considerations for future projects

Based on this review of case studies, future projects should take the following issues into account, particularly to optimise scheme cost-effectiveness. These considerations have been highlighted in sections 5 to 7 of this document and are grouped here under:

- objectives
- risk management
- operations and maintenance.

8.3.1 Objectives

- Identify the catchment objectives for the scheme (e.g. water quality, demand management and stream flow). Also ensure there is a link between the objectives of not only the project, but also an applicable integrated urban water cycle management plan/strategy and the greater strategic goals of the organisation
- Develop quantified water management objectives for the project for:
  - annual volumes of stormwater reused
  - loads of stormwater pollutants reduced
  - percentage reductions in streamflows.
- Determine related end-use objectives relating to volume and water quality requirements and reliability of supply.

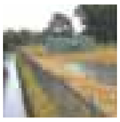
8.3.2 Risk management

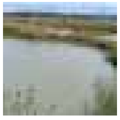
- Identify and manage public health and environmental risks
- Ensure that the level of stormwater treatment meets public health and environmental objectives and any additional specific end-use needs.

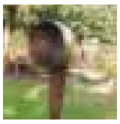
8.3.3 Operations

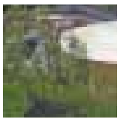
- Assess pollutant sources from within the catchment during the planning stage and manage catchment pollution during the operational phase
- Undertake appropriate maintenance of the scheme
- Undertake water quality monitoring to assess compliance against the stormwater treatment objectives
- Monitor the volumes of treated stormwater reused, to assist with project evaluation and guide development of future projects.
- Communicate with internal and external stakeholders, including reporting of monitoring results.

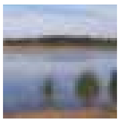
8.4 Case studies

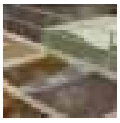


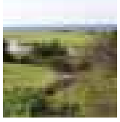












Barnwell Park Golf Course, Five Dock

Brief description

Stormwater is diverted from a stormwater pipe, treated, stored off-line and irrigated onto a golf course, partially replacing mains water.

Project objectives

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

Project manager

City of Canada Bay Council

Completion date

2004

Catchment and site characteristics

The 7 ha catchment upstream of the golf course incorporates residential and industrial land uses in the suburb of Five Dock. Stormwater from this catchment is conveyed to the golf course by a stormwater pipe.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Barnwell Park Golf Course – stormwater channel, retention basins and storage tanks

Project description

A diversion weir was constructed in a pit on a stormwater pipe, diverting low flows into the reuse scheme. Stormwater flows through a gross pollutant trap and into a 1 ML above-ground sand filter basin. Stormwater filters through the sand media under the basin and is collected by under-drains flowing to a monitoring pit. The treated stormwater is pumped from the pit into four above-ground tanks with a total capacity of 100 kL. Overflows were constructed in the sand filter basin and the monitoring pit to an adjacent concrete-lined stormwater channel.

The treated stormwater is pumped into a piped irrigation network to spray-irrigate two fairways, each of 0.25 ha. The annual reliability of supply was estimated to be 81% with mains water used as a supplementary supply.

During the design phase, the option of irrigating three fairways (0.75 ha) was considered, although the reliability of supply for this larger area was found to be 44%. It was considered better to have a system with high reliability of supply for the smaller two-fairway irrigation area. Additional storage could be provided in the future to serve a larger area.

Project costs

Total capital cost	$337,530
Recurrent cost	$27,000
Life-cycle cost	$572,000

Project outcomes

- Design annual stormwater reuse volume of 1.5 ML, saving $2200.
- Estimated annual stormwater pollution loads to Hen and Chicken Bay reduced by 4000 kg for suspended solids, 5 kg for total phosphorus and 20 kg for total nitrogen.

Monitoring results

	Location	
Parameter	**Storage tank inflow**	**Storage tank outflow**
Faecal coliforms (cfu/100 mL)	< 10	< 10
Suspended solids (mg/L)	88	3
Total phosphorus (mg/L)	2.16	0.12
Total nitrogen (mg/L)	5.4	3.2
Oil and grease (mg/L)	Negligible	Negligible
Copper (μg/L)		36
Lead (μg /L)		21
Zinc (μg /L)		110

Sampled 13 September 2004

Sydney Smith Park, Westmead

Brief description

Stormwater is diverted from a stormwater pipe, treated, stored off-line and irrigated on playing fields, partially replacing mains water.

Project objectives

- Protect 30 downstream properties from flooding
- Reduce pollution loads to Domain Creek and Parramatta River
- Irrigate the soccer/cricket fields on Sydney Smith Park with treated stormwater, partially replacing mains water use.

Project manager

Holroyd City Council

Completion date

1999

Catchment and site characteristics

The catchment area to Sydney Smith Park is 26 ha of residential land use in Holroyd. The park covers an area of approximately 2 ha.

Project description

This project incorporated different collection and treatment arrangements for low and high stormwater flows.

A diversion pit was constructed on the pipe beneath Sydney Smith Park. Low flows are diverted to two underground gross pollutant traps for initial treatment. A proportion of this treated stormwater then flows to an underground rapid sand filter for further treatment. The outflows from the sand filter are stored in a 600 kL underground concrete storage tank.

A drainage pipe beneath the park downstream of the diversion pit was removed. Any flows greater than the capacity of the low flow diversion pipeline then flow into the park. The park was excavated to provide temporary storage for floodwaters and an embankment constructed at the downstream end of the park.


Holroyd City Council

Sand filter under construction (showing sedimentation and filtration chambers)

Temporary storage is provided in the park for both major flows for flood mitigation and smaller flows for stormwater treatment. The scheme provided extended detention (temporary) storage for storms up to the 2-year ARI event, with the detained water released over 6 hours. A proportion of the stormwater infiltrates through a filtration media (sand) in the base of the playing fields. This drainage is collected by subsoil drains and conveyed to the underground storage tank.

The existing automatic sprinkler irrigation system was replaced and the playing fields regraded and turfed. Treated stormwater is pumped from the underground tank to the irrigation system to irrigate an area of 1.5 ha. A 25 kL above-ground storage tank was also constructed for mains water back-up to the irrigation supply. The underground storage tank can be drained by a pump which discharges to the stormwater system downstream of the park.

Project costs

Capital cost	$731,827 (excluding flood mitigation cost of $400,000)
Recurrent cost	$45,000
Life-cycle cost	$1,115,000

Project outcomes

- Protection of 30 properties from flooding in a 100-year ARI storm event.
- Estimated annual stormwater reuse volume of 12 ML, saving $17,760.
- Estimated annual stormwater pollution loads to local watercourses reduced by 12,000 kg for suspended solids, 15 kg for total phosphorus and 70 kg for total nitrogen. Design removal of approximately 30 tonnes of gross pollutants annually.

Monitoring results

No monitoring of irrigation water quality has been undertaken.

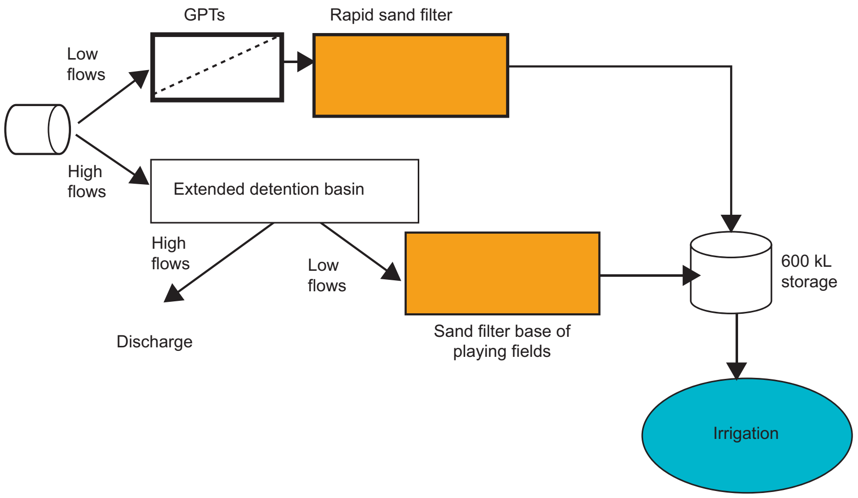


Figure A1 **Schematic diagram showing Sydney Smith Park stormwater reuse scheme**

Bexley Municipal Golf Course, Bexley

Brief description

Stormwater is collected in an on-line weir, with some stormwater pumped to an off-line storage. The stormwater is irrigated on a golf course, replacing mains water use.

Project objectives

- Reduce the 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.

Project manager

Rockdale City Council

Completion date

2001

Catchment and site characteristics

The contributing catchment area comprises 77 ha of urban land use and 5 ha of golf course. Stormwater from this catchment flows through the 20-ha golf course in a concrete-lined channel. The irrigated area on the golf course is 12.6 ha, with an area of only 1.35 ha requiring intensive irrigation and the balance consisting of fairways requiring supplemental irrigation.

Project description

This project was implemented in two stages:

- constructing the system for stormwater collection, storage and treatment
- installing the irrigation system.

Collection, storage and treatment

A weir was built on the stormwater channel with excavation upstream to create an initial storage capacity of 5.3 ML. The storage was dredged in 2005 to clean out accumulated


Z Fink/DEC

Weir at Bexley Golf Course (note spray from aerator) sediment, increase the capacity to 7 ML and increase the yield from the scheme. It is expected that the dam will need to be dredged every 10 years.

A supplementary turkey's-nest dam storage was constructed on a high point on the golf course. This 1.4 ML storage increased the project's storage volume as there was insufficient space available along the concrete channel for a larger storage to deliver a reasonable yield. A two-way-flow pipe connects the two storages, allowing top-up water to be pumped from the weir storage to the turkey's-nest dam and for water from the dam to flow back to the weir storage for irrigation.

Stormwater treatment occurs through a trash rack constructed in the concrete inlet channel upstream of the weir. Further treatment occurs through sedimentation and mechanical aeration in the storage. The storage also reduces faecal coliform levels, primarily through UV light. The irrigation system includes self-cleaning irrigation disc filters.

Installing the irrigation system

Treated stormwater is pumped from the weir storage to a piped spray irrigation system by gravity from the turkey's-nest dam. The system provides a high level of irrigation to 1.4 ha of tees and greens and a lower level of irrigation to 11 ha of fairways. Mains water is available as a back-up supply.

Project costs

Capital cost	$594,197
Recurrent cost	$18,000
Life-cycle cost	$728,000

Project outcomes

- Design annual stormwater reuse volume of 66 ML, saving $97,680 and improving the visual amenity of the golf course
- Estimated annual stormwater pollution loads to Cooks River reduced by 46,000 kg for suspended solids, 60 kg for total phosphorus and 240 kg for total nitrogen. Design reduction of annual gross pollutant load of 100 tonnes.

Monitoring results

Main storage

Parameter	**Results**
E. coli (cfu/100 mL)	90
Total phosphorus (mg/L)	0.1
Boron (mg/L)	<0.1
Chloride (mg/L)	44
Iron (mg/L)	0.7
Sodium (mg/L)	26
Conductivity (dS/m)	0.28
pH	7.1

**E. coli* sample taken on 7 November 2005. Other results from a grab sample in March 2004

Black Beach Foreshore Park, Kiama

Brief description

Stormwater is collected, treated and pumped to an off-line storage and irrigated on two parks, reducing mains water demand.

Project objectives

- Reduce stormwater pollution to Kiama Harbour
- Irrigate two parks to reduce mains water consumption.

Project manager

Kiama City Council

Completion date

2004

Catchment and site characteristics

The catchment to the project site is 6.5 ha, comprising a mixture of residential, commercial and open space. The treatment and reuse scheme is located in Hindmarsh Park, adjacent to Black Beach and Kiama Harbour.

Project description

The project was developed progressively in three stages.

- installing gross pollutant traps
- constructing the primary treatment system
- completing the reuse system.

Installing gross pollutant traps

The first stage involved installing gross pollutant traps in numerous drainage pits within the catchment, particularly focusing on the Kiama business district.

Constructing the primary treatment system

The project's second stage involved constructing a diversion pit on an existing drain and diverting low flows to a sand filter. Flows enter the sand filter through permeable concrete 'Hydrocon' 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 sand filter are surcharged into a shallow basin constructed above the sand filter, and from there they infiltrate through the floor of the basin into the sand filter. Treated stormwater flows back to the main drainage system.


wsud.org

Kiama City Council

Black Beach Foreshore Park showing sand filter and park redevelopment (left) and surcharging during wet weather (right)

Completing the reuse system

Following monitoring of the effectiveness of the sand filter, council proceeded with the reuse system. Treated stormwater low flows from the sand filter are diverted to a holding tank with high flows continuing to the stormwater system. Stormwater is pumped from the holding tank into a 45 kL underground storage tank. Stormwater is then pumped from the tank through a UV disinfection unit into the irrigation network. The scheme irrigates 2 ha of the Black Beach foreshore and Hindmarsh Park. Mains water is used as a back-up supply.

Project costs

Capital cost	$174,900
Recurrent cost	$17,000
Life-cycle cost	$322,000

Project outcomes

- Estimated annual stormwater reuse volume of 12 ML/year
- Estimated annual stormwater pollution loads have been reduced by 5000 kg for suspended solids, 7 kg for total phosphorus and 40 kg for total nitrogen.

Monitoring results

Sand filter*

Pollutant	Upstream	Downstream
Thermotolerant coliforms (cfu/100 mL)	6000	4
Total suspended solids (mg/L)	28	17
Total phosphorus (mg/L)	0.13	0.042
Total nitrogen (mg/L)	1.1	1.2
Iron (mg/L)	0.71	0.26

*Grab sample taken in wet weather, November 2003

Manly stormwater treatment and reuse project

Brief description

Collection of stormwater using permeable pavement, underground storage and irrigation of a previously non-irrigated park.

Project objectives

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

Project manager

Manly Council

Completion date

2001

Catchment and site characteristics

The catchment for the Manly stormwater treatment and reuse (STAR) project comprised 2.6 ha of road and carpark. The site is adjacent to Manly Beach.

Project description

A 500-metre length of concrete dish drain on the eastern side of North Steyne was replaced with 'Atlantis Eco Pavers'. These permeable pavers receive run-off from the road surface and the adjacent car park. Stormwater infiltrates through the pavers into an amended soil media beneath the pavers. The treated stormwater is collected by a plastic channel at the base of the media and piped to a 390 kL geo-cell underground storage. Water levels in the tank are influenced by groundwater interactions.

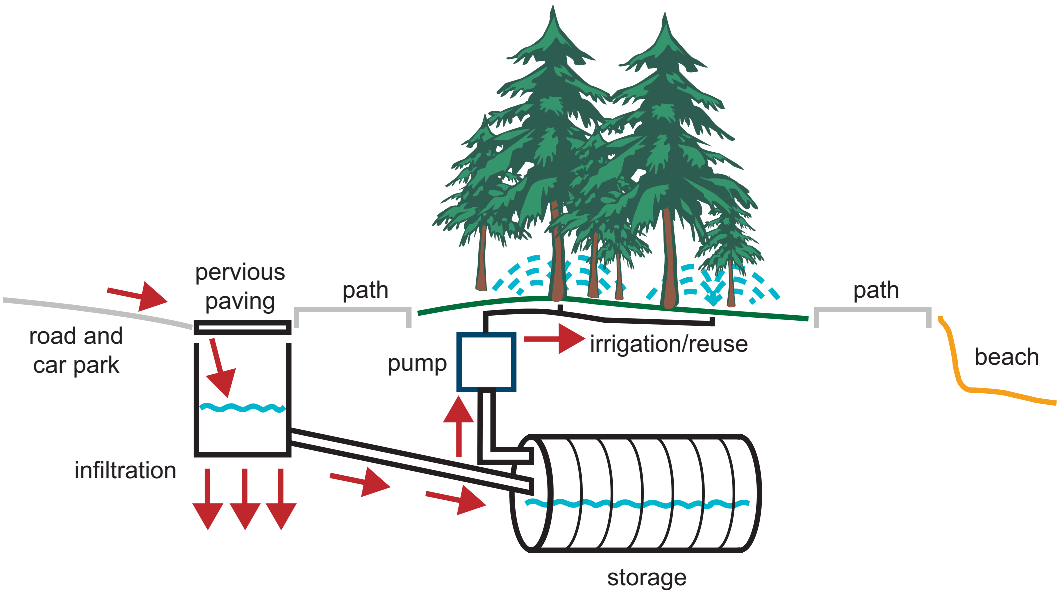
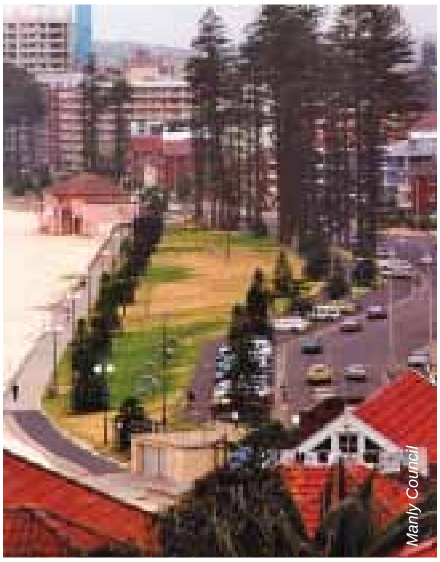


Figure A2 **Infiltration and treatment system at Manly Beach**

Treated stormwater and supplementary groundwater is pumped from the storage and spray irrigated on approximately 4 ha of foreshore lawns and heritage-listed Norfolk Island pines. Mains water is available as a supplementary supply when water restrictions do not apply. Council water tankers can also fill from the storage tank for cleaning and watering.

Project costs

Capital cost	$359,780
Recurrent cost	$39,000
Life-cycle cost	$698,000


Manly Council

Manly Beach foreshore lawn and Norfolk Island pines

Project outcomes

- Estimated annual stormwater reuse volume of 19 ML, saving $28,120.
- Estimated annual stormwater pollution loads reduced by 4000 kg for suspended solids, 6 kg for total phosphorus and 50 kg for total nitrogen.

Monitoring results

	Result	
Parameter	**Minimum**	**Maximum**
Faecal coliforms (cfu/100 mL)	90	870
Total phosphorus (mg/L)	0.02	0.36
Total nitrogen (mg/L)	0.3	1.32
Copper (µg/L)	0.01	0.21
Lead (µg /L)	0.02	0.19
Zinc (µg /L)	0.05	0.32
Turbidity (NTU)	0.9	23

Sampled weekly from storage tank between June 2005 and February 2006

Powells Creek Reserve, North Strathfield

Brief description

Collection of stormwater using pervious road gutters, stormwater treatment and irrigation on a previously non-irrigated park.

Project objectives

- Reduce the level of stormwater pollution entering Homebush Bay, particularly protecting 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 run-off.

Project manager

City of Canada Bay Council (formerly Concord Council)

Completion date

1999

Catchment and site characteristics

The main project site is a series of five short streets in North Strathfield on the eastern side of Powells Creek. The catchment area for each street is approximately 1300 m^2 and the land use is residential. The creek at the discharge points from these streets is a tidal concrete-lined trapezoidal channel. Powells Creek Reserve is located to the north of the five streets.

Project description

The gutters along both sides of a 40- to 50-metre length of the five streets were removed and replaced with porous plastic 'Atlantis geo-blocks'. The geo-blocks were filled with biologically engineered soil (soil with added organic matter and minerals) then grassed. Stormwater infiltrates through the geo-blocks and through a biologically engineered filter media within plastic block channels. For three of the streets, the stormwater is stored

Z Fink / DEC

Irrigation storage tank, Powells Creek Park in three 17 kL plastic cell storage (retention) tanks. Overflows from the tanks are piped to the stormwater system, which then flows to Powells Creek and some of the treated stormwater recharges groundwater. Treated stormwater from the other two streets flows directly to the stormwater system and is not stored for reuse.

Treated stormwater from the three retention tanks is piped to a 50 kL concrete irrigation header tank in Powells Creek Park. The storage tank incorporates top-up water from the mains supply. The irrigation water is then pumped from the tank into a spray irrigation system in the park, which irrigates a grassed area of 2200 m^2.

Project costs

Capital cost	$379,183
Recurrent cost	$30,000
Life-cycle cost	$636,000

Project outcomes

- Estimated annual stormwater reuse volume of 2 ML.
- Estimated annual stormwater pollution loads reduced by 300 kg for suspended solids, 0.5 kg for total phosphorus and 4 kg for total nitrogen.

Pervious gutters, North Strathfield (note loss of grass cover in cells)

Monitoring results

	Location	
Parameter	**Upstream of cells**	**Retention tank**
Faecal coliforms (cfu/100 mL)	(not monitored)	94 (range 1–400)
Suspended solids (mg/L)	291	50
Turbidity (NTU)	449	42
Total phosphorus (mg/L)	0.26	0.06
Total nitrogen (mg/L)	2.0	1.5
Conductivity (mS/m)	24.3	61.9
pH	7.8	9.1

Mean of ten storm events between March and August, 1999

Hawkesbury water reuse project

Brief description

The Hawkesbury water reuse project (HWRP) involves the treatment, storage and reuse of stormwater. It is part of the Hawkesbury water recycling scheme (HWRS), which also includes effluent reuse.

Project objectives

The project manages stormwater in a total catchment context, involving both structural and non-structural strategies, as below:

- develop, trial and implement structural and non-structural control strategies for controlling source pollution affecting Rickaby's Creek (a Hawkesbury River tributary)
- develop infrastructure to integrate stormwater and effluent reuse
- 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.

Project manager

Hawkesbury City Council, with the University of Western Sydney

Completion date

2000

Catchment and site characteristics

There are two main catchments for this project:

- the township of Richmond, consisting of residential and golf course areas – 285 ha
- the University of Western Sydney rural agricultural catchment area – 130 ha.

Project description

The HWRP utilises both treated effluent and treated stormwater to supply a number of irrigation users, including the Richmond Campus of the University of Western Sydney, Richmond TAFE, and a variety of other stakeholders. The project ultimately seeks to establish sustainable use of water within the peri-urban land area of the Richmond township. The project is long-term, implemented in a number of stages.

Stormwater wetlands, Richmond

Approximately 45% of the stormwater from the Richmond township and university grounds flows into a 60 ML detention basin constructed below ground level to minimise flood risk. Retained stormwater is pumped from the basin to a series of four one-hectare constructed wetlands where further treatment occurs.

Detention times in the wetlands were predicted to be seven days, but when water is at a minimum depth this can be as low as two days. As a result, detention times within the wetlands vary according to the volume of residual water and operating depth.

Water from the wetlands is transferred at a rate of 3.4 ML per day to a 24 ML settling pond, where remaining fine sediments settle out of the treated stormwater, and is stored in a 90 ML turkey's-nest dam. From here, treated stormwater is pumped to dams located on University and TAFE grounds for irrigation purposes. Excess treated stormwater is discharged to Rickaby's Creek to contribute to environmental flows.

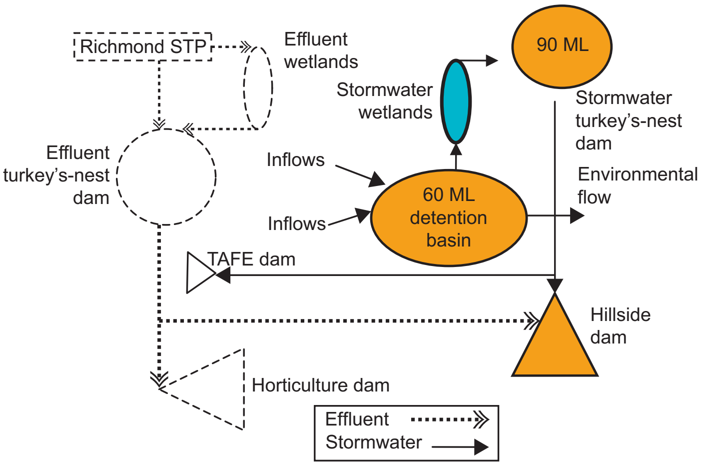


Figure A3 **Richmond model township stormwater reuse schematic**

Project costs

Not available

Project outcomes

At present the amount of mains water saved has not been calculated for the HWRS in its entirety. However, within the university, horticulture production is currently reusing a minimum of 25 ML and potentially 40–50 ML annually. These volumes directly offset mains water use, with potential savings of up to $74,000.

Estimated annual stormwater pollution loads have been reduced by 30,000 kg for suspended solids, 60 kg for total phosphorus and 500 kg for total nitrogen.

Monitoring results

Constructed wetland

Parameter	Wetland inflow	Wetland outflows
Faecal coliforms (cfu/100 mL)	94	90
Enterococci (cfu/100 mL)	117	85
Suspended solids (mg/L)	14.1	77
Turbidity (NTU)	32	324
Total phosphorus (mg/L)	3.4	1.5
Total nitrogen (mg/L)	3.5	4.5
Conductivity (μS/cm)	516	572
pH	7.6	8.0

Mean results from fortnightly monitoring between November 2003 and August 2005

Scope Creek, Cranebrook

Brief description

Collection of stormwater low flows, treatment and initial irrigation of a woodlot.

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.

Project manager

Penrith City Council

Completion date

1999

Catchment and site characteristics

Scope Creek upstream of the project site has a catchment area of some 220 ha.
The drainage system constructed in the early 1980s at the project site consists of dry detention basins with low-flow pipes. The site is located at the junction of two creeks – one draining a predominantly rural residential catchment, and the other draining an urban residential catchment. The downstream creek discharges to the Sydney International Regatta Centre.

Project description

The scheme was designed to target low flows from the catchment. A GPT comprising a trash rack and sediment basin was constructed at the inlet to the site (immediately downstream of the three stormwater pipes leading to the site). A diversion pit was constructed on the low-flow pipe beneath the grass-lined stormwater channel downstream of the GPT to divert a proportion of the low flows into the stormwater harvesting scheme. Flows were treated by an underground oil and grit (sediment) separator.

Treated stormwater from the separator flows to a pumping station with a wet-well volume of 4 kL. The stormwater is pumped into two underground concrete storage tanks with a combined volume of 44 kL. When the storages are full, a bypass pipe directs outflows from the separator to the main low-flow pipe. When originally constructed, the treated stormwater was pumped to a 1 ha (1500-tree) woodlot constructed on adjacent land, where it was distributed by sub-surface drip irrigation to assist with establishment of the newly planted trees. The trees are now fully established and no longer irrigated. Treated stormwater from the oil and grit separator now flows back to the low-flow pipe.

The project also involved significant earthworks to reshape the site to form the woodlot, as well as channel and pipeline construction.

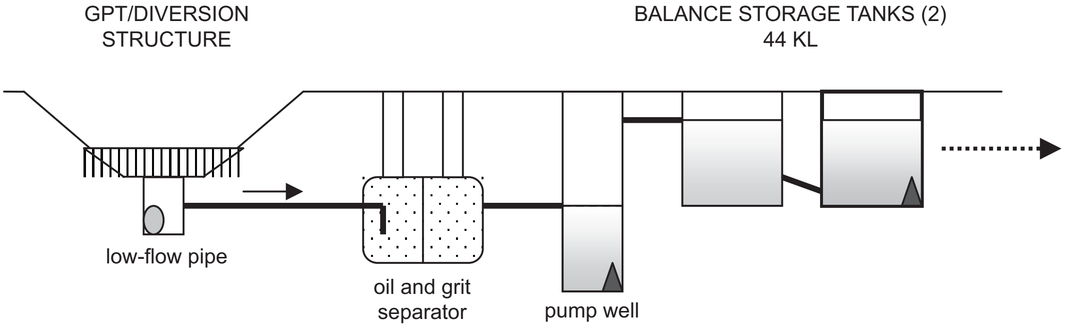


Figure A4 **Scope Creek treatment train**

Project costs

Capital cost	$562,452
Recurrent cost	$44,000
Life-cycle cost	$950,000

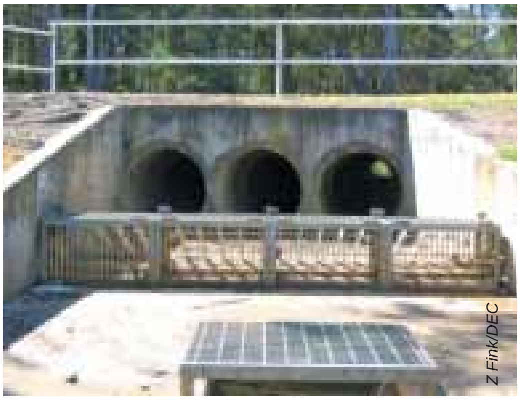
Project outcomes

- Irrigation of a woodlot during its establishment phase without the use of mains water, reusing approximately 6 ML/year of treated stormwater
- Estimated annual stormwater pollution loads to Penrith Lakes Scheme have been reduced by 80,000 kg for suspended solids, 90 kg for total phosphorus and 260 kg for total nitrogen.

Monitoring results

No water quality monitoring has been undertaken.

Scope Creek irrigated woodlot – trees fully established (note drainage channel on centre-right of photo)



Gross pollutant trap on pipes upstream of the scheme

Solander Park, Erskineville

Brief description

Collection of stormwater from an underground pipe system, treatment, and then irrigation onto a park previously irrigated by mains water.

Project objectives

- Reduce the stormwater pollution loads entering Alexandra Canal
- Reduce flooding in nearby residential areas
- Irrigate Solander Park without using mains water by using treated stormwater
- Provide an educational opportunity for the community to learn about:
  - their impacts on water quality
  - stormwater treatment technologies.

Project manager

City of Sydney Council (formerly South Sydney City Council)

Completion date

2001

Catchment and site characteristics

The catchment area to the 0.4-ha park is 65 ha comprising predominantly residential land uses, with some commercial land and a large proportion of railway land. Houses surrounding the park tended to be flooded regularly because of an overland flood route through Solander Park.

Project description

Stormwater from the upstream catchment enters a GPT designed to treat all flows up to the 6-month ARI event. The GPT traps street litter, vegetation and coarse sediments. The treated stormwater is diverted to a 12 kL underground holding tank, then undergoes further treatment by electrolysis in two 1000-litre 'Electropure' units. This removes sediment fines, organics and any heavy metals not already removed by the GPT.

The treated stormwater is directed to a 225 kL storage tank and then pumped through the park's irrigation system to irrigate 0.4 ha. The storage tank also receives surface drainage

Solander Park above the GPT (including sound sculptures) from the park, which is then treated by a sand filtration system located beneath the low point of the park. All system components are below ground. The system originally included a top-up system from mains water, however this has been disconnected due to water restrictions on irrigation.

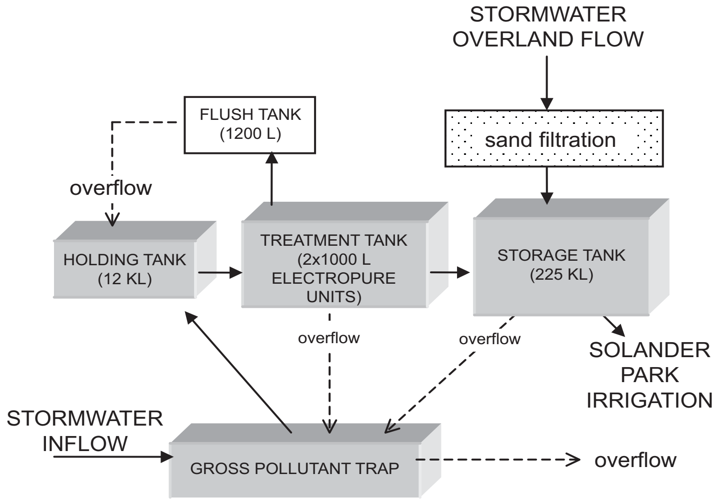


Figure A5 Solander Park treatment and storage arrangements

The project incorporates interpretive art components. This includes a sound sculpture that resonates the water sounds from within the GPT through two brass horns. There are also storyboards with designs on the access lids that depict the water movement underground.

The system is quite complex, which presents an operational and maintenance challenge to council.

Project costs

Capital cost	$544,798
Recurrent cost	$46,000
Life-cycle cost	$946,000

Project outcomes

- Estimated annual stormwater reuse volume of 2.7 ML, saving $4000 and supplying up to 90% of the irrigation demand.
- Estimated annual stormwater pollution loads to Alexandra Canal have been reduced by 40,000 kg for suspended solids, 45 kg for total phosphorus and 190 kg for total nitrogen. Design retention of 20 tonnes of gross pollutants annually.

Monitoring results

Irrigation storage tank

Parameter	Concentration
Faecal coliforms (cfu/100 mL)	343 (4,800 max)
Suspended solids (mg/L)	13
Total dissolved solids (mg/L)	517
pH	7.6
Total phosphorus (mg/L)	0.11
Total nitrogen (mg/L)	1.0

Mean of monthly monitoring from May 2003 to May 2004

Taronga Zoo, Mosman

Brief description

The project collects stormwater from the zoo, provides advanced treatment, and reuses the stormwater for irrigation, washdown and toilet flushing.

Project objectives

- Reduce stormwater pollution loads to Sydney Harbour (prompted by water quality monitoring between 1988 and 1992 indicating high faecal coliform levels at beaches near the zoo)
- Reduce the demand for mains water
- Demonstrate advanced stormwater treatment methods.

Project manager

Zoological Parks Board

Completion date

1996

Catchment and site characteristics

The catchment consists of 38 ha of mixed land use including animal enclosures, moats and tourist facilities. There is a high gross pollutant and organic nutrient load.

Project description

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 installed upstream of the zoo's treatment plant provides first flush collection of up to 1200 kL/day of stormwater from the site. From here, a chamber for screen and grit removal filters roadway and exhibit solids (animal droppings) from the stormwater stream. This primary treated stormwater then flows to an aeration channel and through a biological treatment plant to remove nitrogen and phosphorus.

From here, the stormwater flows to a buffer tank and feeds a continuous membrane microfiltration system where further filtration and disinfection occurs. The treated stormwater is then discharged into a 500 kL holding tank and disinfected by UV


H Pantenburg/Taronga Zoo

Taronga Zoo stormwater and wastewater treatment plant before use. This reuse water is then distributed around the zoo through a recycled water supply pipe to provide for animal exhibit washdown, moat make-up water, public toilet flushing and irrigation for 10 hectares of land on the site.

Water not required for reuse is discharged to Sydney Harbour under an EPA licence. Backwash water from the microfiltration unit is returned to the aeration basin.

The system was constructed to treat 240 ML (60%) of the 400 ML annual average run-off from the site. At present, the average daily demand for treated water is 100 kL (36.5 ML/year).

Project costs

Capital cost	$2,200,000
Recurrent cost	$55,000
Life-cycle cost	$2,585,000

Project outcomes

- Estimated annual stormwater reuse volume of 36.5 ML, saving $54,000.
- Reduction of stormwater pollution loads to Sydney Harbour.

Monitoring results

Not available

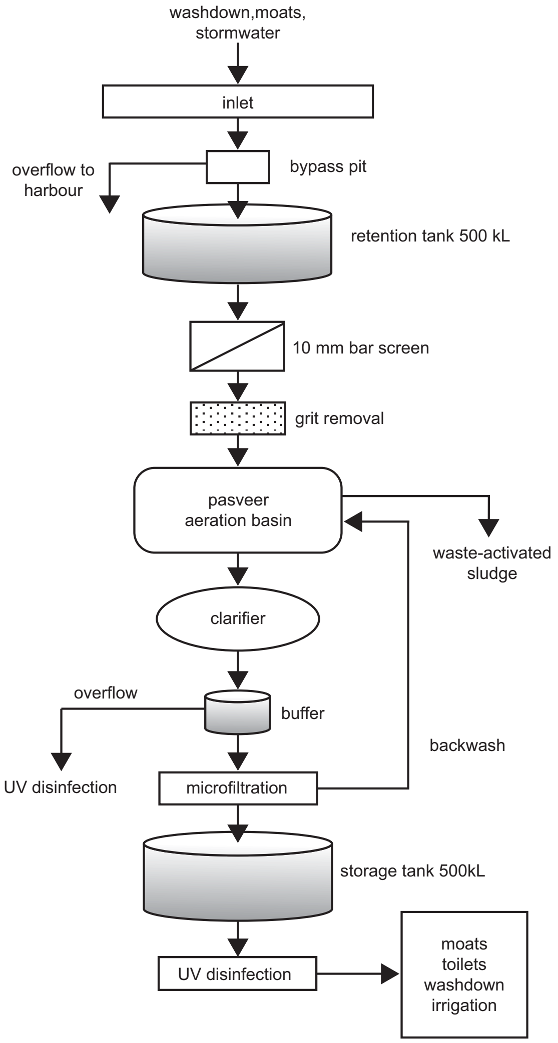


Figure A6 **Taronga Zoo water treatment process**

Riverside Park, Chipping Norton

Brief description

Stormwater is treated by a wetland system and used to irrigate sporting fields, replacing mains water use.

Project objectives

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

Project manager

Liverpool City Council

Completion date

2002

Catchment and site characteristics

The catchment is approximately 47 ha and discharges directly to the Georges River. Land uses consist predominantly of industrial development (47%), residential uses (31%) and the park itself (22%).

Project description

The project added stormwater reuse facilities to an existing off-line wetland system constructed in 2000. A weir diverts low flows from the catchment through a grass-lined stormwater channel to a 2.4 ML storage and sedimentation pond. Stormwater is then pumped to the first of three treatment wetlands. The first two ponds provide water treatment through gravity (sedimentation) and biological processes. Water is stored in a third wetland (polishing pond) from where it flows to the Georges River via groundwater infiltration.

This project involved installing a pump to draw water from the third wetland for distribution to an existing irrigation system for the adjacent baseball fields. This system irrigates an area of 2 ha (baseball fields). Mains water provides a back-up supply for the irrigation system.

Project costs

Capital cost	$68,234
Recurrent cost	$5700
Life-cycle cost	$118,000

Note: these costs relate only to the irrigation headworks and pipeline to the existing irrigation system.

Liverpool City Council

Final wetland from which irrigation water is drawn

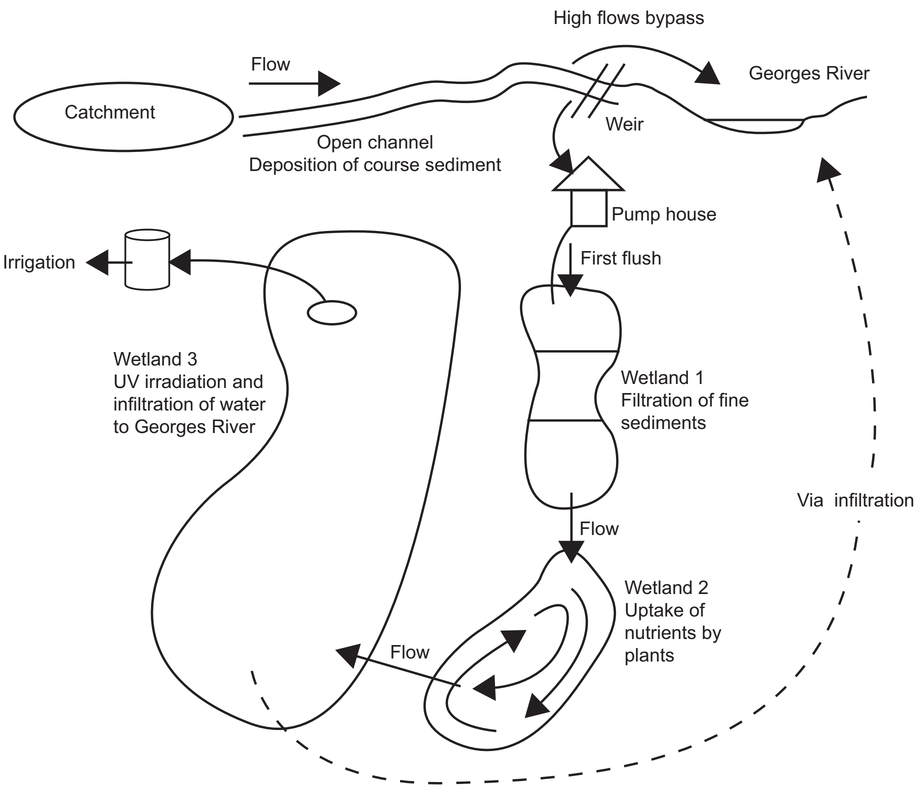


Figure A7 **Process diagram – Riverside Park, Chipping Norton**

Project outcomes

- Estimated annual stormwater reuse volume of 12 ML, saving $17,760.
- Estimated annual stormwater pollution loads have been reduced by 17,000 kg for suspended solids, 23 kg for total phosphorus and 37 kg for total nitrogen.

Monitoring results

Third wetland

Parameter (median values)	Concentration
Faecal coliforms (cfu/100 mL)	150
Suspended solids (mg/L)	2.5
Turbidity (NTU)	<2
Total phosphorus (mg/L)	0.1
Total nitrogen (mg/L)	0.2
Oil and grease (mg/L)	80

Mean results from three storms in 2002

Hornsby Shire Council's nursery and parks depot

Brief description

Collection of stormwater from a nursery, treatment, storage and reuse for nursery irrigation, truck wash and toilet flushing.

Project objectives

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

Project manager

Hornsby Shire Council

Completion date

2003

Catchment and site characteristics

The catchment is a 0.7 ha plant propagation nursery and maintenance depot. The total reuse volume required by the nursery operations averages about 2 kL/day with a noticeable increase in demand during the spring–summer growing period.

Project description

The site was re-graded to direct all run-off into a 90-metre vegetated infiltration trench (bioretention system). Stormwater is then directed into a junction pit, a sediment trap and a series of gravel-filled, baffled wetland bays for initial treatment. This primary treated stormwater is pumped into a 107 kL concrete storage tank.

The stormwater is then pumped through a specialised 27 kL filtration tank. This includes 10% washed river gravel and 70% 'Grodan' (stone wool) filtration media. Outflow from the filtration tank is then pumped to a second 107 kL concrete tank for storage. Treated stormwater is then pumped from the tank into the nursery's irrigation system.

A second sub-surface irrigation system was constructed to complement the existing copper irrigation system which uses mains water. Existing sprinkler heads were replaced with more water efficient heads.


Z Fink/DEC

Sand filter and wetland

Harvested stormwater is used to raise native seedlings

The project also included the installation of three modular rainwater tanks to collect run-off from the roofs of the existing buildings for toilet flushing. One set of toilets is also serviced by the recycled water system. Xeriscaping ('dry landscaping') of the site was also carried out to display plant selection and techniques for minimising water use.

Project costs

Capital cost	$329,500
Recurrent cost	$28,000
Life-cycle cost	$581,000

Project outcomes

- Estimated annual stormwater reuse volume of 0.72 ML, saving $1000.
- Reduction in annual stormwater pollution loads.

Monitoring results

Parameter	Inlet	Outlet
Faecal coliforms (cfu/100 mL)	10,300	114
Suspended solids (mg/L)	39.6	1.3
Turbidity (NTU)	102	4
Total phosphorus (mg/L)	0.262	0.087
Total nitrogen (mg/L)	1.6	1.08
Conductivity (mS/cm)	0.35	0.30
pH	7.23	8.26
Oil & grease (mg/L)	3.6	2.5
Total aluminium (mg/L)	2.48	0.285
Total iron (mg/L)	2.49	0.179
Total copper (mg/L)	0.023	0.011
Total zinc (mg/L)	0.085	0.021
Total lead (mg/L)	0.010	0.0005

Mean results of five grab samples from filtration tanks taken in wet weather during 2004

Prince Henry Development, Little Bay

Brief description

Stormwater from a residential and retail development will be collected, treated and drained to two new storages and two existing storages. This will be used for irrigating three local parks, street trees and road verges within Prince Henry Development, and to irrigate the Coast golf course.

Project objectives

- Reduce stormwater pollution to Little Bay
- Provide a high-reliability alternative supply for irrigation of the adjacent golf course and the local development
- Provide a cost-effective stormwater harvesting and reuse scheme utilising existing infrastructure

Project manager

Landcom

Completion date

2006 (scheduled)

Catchment and site characteristics

The catchment of the project site is 49 ha, consisting of 29 ha of the Prince Henry residential development, 4 ha of protected eastern suburbs Banksia scrub bushland, and 16 ha of golf course fairways and greens.

Project description

The project is the result of a detailed water-sensitive urban design strategy undertaken as a component of the master-planning process for the site. This strategy recommended stormwater reuse rather than the use of individual lot rainwater tanks and reuse, based on the results of a water balance for the site.

Run-off generated from the residential areas of site will be filtered through a sediment/silt arrestor pit before combining with road and open space run-off. All stormwater will then pass through one of six GPTs to remove gross pollutants and coarse sediments.

This partially treated stormwater will be discharged from the GPTs into six bioretention systems. These systems use a combination of fine media filtration, extended detention and biological uptake (through vegetation) to remove nutrients, organics, heavy metals and fine suspended solids. Each of the separate bioretention systems

Coast golf course, Little Bay

have been designed according to the size and nature of the upstream catchment, and aim to reduce total suspended solids by 80% and total phosphorus and total nitrogen levels by 45%.

The treated water will be stored in three open storage ponds with capacities of 4.6 ML, 3 ML and 1 ML. Before being reused for irrigating the golf course, nearby parks and residential recreational areas, the treated stormwater will pass through a fine-mesh irrigation filter to remove sediment resuspended in storage ponds and so protect irrigation lines.

Project costs

Not available

Project outcomes (expected)

- Design annual stormwater reuse volume of 70 ML.
- Design annual stormwater pollution loads reduction of 40,000 kg for suspended solids, 70 kg for total phosphorus and 450 kg for total nitrogen.

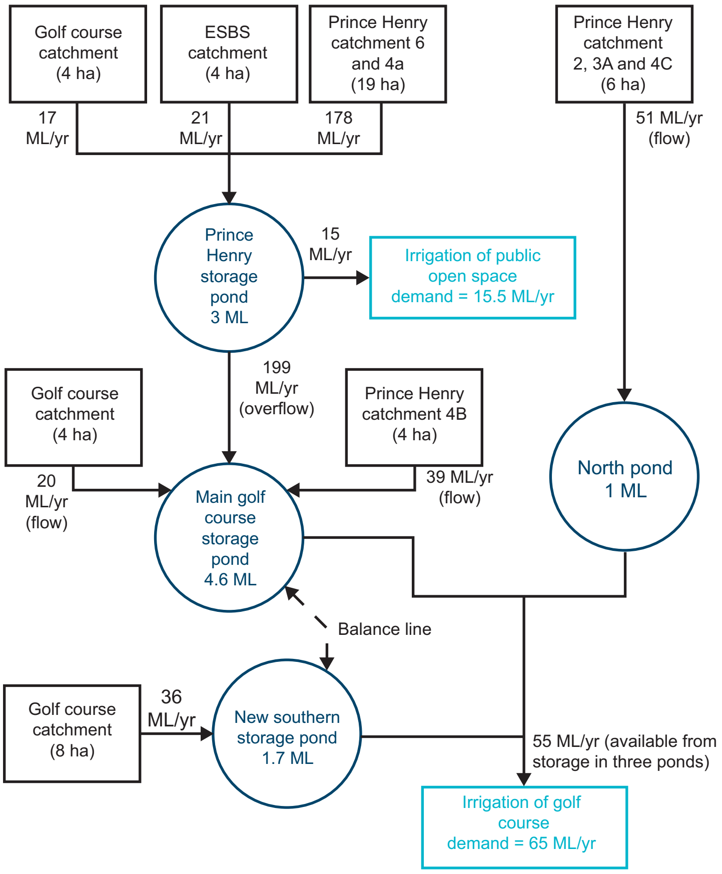
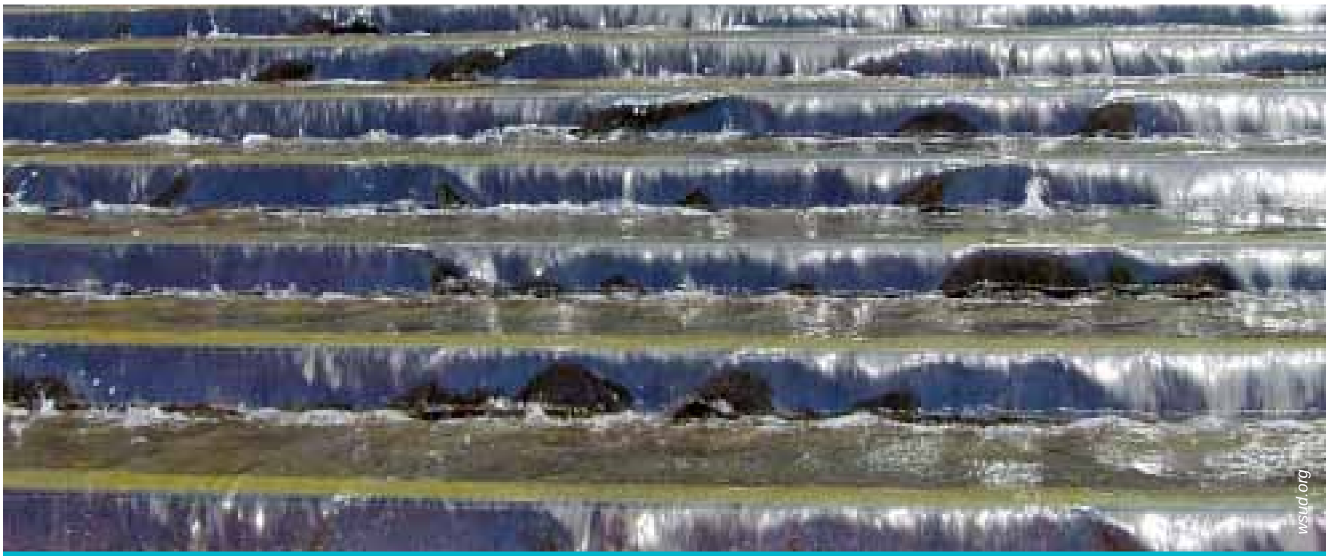


Figure A8 **Golf course harvesting post-development**

Source: Landcom

ESBS: Eastern suburbs Banksia scrub area



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Appendices

Appendix A: Key considerations

A.1 Planning

The planning process should aim to:

- identify all risks to public health, safety and the environment
- identify all catchment characteristics likely to present public health or environmental risks to stormwater reuse
- involve the organisation(s) responsible for operating the scheme, and other key stakeholders
- identify all site constraints and regulatory requirements
- evaluate possible arrangements for a stormwater harvesting and reuse scheme, including evaluating costs and benefits.

A.2 Design

The design process should aim to:

- design the reuse scheme for ease of operations and maintenance
- incorporate elements in the design intended to address public health and environmental risks, to complement operational risk management activities
- cost-effectively meet the project's objectives identified during project planning.

A.2.1 Collection

The design of the collection system should ensure that:

- sufficient stormwater is collected for transfer to storage to meet the end-use volume requirements
- the extraction does not compromise downstream aquatic ecosystems
- collection can be stopped if stormwater is contaminated by an incident within the catchment
- the risk of upstream flooding impacts is minimised.

A.2.2 Storage

The design of the storage system should ensure that:

- sufficient water is stored to balance supply and demand, and meet reliability of supply objectives
- above-ground storages minimise mosquito habitat (virus control), risks to public safety, risks to water quality (e.g. eutrophication), and address dam safety issues.

A.2.3 Treatment

The stormwater treatment system should be based on:

- adopting stormwater quality objectives that:
    - minimise public health risks for the adopted public access arrangements
    - minimise environmental risks
    - meet any additional end-use requirements
- designing appropriate stormwater treatment measures to meet the adopted objectives.

A.2.4 Distribution

The system for distributing treated stormwater should be designed to:

- minimise the potential for public exposure to treated stormwater and ensure there is no potential for cross-connection with mains water distribution networks or confusion with mains water supplies
- minimise the potential for contaminant inputs downstream of the final treatment facilities.

A.2.5 Irrigation

For irrigation systems, ensure that:

- irrigation systems are designed to minimise run-off, groundwater pollution and soil contamination
- where access control is adopted to reduce public health risks, the irrigation scheme minimises spray to areas outside the control zone.

A.3 Construction

In constructing a stormwater harvesting and reuse scheme:

- construct the scheme to minimise water, air and noise pollution and waste generation
- protect any valuable vegetation during construction.

A.4 Operations

Ensure that:

- the organisation is committed to the appropriate management of the scheme
- appropriately qualified staff operate the scheme
- the scheme's management is committed to refining the scheme's operations.

A.4.1 Commissioning

Scheme commissioning should be carried out before starting routine operations. The scheme should ensure that:

- catchment managers should identify and respond to incidents affecting the quality of stormwater entering a scheme
- appropriate incident response procedures are in place
- appropriate equipment and materials are used
- occupational health and safety procedures should be followed, including procedures related to working with recycled water
- appropriate records are maintained.

A.4.2 Maintenance

Plans for maintenance should ensure that:

- the scheme is inspected and maintained regularly
- asset management practices are followed.

A.4.3 Monitoring and reporting

Plans for monitoring and reporting should ensure that:

- water quality should be monitored during the schemes commissioning and operational phases
- monitoring results should be reported to internal and external stakeholders
- monitoring records should be maintained for an appropriate period.

A.4.4 Scheme management plan

A management plan should be prepared for all stormwater harvesting and reuse projects, outlining:

- roles
- responsibilities
- procedures for the scheme's operations.

The scheme management plan should be reviewed regularly and after any major incident.

Appendix B: Risk management

B.1 Risk management

B.1.1 Approaches to risk assessment and management

As noted in section 4, the aim of risk management is to reduce identified risks to acceptable levels. Risk management can be either quantitative, where risks are calculated, or quantitative, where risks are allocated a relative risk level.

The basic approaches to risk management involve steps similar to the following:

- decide on the risk management objective – this may be numerical for a quantitative risk assessment or a 'low' risk for qualitative risk assessment
- identify potential hazards
- identify the level of risk associated with each potential hazard
- reduce the risks to the objective level for each hazard.

The concept of risk combines both the likelihood of a hazard or hazardous event occurring and the resulting consequences. Risk management can therefore address either the likelihood or the consequences or both.

When it comes to public health and the environment, most risk management effort aims to reduce the likelihood of a hazard occurring – there is often only a limited opportunity to manage the consequences of an event once it has occurred.

Risk management may be an incremental process, involving assessing the effectiveness of proposed risk reduction measures, by assessing the level of residual risk. If the residual risk does not meet the objective, further actions will be required.

There are several approaches to risk assessment and management which can be used for a stormwater harvesting and reuse scheme, including:

- AS/NZS 4360: 2004 – Risk management
- the risk assessment and management approach used in the Australian drinking water guidelines (NHMRC & NRMMC 2004a) and the draft national guidelines for water recycling (NRMMC & EPHC 2005)
- adopting the quality management approach in ISO 9001: 2000 – Quality management systems or ISO 14001: 1996 – Environmental management systems
- hazard assessment and critical control point (HACCP) – Codex Alimentarius Commission (1997)

While a stormwater harvesting and reuse scheme should be planned, designed and operated on a risk management basis, there is no required approach to risk management which must be adopted – a proponent should adopt a suitable systematic approach to identifying and managing risks which may include one or more of the above approaches.

B.1.2 Risk management

Risk reduction measures aim to partly or fully reduce the risk associated with a hazard to an acceptable level. These actions may be described as risk treatment options (AS/NZS 4360) or preventive measures (NHMRC & NRMMC 2004).

There is often a degree of uncertainty associated with both the assessment of risks associated with specific hazards and the effectiveness of risk reduction actions. Consequently a 'multiple barrier' approach is adopted in drinking water quality management (NHMRC & NRMMC 2004a) and recycled water management (NRMMC & EPHC 2005, ARMCANZ et al. 2000, DEC 2004).

Multiple barrier approach

A stormwater harvesting and reuse scheme incorporating multiple barriers aims to:

- control hazards
- provide for process reliability
- incorporate redundancy
- enhance overall performance.

It involves the use of a series of hazard reduction actions from the catchment to the end uses which may include:

- managing the catchment to minimise pathogen and chemical loads
- treating stormwater to remove most chemicals and pathogens and enhance subsequent processes
- maintaining moderately long detention times in storages (although these would be generally lower than for a water supply system)
- preventing public access and minimising wildlife access to a storage
- disinfecting stormwater before it enters the distribution system
- maintaining residual disinfection within the distribution system (if chlorine disinfection is used)
- maintaining the integrity of the distribution system, avoiding additional inputs following final treatment
- having on-site controls for some applications to reduce public exposure to stormwater.

Monitoring end-use water quality (refer to section 7) is essentially a way of validating the effectiveness of the various barriers. As microbiological monitoring is not continuous, it can miss short-term peaks in pathogen levels. As microbiological hazards are generally acute, the consequences of short-term variations from ‘average’ levels may be significant. In high-risk applications (e.g. dual reticulation systems), continuous monitoring of a surrogate measure of system effectiveness (e.g. turbidity) can be used. This multiple barrier approach is incorporated in the key considerations contained in sections 5 to 7.

Critical control points

Complementing the multiple barrier approach, critical control points (CCP) can also be used for risk management in drinking water supply and recycled water schemes. CCPs apply to high-risk hazards that require management to achieve an acceptable risk level. A CCP for a stormwater harvesting and reuse scheme is a risk reduction or preventative measure that:

- substantially reduces or eliminates a hazard
- can be monitored and corrective actions applied
- if the measure failed, would lead to immediate notification of key stakeholders (e.g. council, consent authority)

An example of a critical control point is disinfection – it is a risk reduction measure that aims to reduce high public health risks and it meets the three criteria for a critical control point noted above using turbidity as a surrogate for direct monitoring. This is likely to be the main critical control point for schemes below the threshold indicated in table 4.2. For schemes above these thresholds, where a risk assessment is carried out, further critical control points may be identified.

Critical control points apply to operational risk management measures, where there is still some residual risk to be managed during the schemes operations after the projects planning, design and construction. Critical control points have associated mechanisms for operational control. These usually involve establishing a critical limit (e.g. chlorine residual concentration) against which data from continuous or frequent monitoring can be evaluated and where exceedances trigger corrective action.

A more detailed description of critical control points in drinking water supply management is provided in NHMRC & NRMMC (2004a).

B.1.3 Risk management framework

Further details of the recycled water risk management framework summarised in section 4 are detailed in table B.1.

B.2 Potential public health hazards

B.2.1 Introduction

Microbial contamination is the most serious potential public health hazard associated with a stormwater harvesting and reuse scheme. A single infective dose of a small number of pathogenic microorganisms can result in illness.

Some chemicals may present a secondary hazard to human health, but toxicity usually occurs following prolonged intake of toxic material at high levels – it normally requires a major malfunction or accident for a single dose of a chemical to cause illness (Mills 2003).

Further general information on public health hazards can be found in NHMRC & NRMMC (2004b).

B.2.2 Public exposure

The Australian drinking water guidelines (NHMRC & NRMMC 2004a) adopt a standard daily consumption of two litres of water per person for adults and one litre per person for children as the basis for setting trigger values for pathogens and dissolved chemicals in drinking water.

For stormwater ingestion, the exposures for stormwater reuse applications will be considerably lower. Human exposure to contaminants in stormwater includes direct exposure through ingestion of water and inhalation of aerosols or sprays, but there is little information on which to determine trigger values.

For example, NRMMC & EPHC (2005) estimate the:

- consumption of irrigation water in public areas as 1 mL for ingestion and 0.1 mL for aerosols (inhalation), with an estimated frequency of 50–90 exposures annually.
- accidental ingestion for garden watering at 100 mL once a year.

B.2.3 Pathogens

Gastroenteritis is the most common disease derived from water. It can be caused by bacteria, viruses or protozoans from human or animal faeces (Mills 2003). The Australian drinking water guidelines contain a comprehensive account of water-borne pathogens (NHMRC & NRMMC 2004a).

Quantitative microbiological risk assessment (QMRA) can be used to assess the health risks from water-borne pathogens. This involves:

- identifying the potential hazards and their effects on human health
- identifying a relationship between the dose of the hazard and the likelihood of illness
- assessing the size of the exposed population and the amount of exposure

Table B.1 Risk management framework for recycled water quality and use

Element 1: Commitment to the responsible use and management of recycled water quality

- Involve public health and environment protection agencies
- Ensure that schemes are designed and operated by organisations and individuals with appropriate expertise
- Meet all regulatory requirements
- Engage relevant stakeholders
- Develop an organisational policy for recycled water quality (refer to section 5)

Element 2: Assessment of the recycled water system

- Identify recycled water sources, uses and potential exposure routes
- Collect data and analyse the system
- Identify hazards and assess risks (refer to sections 5 and 6)

Element 3: Preventive measures for recycled water management

- Identify the preventive measures required to reduce risks to acceptable levels
- Identify critical control points for operational control (refer to sections 6 and 7)

Element 4: Operational procedures and process control

- Identify and document operational procedures
- Develop and document monitoring protocols for operational performance
- Establish procedures for corrective action when operational parameters are exceeded
- Develop and implement equipment inspection and maintenance
- Ensure only approved materials and chemicals are used (refer to section 7)

Element 5: Verification of recycled water quality and environmental sustainability

- Develop and implement a plan for recycled water quality, the application site and receiving environment monitoring
- Develop and implement a system for managing complaints from users of recycled water
- Review short-term monitoring data and implement any necessary corrective action (refer to section 7)

Element 6: Management of incidents and emergencies

- Establish protocols for incident and emergency response and associated communication procedures. (refer to section 7)

Element 7: Employee awareness and training

- Increase employee awareness of recycled water quality management
- Provide appropriate employee training (refer to section 7)

Element 8: Community involvement and awareness

- Develop an appropriate community consultation strategy
- Develop a communication program with users of recycled water (refer to section 7)

Element 9: Validation, research and development

- Validate processes and procedures to ensure that they appropriately control hazards
- Validate the selection and design of new equipment to ensure reliability
- Investigate the improved management of the recycled water system (refer to section 7)

Element 10: Documentation and reporting

- Manage documents and records appropriately
- Establish procedures for internal and external reporting
- Produce an annual report for stakeholders (refer to section 7)

Element 11: Evaluation and audit

- Collect and evaluate long-term data to assess performance and report results
- Audit and report on the processes for managing recycled water quality (refer to section 7)

Element 12: Review and continual improvement

- Conduct senior management reviews of management systems and the need for change
- Develop and implement a plan for improving the management of recycled water quality (refer to section 6)

Source: adapted from NRMMC & EPHC (2005)

- risk characterisation, based on integration of the hazard present, dose response and exposure.

This approach is taken in the draft national guidelines for water recycling (NRMMC & EPHA 2005). Compared to chemical risk assessment, quantitative microbiological risk assessment is a relatively recent development and so only limited dose–response models are available (Department of Health and Aging & enHealth Council 2002).

For stormwater reuse, the approach would require:
- comprehensive data on levels of specific indicator species of bacteria, viruses and protozoans in stormwater
- data on the effectiveness of stormwater treatment measures in reducing pathogen levels.

As noted in appendix C, data on pathogen levels in stormwater is poor. The limited data available focus on indicator bacteria such as *E. coli*, and the performance of treatment measures is highly variable. Until further data on pathogen levels in stormwater is available, the application of QMRA for assessing health risks from stormwater reuse will be limited. Further, the dose–response models used may also need to be refined (Department of Health and Aging & enHealth Council 2002).

While QMRA can assist in the design of treatment processes and on-site controls, it is both difficult and expensive to validate monitoring results from pathogen reduction treatment. Most treatment processes are more effective in removing bacteria than in treating viruses and protozoa, and the results from monitoring programs may not indicate the system's efficiency in removing pathogens other than bacteria.

To date, most studies into the potential health risks from water recycling schemes have focused on wastewater (sewage) recycling. Most of the pathogens found in sewage are also likely to be present in stormwater, partly because of overflows from sewers into stormwater drains. The levels of these pathogens is around two orders of magnitude lower in stormwater than in effluent, based on limited available data (appendix C).

Based on the QMRA approach, the exposure and dose–response for a given reuse application (e.g. municipal irrigation) will be the same regardless of the source of the recycled water. The level of pathogens in recycled water likely to result in illness among a given population is therefore independent of the source water. The magnitude of the hazard is, however, essentially related to the difference between pathogen levels in the source water and the illness 'threshold' concentration for a particular application. For example, the pathogen levels in sewage are commonly higher than in raw stormwater, with a resulting higher risk to manage (e.g. through disinfection). However, pathogen levels in stormwater are commonly higher than the threshold levels and measures to reduce risks are still required.

QMRA may provide a sound basis for defining the risks to public health from pathogens in stormwater in the future, but given its current limitations and as an interim measure, it is preferable to use the indicator pathogen levels that are widely used in other recycled water applications. Table 6.4 shows these indicators, which were derived largely from RWCC (1993) and ARMCANZ et al. (2000). The values from the latter document were based on:
- a consensus of local practice which has been demonstrated to be safe
- a consideration of the current status of scientific understanding and worldwide practice in reclaimed water use (ARMCANZ et al. 2000).

It is recognised that there are limitations to this approach and it is hoped that a more comprehensive and practical approach can be developed over time.

B.2.4 Toxicants

Stormwater reuse could lead to exposure to a range of chemical contaminants, including both inorganic and organic chemicals. In assessing the potential health risks associated with a broad range of such substances in stormwater, the Australian drinking water guidelines could be used to provide health-related guideline values. However, these values may be too conservative for stormwater reuse, because the volume of drinking water consumed is over 700 times greater than that expected from incidental exposure to a stormwater harvesting scheme.

A review of the available data on the levels of contaminants in raw stormwater (appendix C) indicates that generally raw stormwater falls within guideline values for most parameters, including some heavy metals, organic chemicals, pesticides and disinfection byproducts. While levels of metals such as cadmium, nickel and lead in stormwater are up to 10 times higher than guideline values for drinking water, the associated risks are low because of the low risk of exposure. Further, this review is based on the concentrations found in raw stormwater rather than treated stormwater and is therefore conservative. The risk to human health from chemicals in stormwater is therefore low.

A larger risk however would be from sudden changes in catchment conditions or activities upstream of the harvesting point. These could include inputs of chemicals from spills or industrial discharges that could lead to elevated chemical concentrations in treated stormwater. Smaller schemes would be more susceptible than larger schemes to unauthorised chemical discharges, as there would be less dilution of the contaminants from ‘cleaner’ stormwater.

These risks could be managed by having a way of isolating the system at the inlet or harvesting point, and through more-vigilant catchment management efforts.

B.3 Potential environmental hazards

B.3.1 Introduction

The potential environmental hazards for a stormwater harvesting and reuse scheme fall into two groups: potential hazards for all schemes, and hazards that specifically apply during the irrigation of stormwater, where the potential receiving environments are:

- surface waters
- soils and plants
- groundwater.

The potential hazards for all schemes depend on the design of the scheme and include any on-line storages and stormwater extraction from drains or watercourses.

B.3.2 On-line storages and diversion structures

As noted in section 6.3, several potential hazards are associated with on-line storages, particularly those constructed on a natural creek. These potential hazards include:

- obstructing the passage of fish and other aquatic fauna, impacting on aquatic ecosystem health
- trapping of coarse sediment, potentially causing sediment starvation downstream, with associated channel erosion if flows are not reduced
- removal of riparian vegetation and disruption of associated habitat corridors.

These hazards tend to be site-specific and should be assessed for any project involving an on-line storage on a natural waterway. Weirs constructed on a natural waterway as a stormwater diversion structure (see below) may present similar hazards.

The statutory requirements noted in section 3 relating to impacts on fish habitats, rivers or foreshores may also apply to an on-line storage or diversion weir.

B.3.3 Extraction of stormwater

While urbanisation increases streamflows relative to pre-development conditions, there is a potential for a stormwater harvesting and reuse scheme to extract excessive stormwater, reducing flows to below pre-development conditions. This may impact on aquatic ecosystem health.

An assessment should be made of the sensitivity of aquatic ecosystems downstream of a proposed stormwater harvesting and reuse scheme to determine the critical limit for flow extraction. This may be the pre-urbanisation flow regime.

B.3.4 Flooding

There are potential flooding hazards for stormwater harvesting and reuse schemes excluding those where pumps are used for stormwater collection. Diversions for schemes with off-line storages for collecting stormwater for reuse commonly involve installing a weir in the drain of waterway, with low flows diverted upstream of the weir. On-line storages involve installing a weir or embankment across the drain or waterway.

Weirs and embankments will normally result in higher upstream flood levels. This may present a hazard to riparian vegetation and bank stability. There may also be associated impacts on adjacent properties.

These hazards tend to be specific to each site and project and should be assessed for any project involving a diversion structure or an on-line storage.

B.3.5 Irrigation hazards to surface water

Nutrients, suspended solids, metals and inorganic substances in stormwater present a potential hazard to the environment (Burton & Pitt 2002) because of their potential to affect organisms, natural communities and ecological systems. However, most of these substances are present in natural waters and become hazards at elevated levels.

Run-off from a saturated stormwater irrigation scheme may have impacts on water quality and/or local aquatic ecosystems. If the stormwater was sourced from the same catchment as the irrigation scheme, the overall water quality impacts of any run-off from the scheme (for example, from a saturated irrigation area) are likely to be low. The scheme would harvest a proportion of the catchment's pollution loads and only a fraction of this load would return to the waterway from over-irrigation.

Run-off from an irrigation area reaching a waterway in dry-weather conditions may present a hazard through increased pollutant concentrations in the waterway. Concentrations of pollutants in reused stormwater are likely to be closer to wet-weather levels, unless the stormwater has been treated extensively; these levels are higher than dry-weather levels in stormwater and most waterways (Fletcher et al. 2004). Irrigation area runoff may therefore increase dry-weather pollution concentrations. However, over-irrigation is more likely to occur in wet periods, when soil moisture levels are high, hence the risk associated with this hazard will often be low.

Excessive run-off from an irrigation area may result in soil erosion with consequent sediment inputs to receiving waters. Seasonal waterlogging of soils in an irrigation area may also result in erosion if irrigation occurs. Tables B.2 and B.3 indicate irrigation area landform and soil characteristics and their associated erosion and waterlogging risks.

Harvesting and reuse schemes should be designed and operated in a manner that minimises stormwater run-off. This should be achieved by identifying and applying appropriate hydraulic loading rates for the soil conditions in an irrigation area and making operational decisions such as irrigating only when soil moisture levels are low. If run-off is minimised, the environmental risks are likely to be low. Iron concentrations in stormwater are below the short-term trigger values for irrigation from ANZECC & ARMCANZ (2004), although they can be above the long-term trigger values. The main concerns with elevated iron levels are operational (clogging of irrigation equipment) rather than environmental.

Where a reuse scheme harvests stormwater from another catchment, e.g. through inter-catchment transfers, any run-off from the scheme would introduce additional pollution loads from the harvested catchment to the receiving catchment. Such schemes should be designed to achieve no net increase in loads to the catchment.

B.3.6 Irrigation hazards to soils and plants

A number of chemicals found in stormwater can present a hazard to soils and plants. Key chemicals are noted in table B.4, along with their potential impacts. Other chemicals in stormwater are usually at a low level relative to the concentrations that present an environmental hazard. The potential impacts of excessive water application (hydraulic loading) are also noted in the table.

The impact of the chemicals in table B.4 depends on their concentration in stormwater and the application rate. A review of the available data on their concentrations in raw stormwater (appendix C) indicates that stormwater concentrations are within guidelines levels (DEC 2004, ANZECC & ARMCANZ 2000) for the irrigation of sensitive plants and for minimising impacts on soils. No data on boron concentrations in stormwater has been

Table B.2 Landform risks for stormwater irragtion

	Limitation			
Property	**nil or slight**	**moderate**	**severe**	**Restrictive feature**
Slope (%) for irrigation techniques:				Excess run-off and erosion risk.
– surface/underground	<1	1–3	>3	
– sprinkler	<6	6–12	>12	
– trickle/microspray	<10	10–20	>20	
Landform	• crests • convex slopes • plains	• concave slopes • footslopes	• drainage lines • incised channels	Risk of erosion and seasonal waterlogging
Surface rock and outcrop (%)	nil	0–5	>5	Increased risk of run-off.

Source: modified from NSW DPI (2004)

located – it is assumed that levels in stormwater from a residential catchment with limited sewer overflows will be relatively low.

Impacts on soils tend to be chronic, rather than acute, and site-specific. With the possible exception of salinity impacts on soils, there is generally a low environmental risk of using stormwater to irrigate soils and plants.

Table B.3 Soil risks for stormwater irrigation

	Limitation			
Property	**nil or slight**	**moderate**	**severe**	**Restrictive feature**
Salinity measured as EC_e (dS/m, 0–70 cm)	<2	2–4	>4	Excess salt restricts plant growth
Salinity measured as EC_e (dS/m, 70–100 cm)	<4	4–8	>8	Potential seasonal groundwater rise
Depth to top of seasonal high watertable (m)	>3	0.5–3	<0.5	Wetness, risk to groundwater
Depth to bedrock or hardpan (m)	>1	0.5–1	<0.5	Excess run-off, waterlogging
Saturated hydraulic conductivity (Ks, mm/hr, 0–100 cm)	20–80	5–20 >80	<5	Excess run-off, waterlogging, risk to groundwater
Available water capacity (AWC, mm/m)	>100	<100	–	Risk to groundwater
Emerson aggregate test class (0–100 cm)	4, 5, 6, 7, 8	2, 3	1	Poor structure, risk of subsurface erosion

Source: modified from NSW DPI (2004)

Table B.4 Potential impacts on soils and plants

Hazard	**Potential effect or impact**
Boron	Plant toxicity
Chlorine disinfection residuals	Direct toxicity to plants
Nitrogen	Nutrient imbalance, pests and diseases in plants Eutrophication of soils and effects on terrestrial biota
Phosphorus	Eutrophication of soils and toxic effects on phosphorus-sensitive terrestrial biota (especially some native plants)
Salinity	Salinity may cause rising damp or corrosion of assets, and can arise from excessive hydraulic loading (secondary salinity) Plants stressed from osmotic affects of soil salinity Contamination of soils by increasing bioavailability to plants of cadmium present in the soil
Chloride	Direct toxicity to plants when sprayed on leaves Plant toxicity via uptake through the roots
Sodium	Direct toxicity to plants when sprayed on leaves Plant toxicity via uptake through the roots Loss of soil structure due to sodicity

Herbicides may interfere with plant growth. Phenoxyacid herbicides, such as 2,4-D and its derivatives, are widely used for weed control and they may occur in stormwater. Table B.5 indicates threshold levels of concern for common chemicals for the irrigation of grass. This is derived from ANZECC & ARMCANZ (2000), based on recommended thresholds for the crops lucerne and alfalfa. Only limited data is available for these herbicides in stormwater – site-specific monitoring is recommended if herbicide use is prevalent within a scheme's catchment.

B.3.7 Irrigation hazards to groundwater

Any development should aim to protect the quality of the underlying groundwater which should continue to be able to support its most sensitive beneficial use. Irrigation with stormwater could pose a risk to underlying groundwater. These risks are greatest when:

- irrigated stormwater has high salinity levels and, to a lesser extent, high levels of nutrients, pathogens or other contaminants
- the groundwater has a current or potential beneficial use (e.g. for drinking water or sustaining a groundwater-dependent ecosystem, such as a wetland).

The actual impact from any chemicals in the stormwater would depend on both their concentration and the application rate – as discussed above, such impacts tend to be chronic rather than acute. The risk of impacts from stormwater on groundwater is expected to be low when:

- the application rate is controlled by irrigation scheduling or soil moisture monitoring to ensure that stormwater does not percolate deeper than the root zone or intersect groundwater
- salinity (as electrical conductivity) in stormwater is less than 0.3 dS/m (DEC 2004).

If the application rate and salinity are higher than these, the site should be investigated and a comprehensive risk management approach adopted – DEC (2004) provides further guidance. Salinity in stormwater tends to be below this threshold and lower than in effluent (refer to appendix C), hence the risks of salinity impacts on irrigated land and groundwater from a stormwater reuse scheme would be lower than from an effluent irrigation scheme.

Further considerations for minimising risks include avoiding areas where the groundwater has a current or potential beneficial use or is close to the soil surface, or where there is evidence of dryland salinity.

Table B.2 lists the soil characteristics that indicate potential risks to groundwater.

For further information on protecting groundwater quality, see the NSW state groundwater quality protection policy (DLWC 1997, 1998), the NSW state groundwater policy (DLWC 1997) and the national guidelines for groundwater protection (ARMCANZ & ANZECC 1995).

Table B.5 Indicative threshold concentrations of herbicides

Herbicide	Indicative threshold for injury to grass (mg/L)
Amitrol	1600
Dichlobenil	10
Fluometuron	2.2
Propanil	0.15

B.4 Schemes meeting default criteria

B.4.1 Basis for risk thresholds in default approach

The thresholds in table 4.3 for the default approach to risk management were derived considering the potential public health and environmental hazards described in section B.2 and B.3, and critical operating constraints. The basis for these thresholds is presented in table B.6.

B.4.2 Generic risk assessment for default approach

Tables B.7 to B.11 present a simplified public health and environmental risk assessment for a stormwater harvesting and reuse scheme. The risk assessment is generic as it is intended to apply for all schemes within the thresholds noted in table 4.3. It is also qualitative because there is currently insufficient data for quantitative health risk assessment for stormwater reuse. The risk assessment is based on the qualitative criteria noted in tables B.7 to B.9. These tables also include the risk management measures shown in tables 4.4 and 4.5, noting any residual risks.

For schemes with characteristics above the thresholds noted in table 4.1 and/or where different management measures are used, the draft national water recycling guidelines (NRMMC & EPHC 2005) and the Queensland water recycling guidelines (Queensland EPA 2005a) provide guidance on possible approaches to risk management.

Table B.6 Thresholds for use of default risk management approach

Threshold criteria – all schemes	Basis
Catchment land use	Residential/commercial areas generate lower heavy metal concentrations in stormwater – high concentrations that may occur from industrial catchments may present public health or environmental risks.
Sewer overflows in the catchment	High levels of sewer overflows can significantly increase pathogen levels and concentrations of some contaminants in stormwater
Stormwater reuse application	This document is targeted at typical urban applications. Medium to large-scale residential schemes have a higher potential public exposure and should be subject to a risk assessment.
Storage	Storages constructed on a natural waterway present a potential environmental hazard (refer to section B.3.2)
Extraction	Excessive extraction present a potential environmental hazard (refer to section B.3.3)
Stormwater quality	High turbidity levels may have a significant impact on disinfection effectiveness and site-specific studies are appropriate.
Additional threshold criteria – irrigation schemes	
Salinity levels in stormwater	High salinity levels in stormwater present an environmental hazard to soils and groundwater
Groundwater	Groundwater vulnerability areas are sensitive to additional groundwater inputs
Location of irrigation area	Potential impact on groundwater beneficial use if located within 1 km of a town water supply bore
Landform and soil characteristics	Low limitations from tables B.2 and B.3.

Table B.7 Qualitative measures of likelihood

Level	Descriptor	Example description
A	Rare	May occur only in exceptional circumstances. May occur once in 100 years
B	Unlikely	Could occur within 20 years or in unusual circumstances
C	Possible	Might occur or should be expected to occur within a 5-year to 10-year period
D	Likely	Will probably occur within a 1-year to 5-year period
E	Almost certain	Is expected to occur with a probability of multiple occurrences within a year

Table B.8 Qualitative measures of consequence or impact

Level	Descriptor	Example description
1	Insignificant	Insignificant impact or not detectable
2	Minor	Health – Minor impact for small population Environment — Potentially harmful to local ecosystem with local impacts contained to site
3	Moderate	Health – Minor impact for large population. Environment – Potential harmful to regional ecosystem with local impacts primarily contained to site
4	Major	Health – Major impact for small population Environment – Potentially lethal to local ecosystem. Predominantly local, but potential for off-site impacts
5	Catastrophic	Health – Major impact for large population. Environment – Potentially lethal to regional ecosystem or threatened species. Widespread on-site and off-site impacts

Table B.9 Qualitative risk analysis matrix: level of risk

	Consequences				
Likelihood	**1 Insignificant**	**2 Minor**	**3 Moderate**	**4 Major**	**5 Catastrophic**
A Rare	Low	Low	Low	Low	High
B Unlikely	Low	Low	Moderate	High	Very high
C Possible	Low	Moderate	High	Very high	Very high
D Likely	Low	Moderate	High	Very high	Very high
E Almost certain	Low	Moderate	High	Very high	Very high

Source: NRMMC & EPHC (2005)

Table B.10 Qualitative public health risk assessment – sub-threshold schemes

Hazard and pathway	Uncontrolled risk			Control strategies	Residual risk			Comments
	Likelihood	**Consequences**	**Risk**		**Likelihood**	**Consequences**	**Risk**	
General (all uses)								
Pathogens – ingestion (cross-connection with drinking water supply)	Possible	Moderate	High	Plumbing controls	Unlikely	Minor	Low	Likelihood is greatest for dual reticulation although may occur for any scheme with a mains water backup supply.
Non-potable residential								
Pathogens – ingestion, aerosol	Almost certain	Minor		Treatment to achieve median *E. coli* levels of <1 cfu/100 mL Disinfection residual Plumbing controls	Unlikely	Minor	Low	Likelihood of exposure is high relative to other applications – refer to section B.2.2 re ingestion volumes. Treat to level in NSW RWCC (1993) to achieve low risk.
Toxicants – ingestion	Unlikely	Insignificant	Low	Plumbing controls	Unlikely	Insignificant	Low	Concentrations of toxicants in urban stormwater are less than drinking water values (NHMRC & NRMMC 2004a) except for some metals. Ingestion volumes are, however, relatively low (section B.2.2), hence low risk.
Irrigation – open space								
Pathogens – ingestion, aerosol	Almost certain	Major	Very high	Treatment to achieve median *E. coli* levels of <10 cfu/100 mL with uncontrolled public access OR Treatment to achieve median *E. coli* levels of <1000 cfu/100 mL and controlled public access with spray controls	Unlikely	Minor	Low	Likelihood of exposure is moderate relative to other applications – refer to section B.2.2 re ingestion volumes. Control risks through either high treatment or moderate treatment and access controls (ARMCANZ et al. 2000).

Table B.10 Qualitative public health risk assessment – sub-threshold schemes (cont'd)

Hazard and pathway	Uncontrolled risk			Control strategies	Residual risk			Comments
	Likelihood	**Consequences**	**Risk**		**Likelihood**	**Consequences**	**Risk**	
Toxicants – ingestion	Unlikely	Insignificant	Low	Nil	Unlikely	Insignificant	Low	See comment for residential non-potable.
Industrial								
Pathogens – ingestion, aerosol	Almost certain	Major	Very high	Treatment to achieve median *E. coli* levels of <10 cfu/100 mL with uncontrolled public access OR Treatment to achieve median *E. coli* levels of <1000 cfu/100 mL and controlled public access with spray controls	Unlikely	Minor	Low	Likelihood of exposure is variable depending on the industrial use and the associated level of public exposure. Likely ingestion volumes are expected to be considerably less than for drinking water. Control risks through either high treatment when there is no access limitation or moderate treatment with access controls (ARMCANZ et al. 2000).
Toxicants – ingestion	Unlikely	Insignificant	Low	Nil	Unlikely	Insignificant	Low	See comment for residential non-potable.
Water features (ornamental)								
Pathogens – ingestion, aerosol	Almost certain	Major	Very high	Treatment to achieve median *E. coli* levels of <10 cfu/100 mL with uncontrolled public access OR Treatment to achieve median *E. coli* levels of <1000 cfu/100 mL and controlled public access with spray controls	Unlikely	Minor	Low	Likelihood of exposure is variable depending on the associated level of public exposure – refer to section B.2.2 re ingestion volumes. Control risks through either high treatment when there is no access limitation or moderate treatment with access controls (ARMCANZ et al. 2000).

Table B.10 Qualitative public health risk assessment – sub-threshold schemes (cont'd)

Hazard and pathway	Uncontrolled risk			Control strategies	Residual risk			Comments
	Likelihood	**Consequences**	**Risk**		**Likelihood**	**Consequences**	**Risk**	
Toxicants – ingestion	Unlikely	Insignificant	Low	Nil	Unlikely	Insignificant	Low	See comment for residential non-potable.
Aquifer storage and recovery								
Pathogens – ingestion	Likely	Minor	Moderate	Stormwater treatment to achieve median *E. coli* levels of <1000 cfu/100 mL	Unlikely	Minor	Low	Likelihood of direct exposure is relatively low. Control risks through low-level treatment (Dillon & Pavelic 1996).
Toxicants – ingestion	Unlikely	Insignificant	Low	Nil	Unlikely	Insignificant	Low	See comment for residential non-potable.
Pathogens – ingestion, aerosol	Almost certain	Major	Very high	Treatment to achieve median *E. coli* levels of <10 cfu/100 mL with uncontrolled public access OR Treatment to achieve median *E. coli* levels of <1000 cfu/100 mL and controlled public access with spray controls	Unlikely	Minor	Low	Likelihood of exposure is moderate relative to other applications – refer to section B.2.2 re ingestion volumes. Control risks through either high treatment or moderate treatment and access controls (ARMCANZ et al. 2000).

Table B.11 Qualitative environmental assessment – sub-threshold irrigation schemes

Hazard and receiving environment	Uncontrolled risk			Control strategies	Residual risk			Comments
	Likelihood	**Consequences**	**Risk**		**Likelihood**	**Consequences**	**Risk**	
General								
Over-extraction – surface waters	Possible	Moderate	High	Design and operate to limit extraction	Unlikely	Minor	Low	Limit extraction to pre-development flows or other flow depending on ecosystem characteristics
On-line storages (on drains) – surface waters and ecosystems	Rare	Insignificant	Low	Nil	Rare	Insignificant	Low	Risks are low for on-line storages constructed on piped drainage systems or constructed channels
Nutrient and organic matter inputs to open storages	Likely	Minor	Moderate	Treatment to remove phosphorus and organic matter if design residence times are long. Monitoring Incident response	Unlikely	Minor	Low	Growth of cyanobacteria is also influenced by temperature and turbidity levels.
Weirs for diversion systems – surface waters (flood impacts)								Impacts are site and project-specific and should be assessed for each project
Irrigation applications								
Boron – soil (plant toxicity)								No data located on boron concentrations in stormwater – assume risk is low for reuse of stormwater from residential catchments.

Table B.11 Qualitative environmental assessment – sub-threshold irrigation schemes (cont'd)

Hazard and receiving environment	Uncontrolled risk			Control strategies	Residual risk			Comments
	Likelihood	Consequences	Risk		Likelihood	Consequences	Risk	
Nitrogen – surface waters, groundwater	Unlikely	Minor	Low	Irrigation controls	Unlikely	Minor	Low	Typical stormwater concentrations less than long-term trigger value for irrigation in ANZECC & ARMCANZ (2000). Low impact likely in any surface run-off.
Phosphorus– surface waters	Unlikely	Minor	Low	Irrigation controls	Unlikely	Minor	Low	Typical stormwater concentrations less than short-term trigger value for irrigation in ANZECC & ARMCANZ (2000) (long-term value applies for bioclogging). Low impact likely in any surface run-off.
Salinity – plants	Unlikely	Minor	Low	Irrigation controls	Unlikely	Minor	Low	Typical stormwater concentrations less than values for sensitive crops or soil structure impacts in ANZECC & ARMCANZ (2000). Groundwater impacts low if no site constraints and irrigation controlled.
Chloride – plants	Unlikely	Minor	Low	Nil (monitor for any impacts)	Unlikely	Minor	Low	Typical stormwater concentrations less than values for sensitive crops in ANZECC & ARMCANZ (2000).

Table B.11 Qualitative environmental assessment – sub-threshold irrigation schemes (cont'd)

Hazard and receiving environment	Uncontrolled risk			Control strategies	Residual risk			Comments
	Likelihood	**Consequences**	**Risk**		**Likelihood**	**Consequences**	**Risk**	
Pesticides (herbicides) – crops, surface waters	Unlikely	Minor	Low	Nil (monitor for any impacts)	Unlikely	Minor	Low	Little data on herbicide levels in stormwater. Risk assumed to be low – monitor if plant impacts occur
Metals	Unlikely	Minor	Low		Unlikely	Minor	Low	Typical stormwater concentrations less than long-term trigger values in ANZECC & ARMCANZ (2000). Exception is iron, where concentrations are less than short-term values (long-term values are operational).
Hydraulic loading – soils (salinity, erosion), plants (waterlogging)	Likely	Minor	Moderate	Site selection Irrigation design and operation	Unlikely	Minor	Low	Refer to tables B.2 and B.3 for site characteristics for low-risk schemes.

Appendix C: Stormwater quality

C.1 Introduction

The three aspects of stormwater quality of particular relevance to stormwater harvesting and reuse schemes are:

- pathogens, including faecal coliforms and *E. coli* – for public health implications
- chemical constituents – for public health and environmental considerations, and some end-use requirements (e.g. irrigation)
- suspended solids and turbidity – for their potential impact on both the effectiveness of disinfection and the function of irrigation schemes.

C.2 Relationship between faecal coliforms and *E. coli*

The relationship between total and faecal coliforms, and *E. coli* is:

- total coliform bacteria comprise 16 species of bacteria found in soil, vegetation, animal wastes and human sewage
- faecal coliforms comprise six species of coliform bacteria that are found in animal wastes and human sewage
- *E. coli* is one of the six faecal coliform bacteria species and is found in animal wastes and human sewage.

The three guidelines used to derive the pathogen public health treatment objectives in table 6.4 (NSW RWCC 1993, DEC 2004, and ANZECC & ARMCANZ 2000) describe pathogen (bacterial) criteria in terms of thermotolerant (faecal) coliforms. Since those guidelines were prepared, there has been considerable research into appropriate microbial indicators of faecal contamination (e.g. Edberg et al. 2000). The Australian drinking water guidelines (NHRMC & NRMMC 2004a) and the draft national guidelines for water recycling (NRMMC & EPHC, 2005) have adopted *E. coli* as the primary indicator of faecal contamination, as recommended by Stevens et al. (2003). Based on this more recent research, *E. coli* has been used in table 6.4 in place of thermotolerant coliforms. *E. coli* are also used in the recent Queensland guidelines for water recycling (Queensland EPA 2005a).

Most monitoring of pathogen levels in stormwater and freshwater in NSW has focused on faecal coliforms. The relationship between faecal coliform and *E. coli* levels is variable. Ideally, a site-specific relationship should be derived from concurrent faecal coliform and *E. coli* monitoring data.

In the absence of site-specific data, the approach derived in the US by the Virginia Department of Environmental Quality (VADEQ) and approved by the US EPA could be adopted. The translator equation was developed by VADEQ to translate faecal coliform data into *E. coli* data through a regression analysis of 493 paired datasets from the department's statewide water quality monitoring network.

The resulting equation is:

$$EC = 0.988\ FC^{0.919}$$

where EC = *E. coli* level (cfu/100 mL)

FC = faecal coliform level (cfu/100 mL)

The *E. coli* proportion derived from this equation is presented in figure C.1. Further details can be obtained from VADEQ (2003). No correlation coefficient for this equation was provided in this reference.

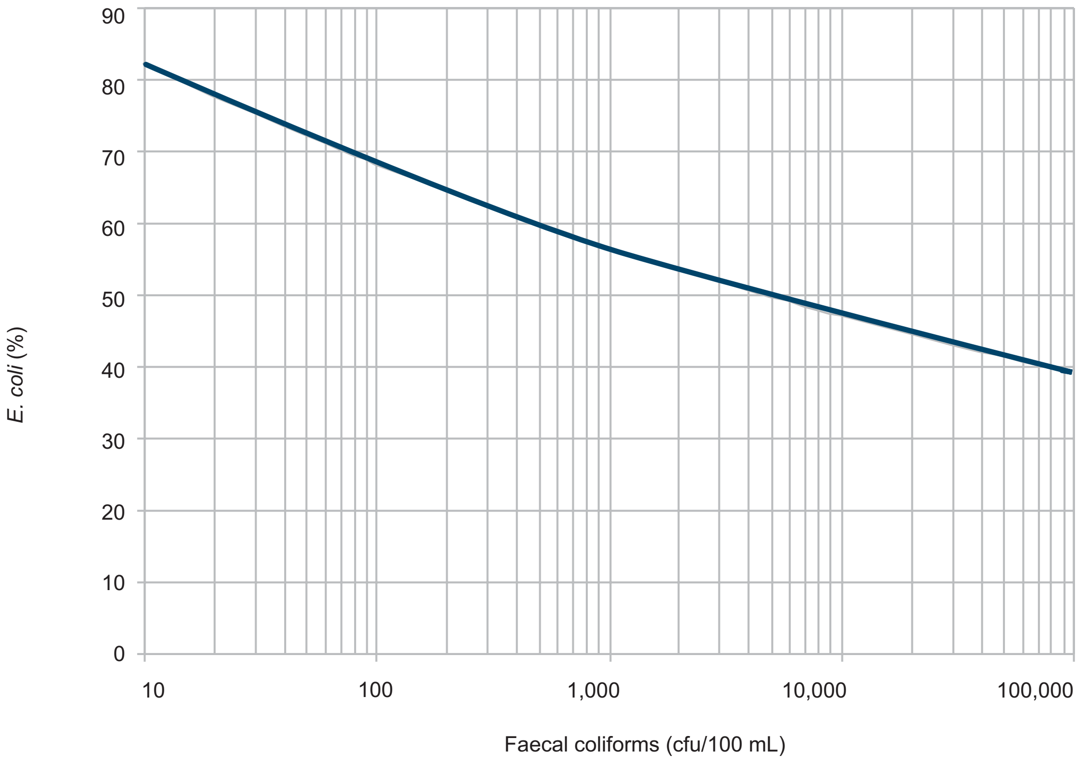

Figure C.1 Relationship between *E. coli* and faecal coliforms derived in Virginia, USA

C.3 Pathogens in stormwater

Table C.1 summarises reported *E. coli* levels in untreated urban stormwater, based on the faecal coliform data reported in Fletcher et al. (2004) and the VADEQ (2003) conversion equation (above). This table indicates that *E. coli* levels in stormwater run-off can be highly variable. The *E. coli* concentrations reported from residential catchments tend to be higher than those from industrial and commercial catchments (McCarthy et al. 2006), probably because of household pets.

For comparison, figure C.2 indicates the relative median levels of *E. coli* concentrations from various wastewater and rainwater streams, both raw and treated. The stormwater levels are typical outflow concentrations from conventional stormwater treatment measures (e.g. constructed wetlands) with no additional disinfection. The levels from the different streams should be compared cautiously as both sewage effluent and

Table C.1 Indicative *E. coli* levels in urban stormwater

Land use	Wet-weather concentration (cfu/100 mL)			Dry-weather concentration (cfu/100 mL)		
	Lower	Typical value	Upper	Lower	Typical value	Upper
Roofs	5	40	400	–	–	–
General urban	200	2,000	20,000	20,000	200	1,500
Residential	1,000	9,000	75,000	100	1,300	13,000
Industrial/ commercial	200	2,000	20,000	20	200	1,500

Source: modified from Fletcher et al. (2004)

stormwater quality depend heavily on the level of treatment provided as well as the inflow concentrations.

Figure C.2 highlights a trend in *E. coli* between water types, with relatively low levels in rainwater, moderate levels in stormwater, and high levels in raw wastewater. Treated stormwater tends to have higher bacterial levels than rainwater. There can, however, be considerable variability in these levels depending on catchment characteristics and rainfall event history.

Table C.2 provides a more detailed comparison of pathogen levels in urban stormwater (in wet-weather conditions) compared to sewage, and is derived from a literature review. Considerable variability in levels was found both within and between sites. Where data was sourced from North America or Europe, sites influenced by combined sewer overflows were not included. Combined sewer overflows considerably increase pathogen levels in stormwater and almost all sewerage systems in Australia are separate, rather than combined systems.

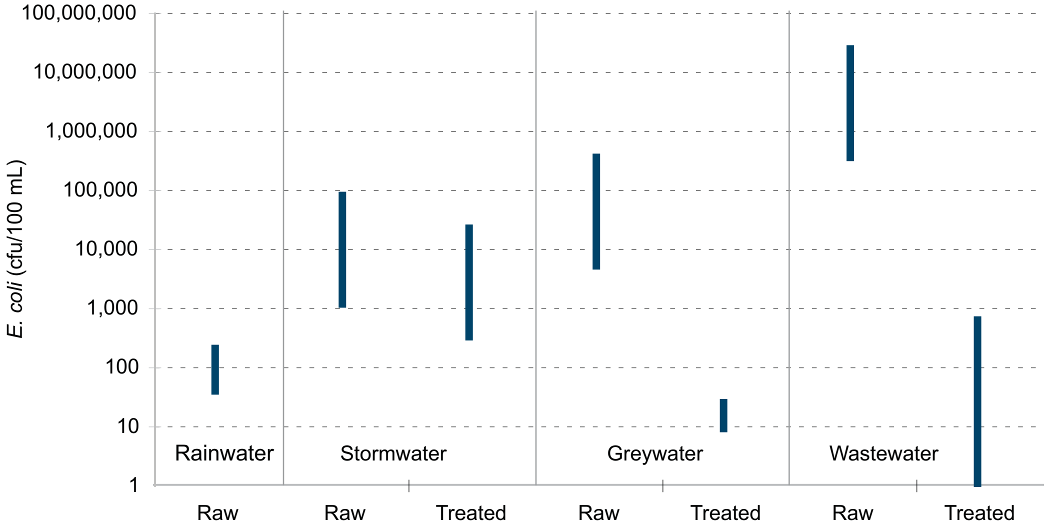

Figure C.2 Indicative median *E. coli* levels for rainwater, stormwater, greywater and wastewater

Source: adapted from Fletcher et al. (2004), NSW Health (2000), SWC (1998, 2004)

Monitoring of pathogens in stormwater has focused heavily on indicator organisms such as thermotolerant (faecal) coliforms and *E. coli*. Relatively limited monitoring data is available on the levels of other specific bacteria and viruses in stormwater, as is the case elsewhere, such as the USA (Smith & Perdek 2004). This limitation may hinder the application of a comprehensive risk-based approach contained in the draft national guidelines for water recycling (NRMMC & EPHC 2005).

In general, bacterial and viral concentrations are around two orders of magnitude lower in stormwater than in sewage. However, a direct comparison is difficult, due to different monitoring and reporting techniques used in the literature.

Table C.2 Reported levels of micro-organisms in stormwater and raw sewage

Bacteria	**Numbers in stormwater (per 100 mL)**	**Numbers in sewage (per 100 mL)**
Thermotolerant (faecal) coliforms[1,2,3]	$10^2 – 10^5$	
Escherichia coli[6, 8]	$10^2 – 10^6$	$10^4 – 10^9$
Faecal streptococci[2, 3, 4, 5, 6]	$10^2 – 10^5$	
Enterococci[6, 12, 13, 14]	$10^2 – 10^5$	$10^5 – 10^6$
Shigella	No data available	$10 – 10^3$
Salmonella[7, 12]	$0 – 10^1$	$10^2 – 10^4$
Clostridium perfringens[6]	$10^2 – 10^4$	$10^4 – 10^5$
Campylobacter[11]	$10^0 – 10^1$	
Viruses		
Enteroviruses[7, 12]	$10 – 10^2$	$10^1 – 10^5$
Adenoviruses[10, 12]	$10 – 10^3$	$10 – 10^3$
Noroviruses	No data available	$10 – 10^3$
Rotaviruses	No data available	$10^1 – 10^4$
Somatic coliphages (indicators)[5, 10, 15]	$10^1 – 10^5$	$10^5 – 10^8$
F-RNA coliphages (indicators)[10, 15]	$0 – 10^2$	$10^4 – 10^6$
Protozoans and helminths		
Cryptosporidium[9, 11]	$10^{-2} – 10^2$	$0 – 10^3$
Giardia[9]	$10^{-2} – 10$	$10^1 – 10^4$
Helminth ova	No data available	$0 – 10^3$

Source: Stormwater data – 1 Fletcher et al. (2004), 2 Engineers Australia (2005), 3 Duncan (1999), 4 Jagals et al. (1995), 5 Jagals (1997), 6 Leeming et al. (1998), 7 Oliveri et al. (1977), 8 McCarthy et al. (2006), 9 LeChavellier et al. (1991), 10 Jiang (2004), 11 CRCWQT, 12 Makepeace et al. (1995), 13 Davies & Bavor (2000), 14 Gannon & Busse (1989), 15 Davies et al.(2003). Sewage data – as cited in NRMMC & EPHC (2005)

C.4 Chemicals in stormwater

Table C.3 summarises the reported data on wet-weather concentrations of key chemicals in urban stormwater. The data reported in this table is from urban residential catchments – data from specific catchment types (e.g. industrial or roads) can be sourced from the references provided. In the table, the upper and lower concentrations are the mean +/– one standard deviation from the studies of Fletcher et al. (2004), Engineers Australia (2005) and Duncan (1999). As with the pathogen data in table C.2, chemical pollutant levels vary considerably both within and between sites. Where data was sourced from North America or Europe, sites influenced by combined sewer overflows were not included (where these could be identified).

Note that the nitrogen and phosphorus data was obtained from different sources, as no single source provided comprehensive data. Therefore the components of these nutrients (particularly nitrogen) do not necessarily sum to the quoted total nitrogen or phosphorus values.

For comparative purposes, typical values for raw municipal sewage and secondary treated STP effluent are also provided in this table. In general, nutrient and salinity levels are typically higher in effluent compared to urban stormwater, with the converse applying to metals.

Table C.3 Indicative stormwater, sewage and effluent concentrations

		Stormwater				
Constituent	**Units**	**Lower**	**Typical**	**Upper**	**Sewage**	**Effluent**
Suspended solids[1]	mg/L	40	140	500	300	n/a
Turbidity[2,3]	NTU	14	60	260		n/a
Total phosphorus[1]	mg/L	0.08	0.25	0.8	12	5.9
Filterable phosphorus[6]	µg/L	18	70	170		
Soluble phosphorus[5, 7]	mg/L	0.0381	0.129	3.52		
Total nitrogen[1]	mg/L	0.7	2	6	55	15.2
Total Kjeldahl nitrogen[5,6]	mg/L	1.73	3.02	4.7		
Ammonia[6]	mg/L	0.15	0.17	0.23		
Nitrate and nitrite[5,6]	mg/L	0.15	0.34	0.34		
Chemical oxygen demand[2,3]	mg/L	35	78	175		n/a
Biochemical oxygen demand[2,3]	mg/L	7	14	26	275	n/a
Total organic carbon[2,3]	mg/L	13	24	40		n/a
Oil and grease[1]	mg/L	3	9.5	30		n/a
pH[2,3]	–	6.3	6.9	7.5		7.9
Total dissolved salts[4]	mg/L	110	160	220		675
Electrical conductivity[4]	dS/m	0.17	0.25	0.34		1.3
Aluminium[7, 8]	mg/L	0.1	1.7	4.9		
Boron[8]	mg/L					289
Cadmium (total)[1]	µg/L	1	4.5	20		0.3
Chloride[7, 9]	mg/L	0.3	2.4	4.5		135
Chromium (total) [2,3]	µg/L	6	20	25		9.4
Copper (total)[1]	µg/L	20	80	300		23.5
Cyanide[7,8]	µg/L	2	33	80		
Iron (total)[2,3]	µg/L	800	2,700	9,000		722
Manganese (total) [2,3]	µg/L	80	230	660		35
Mercury (total)[2,3]	µg/L	0.06	0.22	0.78		0.1
Nickel (total)[2,3]	µg/L	14	24	25		7
Sodium[7, 9]	mg/L	0.18	10.7	21.3		181
Zinc (total)[1]	µg/L	100	300	1,000		48
PAH[7]	µg/L	0.24	0.77	1.3		
MTBE	µg/L		1.6			

Source: stormwater data – 1 Fletcher at al. (2004), 2 Engineers Australia (2005), 3 Duncan (1999), 4 Sharpin (1995), 5 Smullen et al. (1999), 6 SWC (1995), 7 Makepeace et al. (1995), 8 Dannecker et al. (1990). Sewage data – SWC (1998). Effluent data – NRMMC & EPHC (2005)

Note = total dissolved solids (TDS) levels were converted to electrical conductivity using the equation
EC (dS/m) x 670 = TDS (mg/L) (ANZECC & ARMCANZ 2000)

PAH: Polycyclic aromatic hydrocarbons

Appendix D: Maintenance costs

Table D.1 Estimated annual maintenance costs for stormwater treatment measures

Stormwater treatment measure		Estimated annual maintenance cost (% of construction cost)	Source(s)
Retention basins and constructed wetlands		~2% – 6%	Wiegand et al. (1986), Schueler (1987), SWRPC (1991), Livingston et al. (1997), Taylor & Wong (2002),
Infiltration trench		~5% – 20%	Schueler (1987), SWRPC (1991), Taylor & Wong (2002)
Sand filters		~11% – 13%	Livingston et al. (1997), Brown & Schueler (1997), Taylor & Wong (2002)
Vegetated swales		~5% – 30%	SWRPC (1991), UPRCT (2004)
Bioretention systems		~5% – 7%	SWRPC (1991), Taylor & Wong (2002)
Gross pollutant trap	Side entry pit	~ 30%	UPRCT (2004)
	Trash racks	~ 30%	UPRCT (2004)
	End of pipe devices	~ 10% – 25%	UPRCT (2004)
	Wet vault devices	~ 7%	UPRCT (2004)

Trash removal, Centenial Park

Appendix E: Water balance considerations

E.1 Water balance modelling

A water (mass) balance analysis is an essential part of developing a stormwater harvesting and reuse scheme. The water balance accounts for inputs to the scheme, primarily stormwater flows and any significant direct rainfall onto open storages, and outputs including:

- reuse water demand (for irrigation, this will be related to rainfall, evapotranspiration and infiltration, and is discussed further in section 6)
- evaporation from open storages
- exfiltration losses from open storages or permeable underground storages.

The key output from a water balance study is an analysis of the performance of the storage, in particular the:

- yield from storage (the volume supplied for reuse)
- volumetric reliability of supply (the proportion of the demand met by stormwater).

The analysis enables an assessment of the influence of different storage sizes and reuse demands on these key parameters. A water balance is usually undertaken over a relatively long period, for example a 10-year period that incorporates ‘average’, ‘wet’ and ‘dry’ years. A daily time step or smaller is normally used for the analysis.

A number of computer models are available for water balance analysis. Alternatively a spreadsheet analysis could be used for small schemes or for the preliminary analysis of larger schemes.

E.2 Relationships between storage size and demand

As noted in section 6, the relationship between storage size, stormwater reuse volume and annual run-off volume is complex and depends on the nature of the demand and the run-off characteristics.

Figure E.1 illustrates the results of an analysis undertaken for a hypothetical stormwater harvesting and reuse scheme that includes various levels of irrigation demand (derived from WBM 2004, 2005). This illustrates the interrelationship between demand, yield and storage size (expressed in volume per unit of catchment area). For a given storage size, the irrigation yield increases with the demand. This is because there is a greater chance of the storage having volume available for inflows. Where the demand is similar to the average annual run-off volume, significant storage sizes are required for the irrigation yield to approach the demand.

The figure also illustrates that for a given demand, there is a ‘point of diminishing returns’ in storage size, where increasing the size further does not provide a significant increase in yield.

Figure E.2 illustrates the variation in reliability of supply for this hypothetical reuse system (derived from WBM 2004, 2005). It also highlights the interrelationship between storage size, demand and reliability. As expected, reliability (the percentage of the demand that can be met by the available stormwater) decreases with increasing demand for a given storage size. These findings are similar to those of Mitchell et al. (2005).

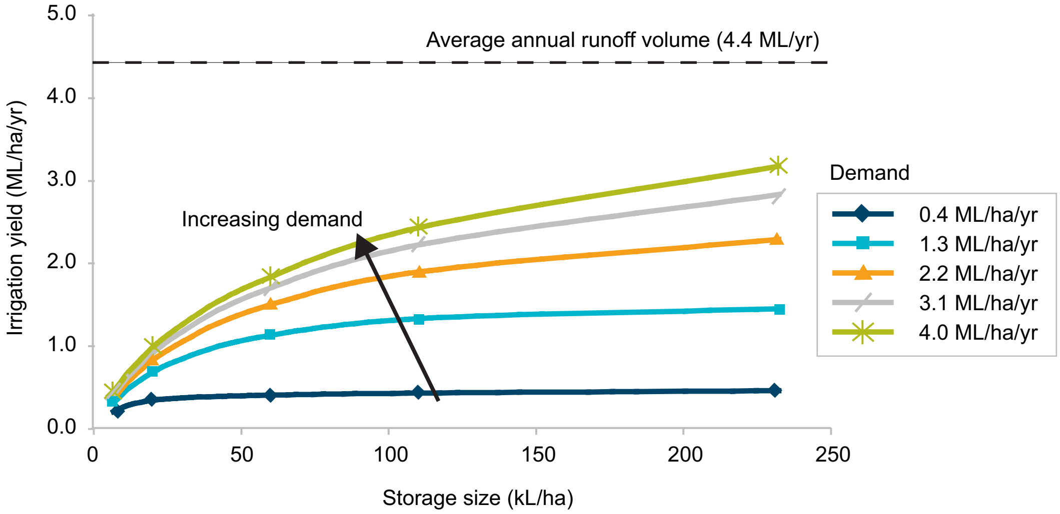

Figure E.1 **Illustrative relationship between storage volume, yield and demand**

Source: DEC, derived from WBM 2004, 2005

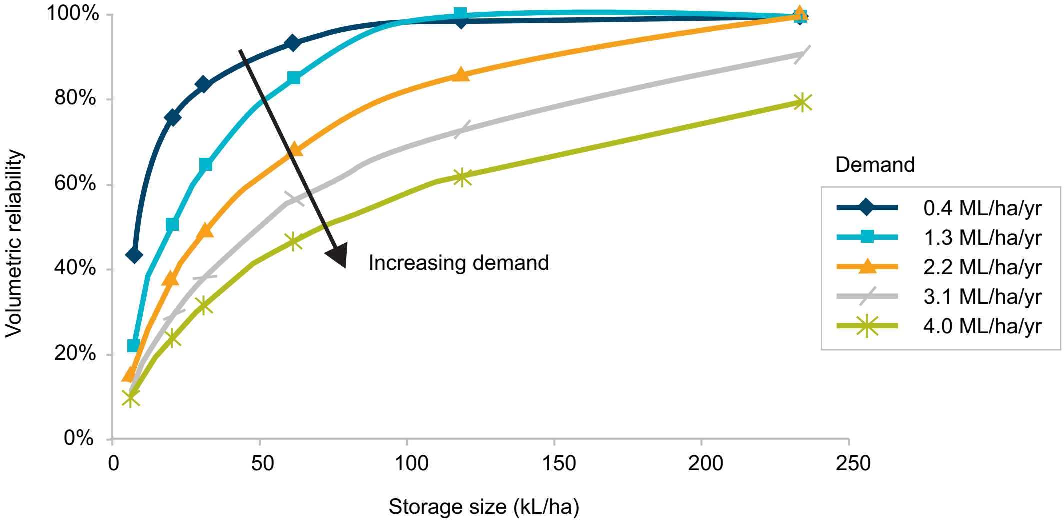

Figure E.2 **Illustrative relationship between storage volume, reliability and demand**

Source: DEC, derived from WBM 2004, 2005

The storage capacity can be either storage limited or supply limited. Where the average annual demand is equal to or less than the average annual run-off diverted into storage, the storage capacity is the factor that normally determines the reliability (storage limited). Where the average demand is greater than the average annual run-off, it will not be able to meet all the demand, irrespective of the size of the storage (supply limited).

There can be a range of combinations of demand and storage options available to achieve a target volumetric reliability. In general, the greater the demand or the variation in either the demand or the supply pattern, the greater the storage volume required for a given volumetric reliability of supply.

E.3 Influence of climate

Climatic conditions, particularly rainfall patterns, have a significant influence on stormwater harvesting reuse schemes. This particularly applies to schemes where irrigation is the end use, as both stormwater flows and irrigation demand are climate dependent.

This is illustrated in figure E.3 for a hypothetical urban development incorporating irrigation use in Sydney, Dubbo and Coffs Harbour (derived from WBM 2004, 2005). Dubbo is the driest site (annual rainfall of 580 mm) and while the demand is high, the available run-off is low. Coffs Harbour is the wettest site (1680 mm), however the irrigation yield is lower than the intermediate rainfall site (coastal Sydney – 1260 mm). This is because the higher rainfall satisfies more of the demand, whereas in Sydney there is still a reasonable demand (albeit lower than Dubbo) which can be readily met by stormwater.

The situation in Coffs Harbour is effectively demand limited, while in Dubbo a supply limit applies. This highlights the importance of water balance modelling for all projects.

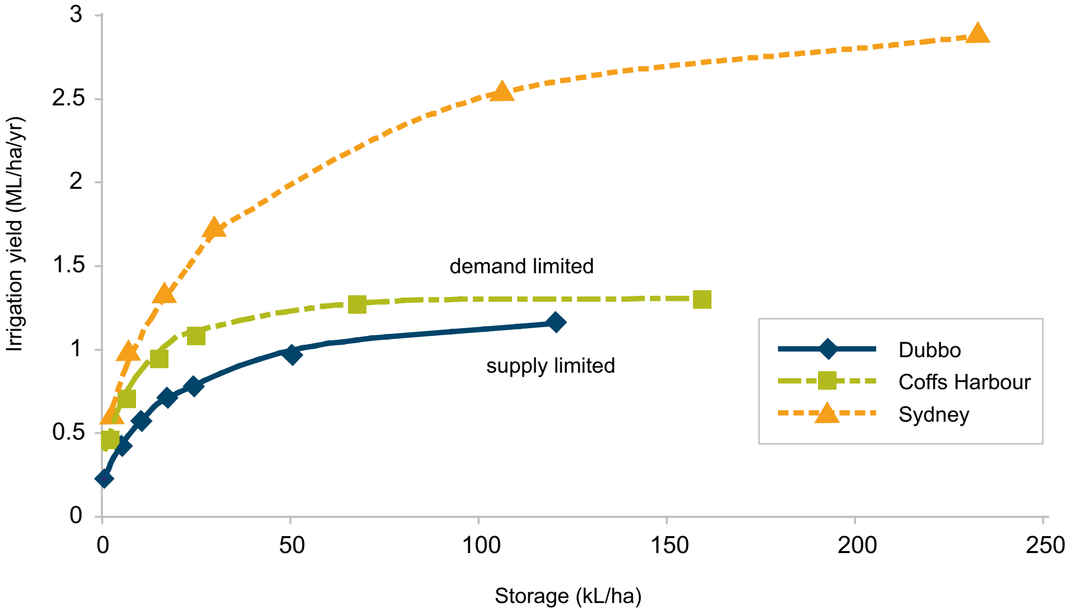

Figure E.3 Illustrative relationships between storage volume and irrigation yield

Source: DEC, derived from WBM 2004, 2005

The converse of this relationship applies when stormwater volume reductions are considered, as shown in figure E.4 (derived from WBM 2004, 2005). The highest reductions occur for the driest location (Dubbo), as a greater proportion of the annual stormwater run-off volume is captured and reused. In the wettest location (Coffs Harbour), a relatively small proportion of the stormwater run-off is reused, as the annual rainfall is high and the demand is relatively low. These run-off volume reductions correlate directly with stormwater pollution load reductions achieved by reuse (excluding any additional reductions achieved by on-line storages).

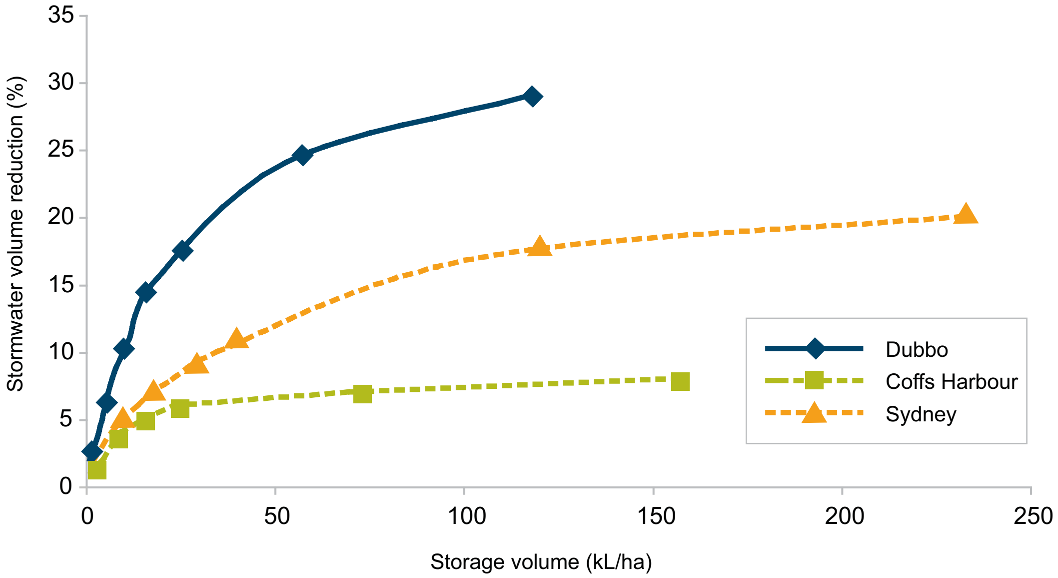

Figure E.4 **Illustrative relationship between storage volume and stormwater reductions**

Source: DEC, derived from WBM 2004, 2005

Glossary

Biochemical oxygen demand (BOD)	the decrease in oxygen content in a sample of water caused by the bacterial breakdown of organic matter.
Bioretention system	a stormwater treatment measure similar to a sand filter, in which vegetation is planted at the top of the filter in a soil filter medium. Also known as a biofiltration system.
Controlled public access	the limitation of public access to sites so as to minimise the likelihood of direct physical contact with reuse water.
Cost-benefit analysis	a method used to assess the costs and benefits of a proposal.
Cost-effectiveness analysis	a method used to find the least-cost means of meeting a single objective.
Cyanobacteria	the scientific name for blue-green algae
Discount rate	the percentage rate of compound interest at which future benefits and costs are adjusted to their equivalent present-day values in a cost-benefit analysis
Disinfection	destruction of disease-causing organisms.
E. coli	*Escherichia coli,* a common rod-shaped bacillus that indicates faecal contamination of water.
Electrical conductivity (EC)	a measure of the conduction of electricity through water. This can be used to determine the soluble salts content.
Eutrophication	enrichment of waters with nutrients causing excessive aquatic plant growth.
Evapotranspiration	the combined loss of water from a given area during a specified period of time by evaporation from the soil or water surface and transpiration from plants.
Gross pollutants	litter and debris transported by urban run-off.
Gross pollutant trap	a stormwater treatment measure that traps gross pollutants using a screen or trash rack.
Levelised unit costing	the present value of the costs over the planning period divided by the volume of water supplied or pollutant load removed over this period.
Life-cycle cost assessment	a method of costing that includes all costs incurred in the life of an item from inception through to decommissioning.

Log reduction	logarithmic (base 10) concentration reductions (e.g. 1 log reduction equals 90% reduction, 2 log reduction equals 99% reduction, 3 log reduction equals 99.9% reduction)
Mains water	potable water from a reticulated water supply, e.g. town water supply.
Nutrient	a substance that provides nourishment for an organism. For the purposes of stormwater run-off, the key nutrients are nitrogen and phosphorus.
Pathogen	an organism capable of eliciting disease symptoms in another organism (e.g. humans).
pH	value taken to represent acidity or alkalinity of an aqueous solution; expressed as the logarithm of the reciprocal of the hydrogen ion activity in moles per litre at a given temperature.
Potable water	water of drinking quality
Rainwater	water collected from the roofs of buildings.
Reuse	utilisation of water for domestic, commercial, agricultural or industrial purposes, which would otherwise be discharged to wastewater or stormwater systems.
Storage	an area, dam, pond, tank or other facility for storing water
Stormwater	rainfall that runs off all urban surfaces such as roofs, pavements, carparks, roads, gardens and vegetated open space.
Suspended solids (non-filterable residue)	the solids in suspension in water that are removable by laboratory filtering, usually by a filter of nominal pore size of about 1.2 micrometres (μm).
Swale	a shallow and wide grass-lined channel.
Treatable flow	the minimum flow that a pollution control device must be capable of treating without bypass.
Turkey's-nest dam	a dam constructed on a valley slope or plain rather than a watercourse, usually with no catchment.
Yield	the volume of water extracted from a stormwater system or creek and used in a stormwater harvesting and reuse scheme, usually expressed as an annual volume. This is a proportion of the annual runoff volume from the catchment, which can be termed the 'catchment yield'.

Abbreviations

ANZECC	Australian and New Zealand Environment Conservation Council
ARI	average recurrence interval
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ASR	aquifer storage and recovery
BASIX	building sustainability index
cfu	colony-forming units
CRCCH	Cooperative Research Centre for Catchment Hydrology
CRCWQT	Cooperative Research Centre for Water Quality and Treatment
DEC	Department of Environment and Conservation (NSW)
DEUS	Department of Energy, Utilities and Sustainability (NSW)
DPI	Department of Primary Industries (NSW)
EMP	environmental management plan
EPA	Environment Protection Authority (now part of the Department of Environment and Conservation in NSW)
EPHC	Environment Protection and Heritage Council
GPT	gross pollutant trap
ha	hectare (10,000 m^2)
HACCP	hazard analysis and critical control point
IPART	Independent Pricing and Regulatory Tribunal (NSW)
IPWEA	Institute of Public Works Engineering Australia
kL	kilolitre (1000 litres)
mL	millilitre (0.001 litres)
ML	megalitre (1,000,000 litres)
MPN	most probable number
NHMRC	National Health and Medical Research Council
NPV	net present value
NRMMC	Natural Resource Management Ministerial Council
NSW	New South Wales
NTU	nephelometric turbidity unit
NWQMS	National Water Quality Management Strategy

SA	South Australia
SS	suspended solids
STAR	stormwater treatment and reuse
STP	sewage treatment plant
TBL	triple bottom line
TDS	total dissolved solids
TN	total nitrogen
TP	total phosphorus
UV	ultraviolet
WSUD	water-sensitive urban design