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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

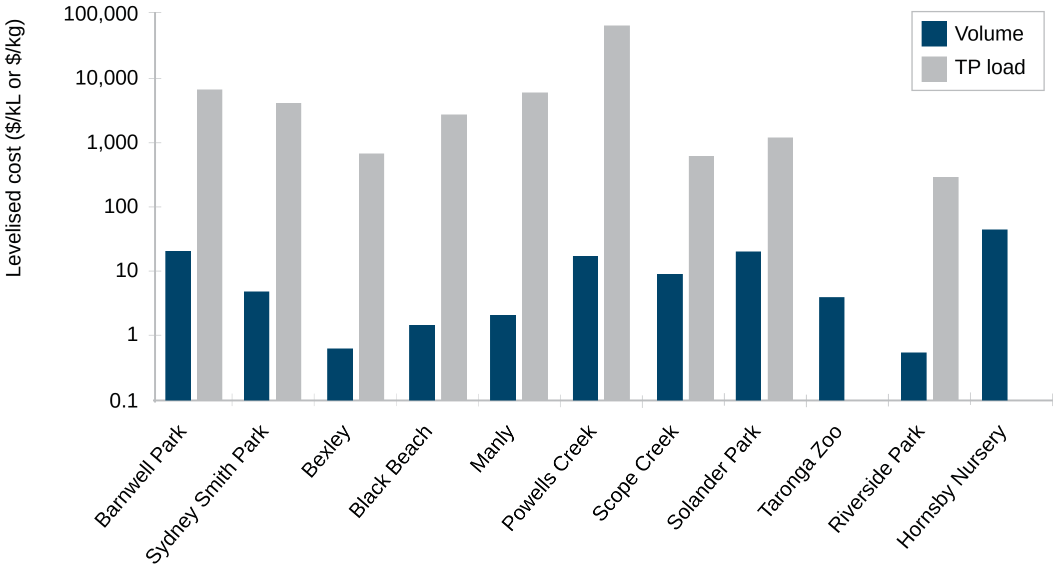

Figure 8.1 **Levelised unit costs for case studies**

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

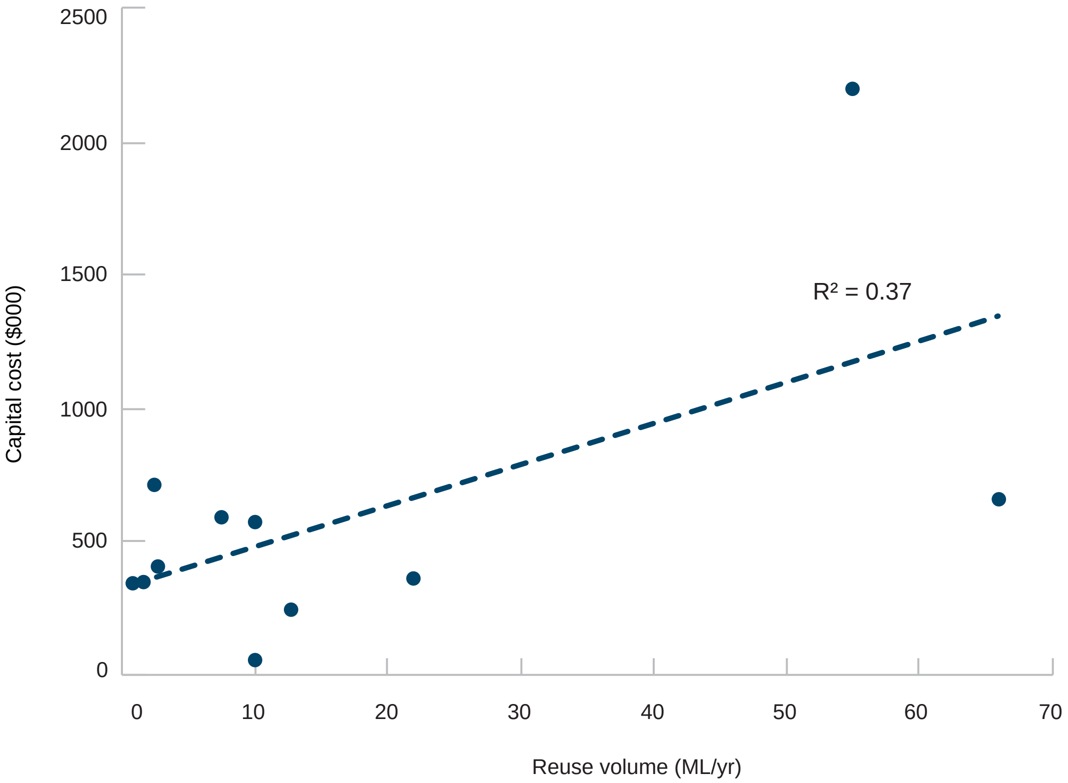

Figure 8.2 **Project costs for case studies**

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).

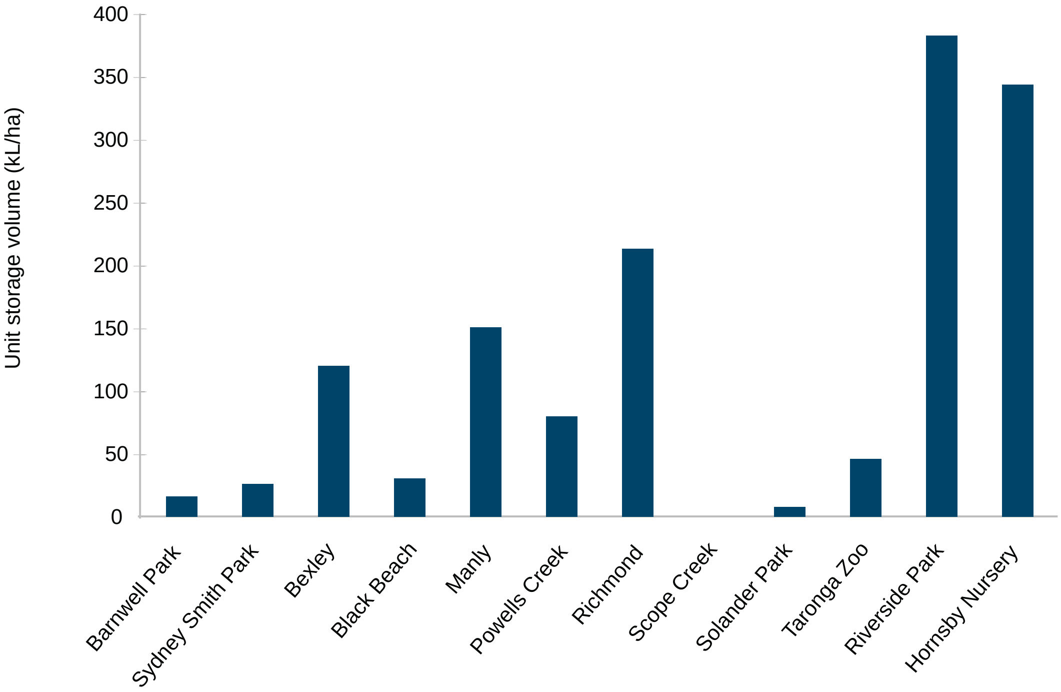

Figure 8.3 Unit storage volumes for case studies

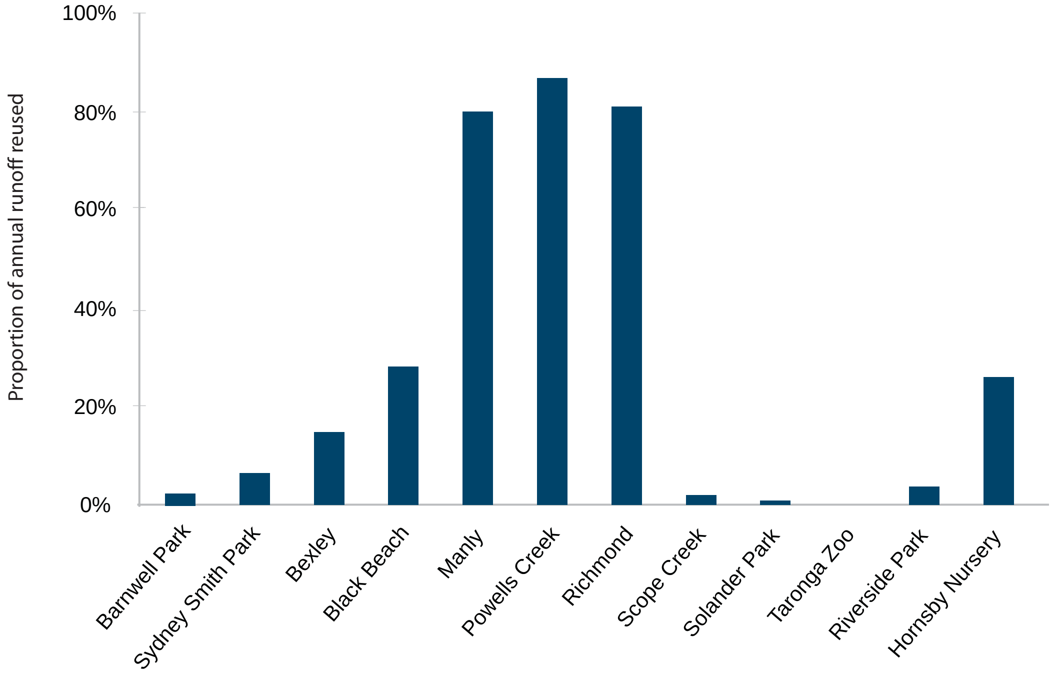

Figure 8.4 Run-off volume use for case studies

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.

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.

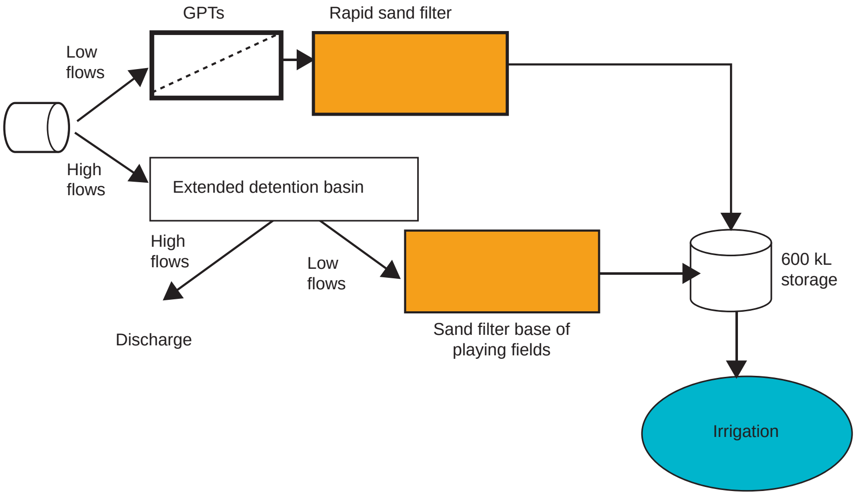


Figure A1 **Schematic diagram showing Sydney Smith Park stormwater reuse scheme**

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

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.

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.

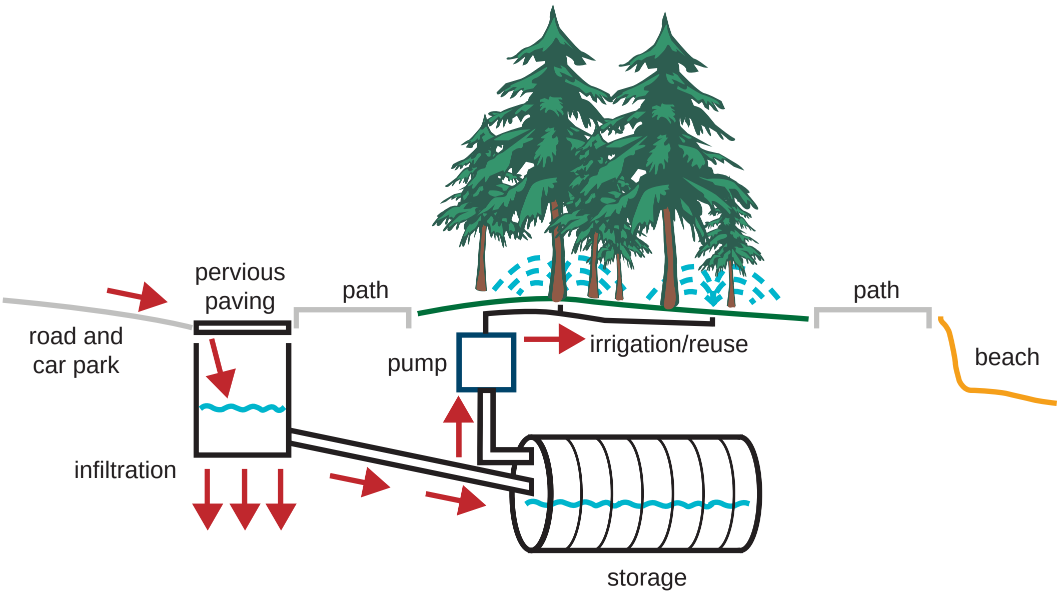
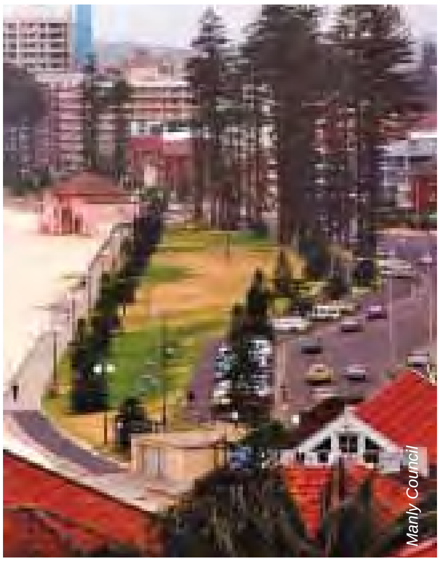


Figure A2 Infiltration and treatment system at Manly Beach

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 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.


Z Fink / DEC

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.


Z Fink / DEC

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.

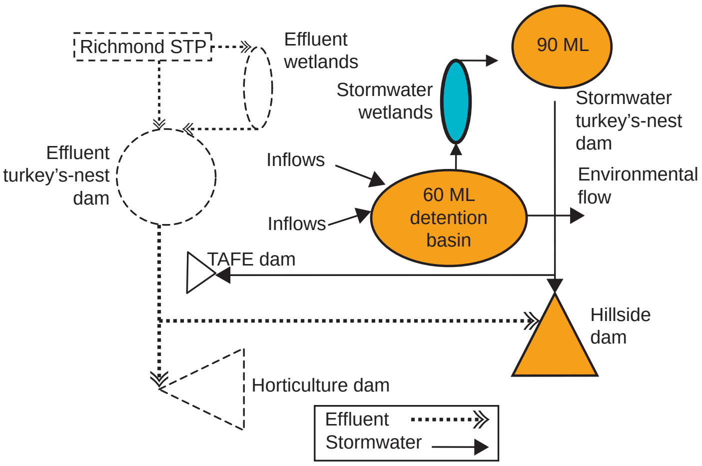


Figure A3 **Richmond model township stormwater reuse schematic**

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.

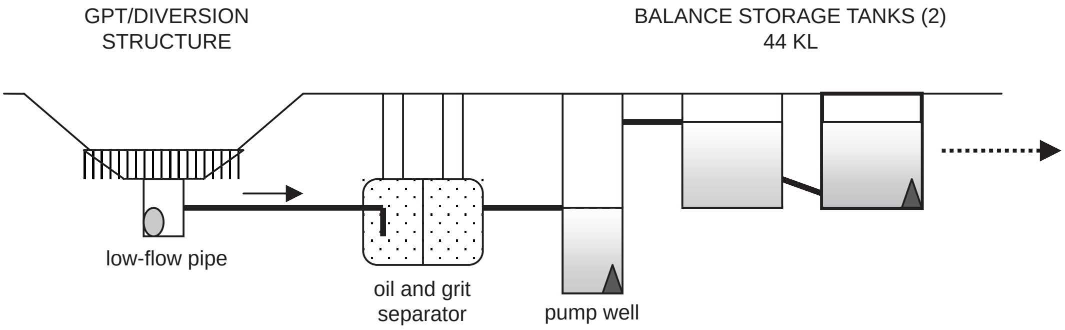


Figure A4 **Scope Creek treatment train**

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.


Z Fink/DEC

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


Z Fink/DEC

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.

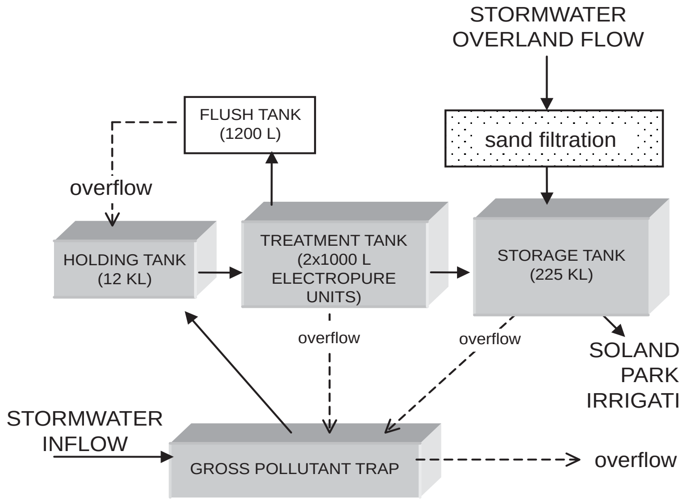


Figure A5 **Solander Park treatment and storage arrangements**

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

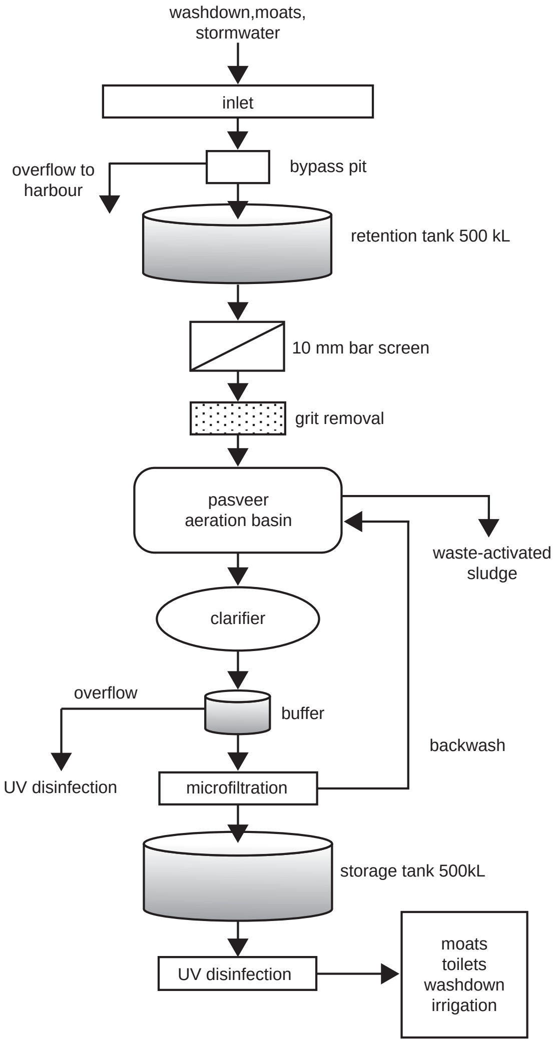


Figure A6 **Taronga Zoo water treatment process**

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

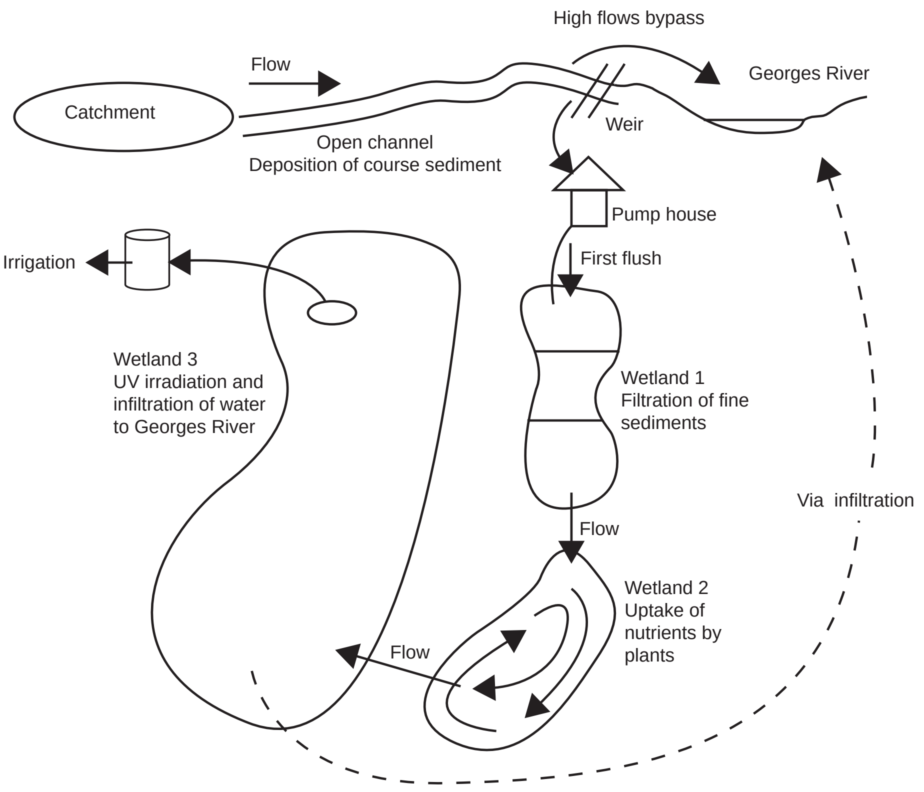


Figure A7 **Process diagram – Riverside Park, Chipping Norton**

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.

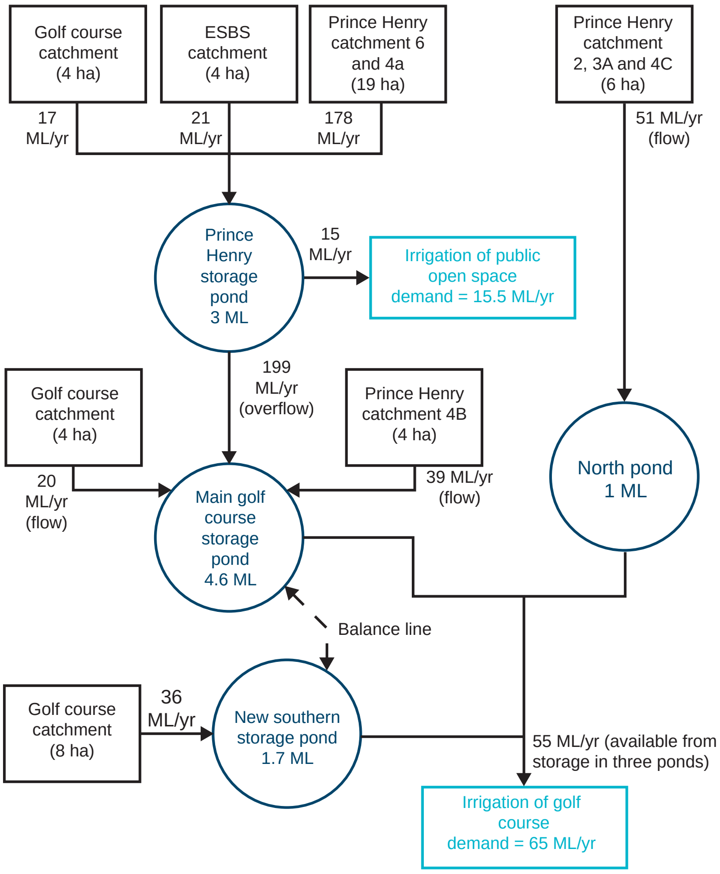


Figure A8 Golf course harvesting post-development

Source: Landcom

ESBS: Eastern suburbs Banksia scrub area

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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.

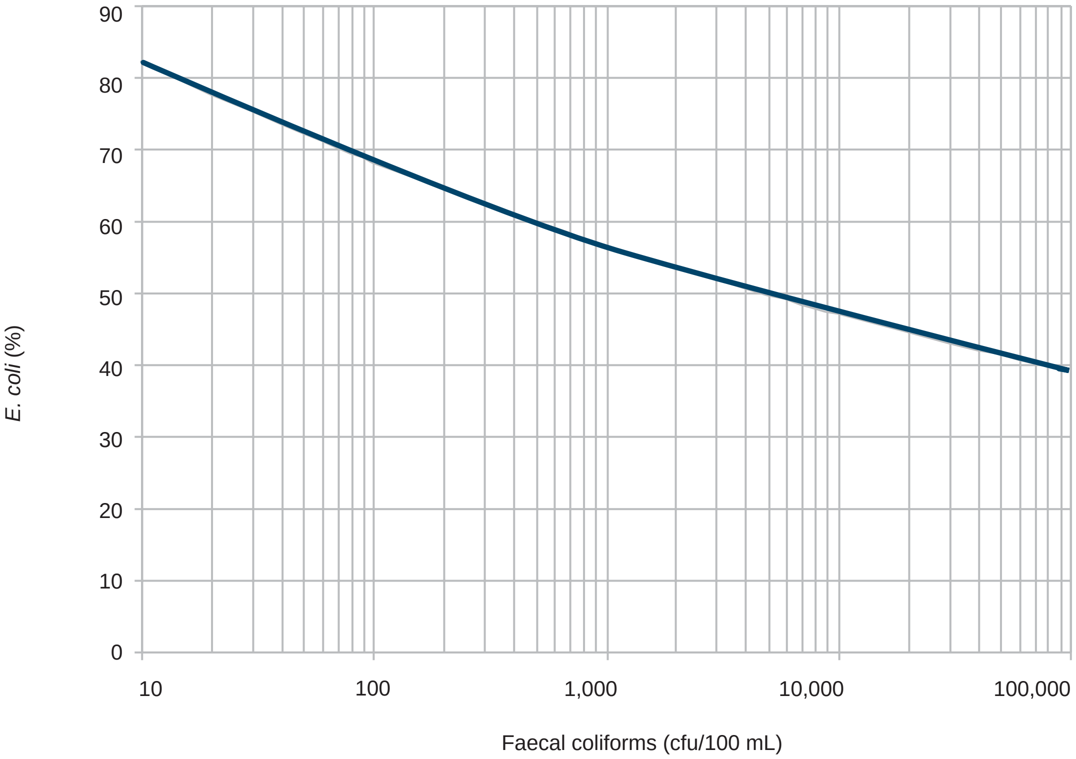

Figure C.1 Relationship between *E. coli* and faecal coliforms derived in Virginia, USA

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.

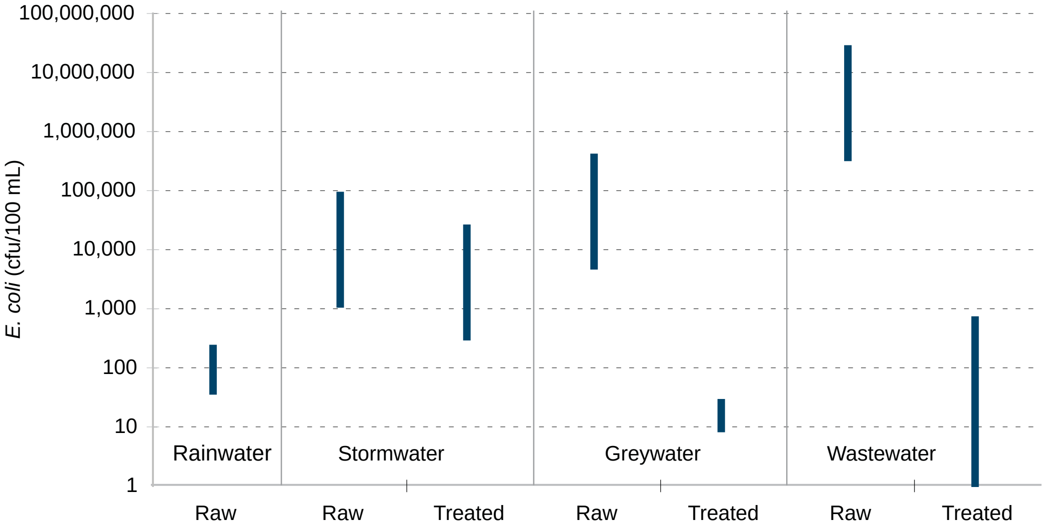

Figure C.2 Indicative median *E. coli* levels for rainwater, stormwater, greywater and wastewater

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)


M Sharpin/DEC

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).

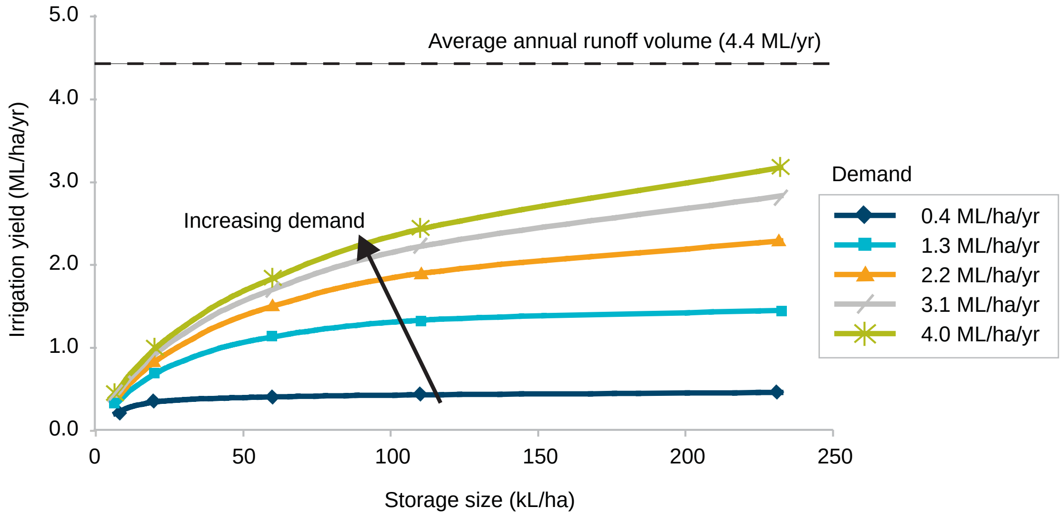

Figure E.1 Illustrative relationship between storage volume, yield and demand

Source: DEC, derived from WBM 2004, 2005

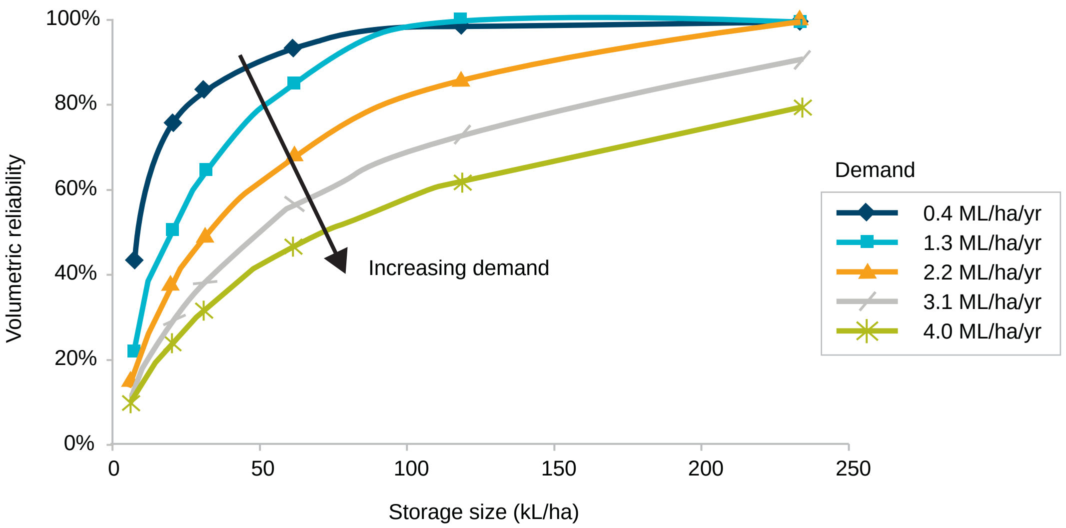

Figure E.2 Illustrative relationship between storage volume, reliability and demand

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.

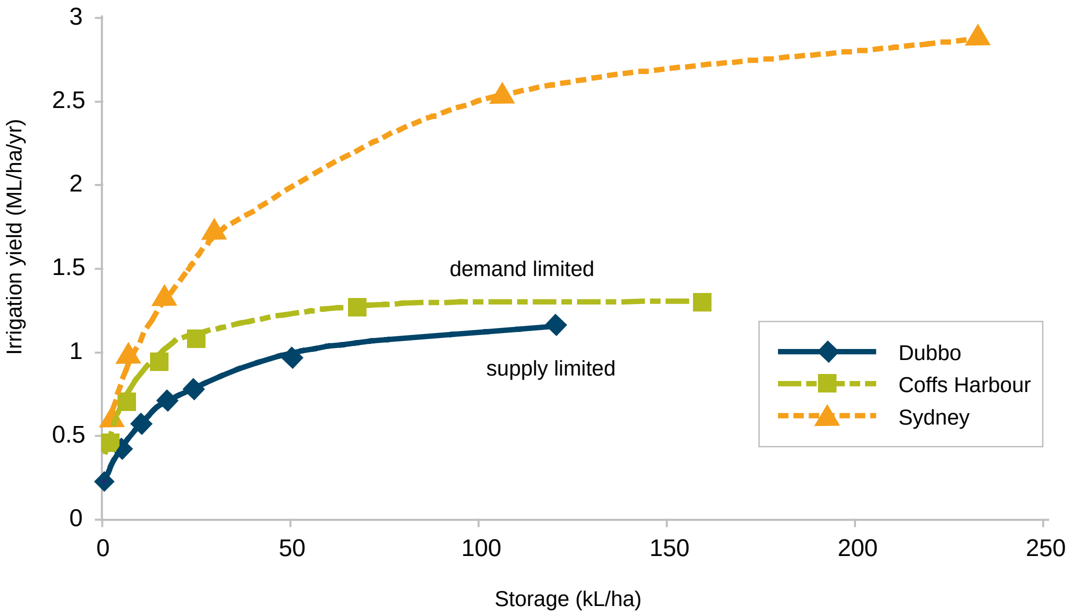

Figure E.3 Illustrative relationships between storage volume and irrigation yield

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).

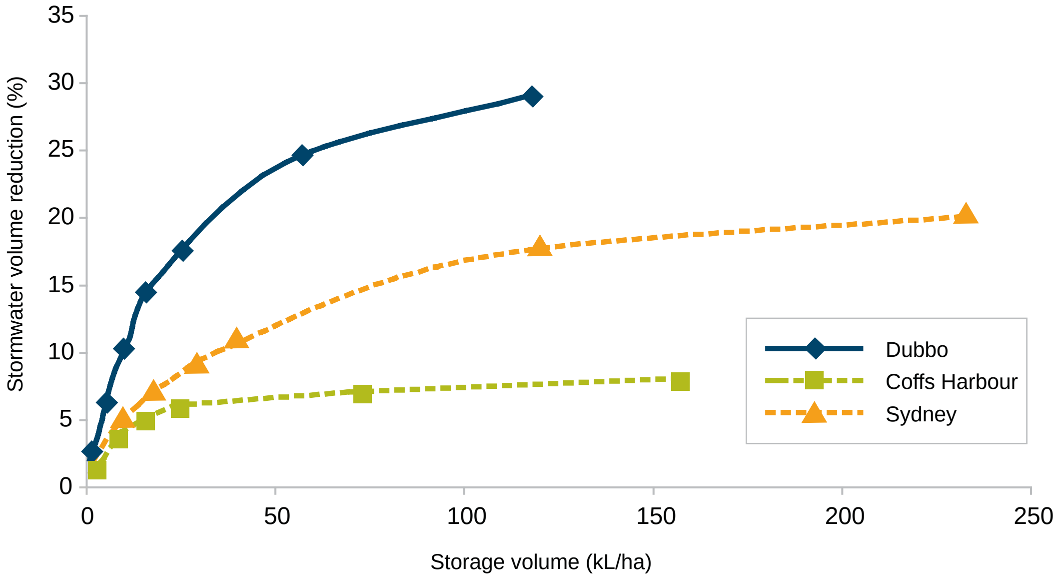

Figure E.4 **Illustrative relationship between storage volume and stormwater reductions**

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