NATIONAL WATER QUALITY MANAGEMENT STRATEGY

AUSTRALIAN GUIDELINES FOR WATER RECYCLING: MANAGING HEALTH AND ENVIRONMENTAL RISKS (PHASE 2)

23

STORMWATER HARVESTING AND REUSE

JULY 2009

Natural Resource Management Ministerial Council
Environment Protection and Heritage Council
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Australian Guidelines for Water Recycling

Stormwater Harvesting and Reuse

National Water Quality Management Strategy

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Contents

Abbreviations and acronyms

General

AHMC	Australian Health Ministers' Conference
ANZECC	Australian and New Zealand Environment and Conservation Council (replaced in 2001 by EPHC and NRMMC)
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand (replaced in 2001 by NRMMC)
AS	Australian Standard
CFU	colony forming unit
Ct	term used in disinfection to describe the product of disinfectant concentration ('C' in mg/L) and contact time ('t' in minutes)
DALY	disability adjusted life year/s
EPHC	Environment Protection and Heritage Council
MPN	most probable number
NHMRC	National Health and Medical Research Council
NRMMC	Natural Resource Management Ministerial Council
NTU	nephelometric turbidity units
NZS	New Zealand Standard
SAR	sodium adsorption ratio
UV	ultraviolet

Units

cm	centimetre
dS/m	deci-Siemens per metre
g	gram
km	kilometre
L	litre
m	metre
mg	milligram
mJ	millijoule
mm	millimetre
nm	nanometre
µg	microgram
µS	microsiemens

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1 Introduction

This publication is one of the three modules that comprise the second phase of the *Australian Guidelines for Water Recycling*, which address health and environmental risks associated with water recycling (see Box 1.1 below).

The guidelines as a whole, including this module, are designed to provide an authoritative reference that can be used to support beneficial and sustainable recycling of waters generated from sewage, grey water and stormwater, which represent an underused resource. The guidelines describe and support a broad range of recycling options, without advocating particular choices. It is up to communities as a whole to make decisions on uses of recycled water at individual locations. The intent of these guidelines is simply to provide the scientific basis for implementing those decisions in a safe and sustainable manner.

Box 1.1 Summary of Australia's existing and planned water recycling guidelines

National water recycling guidelines are being produced in two phases.

Phase 1

- *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks* (Natural Resource Ministerial Management Council (NRMMC), Environment Protection and Heritage Council (EPHC), Australian Health Ministers' Conference (AHMC) 2006).
  Phase 1 of the guidelines provides a generic 'framework for management of recycled water quality and use' that applies to all combinations of recycled water and end uses. It also provides specific guidance on the use of treated sewage and grey water for purposes other than drinking and environmental flows.

Phase 2

- *Australian Guidelines for Water Recycling: Augmentation of Drinking Water Supplies* (NRMMC–EPHC–National Health and Medical Research Council (NHMRC) 2008).
  The first module of Phase 2 of the guidelines extends the guidance given in Phase 1 on the planned use of recycled water (treated sewage and stormwater) to augment drinking water supplies.

- *Australian Guidelines for Water Recycling: Stormwater Harvesting and Reuse*.
  This current document is the second module of Phase 2 of the guidelines and extends the guidance given in Phase 1 to cover the harvesting and reuse of stormwater.

- *Australian Guidelines for Water Recycling: Managed Aquifer Recharge* (NRMMC–EPHC–NHMRC 2009).
  The third module of Phase 2 of the guidelines focuses primarily on the protection of aquifers and the quality of the recovered water in managed aquifer recharge projects.

1.1 Harvesting and reuse of stormwater and roofwater

Harvesting roofwater and urban stormwater for safe reuse has many potential benefits. It can help to reduce the impact of urban development on water quality and stream flow, and can also help to meet water conservation objectives. These potential benefits are important to the economic and environmental viability of many roofwater and stormwater reuse projects. Roofwater and stormwater reuse schemes are commonly used in water sensitive design strategies for new urban developments.

Roofwater harvesting generally involves installing rainwater tanks to collect roofwater from residential dwellings for uses such as garden watering and toilet flushing. There is increasing demand for harvesting roofwater from larger buildings, such as community halls, schools and commercial premises.

Stormwater harvesting involves collecting runoff from drains or creeks, and represents a relatively new form of water reuse compared to rainwater tanks and the reuse of effluent from sewage treatment plants. However, reuse of stormwater is increasingly seen as a potential option for meeting water demands and other objectives. At present, harvested stormwater is mainly used for irrigating public parks and golf courses. Strictly speaking, harvesting of stormwater might not be classified as 'reuse' or 'recycling', because the water has not been used previously. However, the term 'reuse' is used here to be consistent with the other publications that comprise the water recycling guidelines.

Roofwater and stormwater should be harvested in a way that minimises health and environmental risks, or at least reduces such risks to acceptable levels. Stormwater may contain chemicals and disease-causing microorganisms (pathogens). Roofwater generally has lower levels of chemical contaminants and pathogens than urban stormwater, which collects contaminants during its passage over roads and other surfaces, picking up chemicals and pathogens from environmental and sewage sources. Consequently, the health and environmental risks associated with roofwater reuse are typically lower than those associated with stormwater reuse in similar applications. The most commonly recognised illness associated with polluted water is gastroenteritis (with symptoms such as diarrhoea and vomiting) arising from waterborne pathogens following the drinking of contaminated water. Potential environmental risks include impacts on plants and soils in irrigation areas. The health risks tend to be acute, whereas environmental risks tend to be chronic, developing over time.

These guidelines have been developed on the basis that most roofwater and stormwater reuse schemes in Australia are relatively small compared to most wastewater recycling schemes (Hatt et al 2004, DEC NSW 2006), and are operated by organisations that are not water utilities (eg metropolitan councils and golf clubs). The guidelines have therefore been written to suit a nonspecialist reader involved in a small to medium-sized scheme, while also providing information for a specialist reader involved in a large scheme.

1.2 Purpose and scope of this document

The primary purpose of this document is to provide guidance on managing potential public health and environmental risks associated with the reuse of:

- roofwater collected from nonresidential buildings (including industrial buildings)
- urban stormwater from sewered areas, including stormwater collected from drains, waterways and wetlands.

These guidelines cover only nonpotable (ie non-drinking water) potential end uses of roofwater and stormwater (see Table A6.1 for a list of potential non-drinking uses of harvested roofwater and stormwater).

This document extends the scope of Phase 1 of the water recycling guidelines (NRMMC–EPHC–AHMC 2006), which focuses primarily on reuse of wastewater and grey water. The same risk-based management approach is used, and the technical approach adopted is identical (eg the approach to completing the underlying risk assessment, given in

Appendix 3). Appendix 1 outlines how these guidelines incorporate the 12-element risk management framework for recycled water quality and use.

These guidelines are primarily intended to support health and environmental risk management for proposed water harvesting and reuse schemes that draw source water from stormwater systems. These guidelines are not intended for retrospective application to existing schemes.

This document does not address:

- the potential benefits and limitations of schemes and the sizing of a scheme to meet other project objectives (eg assessing yield through a water balance) (for relevant information see DEC NSW 2006, Mitchell et al 2006)
- integrated urban water cycle planning or water sensitive urban design, which may provide a strategic context for stormwater reuse (national guidelines on water sensitive urban design are being prepared)
- rainwater reuse using domestic rainwater tanks (for relevant information see enHealth 2004)
- combined effluent and stormwater reuse schemes (for relevant information see NRMMC–EPHC–AHMC 2006)
- harvesting stormwater from predominantly nonurban catchments (eg rural or forested) (see ANZECC–ARMCANZ (2000a) for details)
- irrigation schemes using river water from largely nonurban catchments
- other aspects of a scheme’s risk management, including public safety, occupational health and safety, operation or construction-phase environmental management (for relevant information see DEC NSW 2006)
- potential environmental impacts due to the construction of infrastructure associated with a scheme (eg potential impacts on vegetation or threatened species)
- other aspects of designing and operating a successful scheme, including cost-effectiveness.

The target audience for these guidelines includes:

- planners, designers and operators of stormwater reuse schemes, which may include golf clubs, schools and other nonspecialist organisations
- planners, designers and operators of roofwater reuse schemes
- local councils, including the planning, environmental health, operational and environmental departments
- state government authorities, including health, environmental protection, water management and planning agencies
- water utilities.

1.3 Relationship to other national guidelines

The national guidelines for urban stormwater management were prepared by the Australian and New Zealand Environment and Conservation Council (ANZECC) and the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) (ANZECC–ARMCANZ 2000b) under the National Water Quality Management Strategy. The national guidelines focus on stormwater management in a water-quality protection context, and do not address stormwater reuse.

The use of stormwater for drinking purposes and for managed aquifer recharge is covered in the other two publications in Phase 2 of the water recycling guidelines.

The enHealth document *Guidance on the Use of Rainwater Tanks* (enHealth 2004) focuses on the management of public health risks for roofwater use from residential dwellings. Additional information is provided in the *Rainwater Tank Design and Installation Handbook* (Standards Australia 2008).

The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC–ARMCANZ 2000a) addresses water quality requirements for irrigation using river water. The document applies to schemes where only a small proportion of a catchment is urbanised.

1.4 Relationship to state and territory legislation and guidelines

These guidelines provide a risk management framework for the beneficial and sustainable management of roofwater and stormwater reuse systems. However, they are not mandatory and have no formal legal status. Alternative risk management practices can be used where these achieve the same outcomes for managing risks to health and the environment. National guidelines provide a shared national objective while allowing flexible responses to different circumstances at regional and local levels. All states and territories are encouraged to adopt the framework set out in this document, to help provide national consistency. Application of the framework may vary across states and territories depending on water management arrangements.

The roofwater and stormwater reuse systems addressed in this document may be regulated by states and territories, but are not regulated by the Australian Government. State or local jurisdictions may use their own legislative and regulatory tools to develop their own guidelines based on this document. Relevant state and territory regulations, standards or guidelines, where they exist, should be consulted to ensure that any local requirements are met. Where state and territory guidelines differ from this document, the state and territory guideline should be followed, or the local regulatory agency consulted to clarify requirements.

State and territory legislation relevant to a roofwater or stormwater harvesting project may relate to:

- planning approvals
- water resource allocation
- natural resource management, including works in watercourses or riparian zones
- public health
- pollution control
- dam safety.

1.5 How to use these guidelines

These guidelines assume that most roofwater schemes and small-to-medium stormwater reuse schemes involving open space irrigation can be readily managed using standard practices to minimise health and environmental risks. The document identifies some of these practices. Where schemes are larger or more complex, or where alternative management practices are proposed, the document provides additional guidance on how to conduct a risk assessment and identify appropriate risk management practices.

This approach is analogous to that adopted for regulating sewage treatment schemes in many states and territories. Small sewage treatment plants (eg package plants) are usually managed by reference to best-practice guidance, and medium-to-large plants are generally regulated by an environment protection agency on a case-by-case basis. This ensures that the greatest management effort is targeted at the highest risk plants.

In a stormwater reuse context the standard approach could be used, for example, for a scheme involving irrigation of a sporting oval or a golf course. Thus, the risks associated with a small irrigation scheme can be appropriately managed without the burden of a full risk assessment. However, for a larger municipal irrigation scheme or a scheme with other end uses (eg dual reticulation), a comprehensive risk assessment should be carried out using the 12-element framework from Phase 1 of the water recycling guidelines (NRMMC–EPHC–AHMC 2006), combined with the information in Appendixes 2–5. Such an assessment is particularly important when a scheme operator will be providing stormwater for reuse by a third party.

The standard management practices in these guidelines have been developed based on an analysis of available data on roofwater and stormwater quality. An individual scheme operator may carry out site-specific water-quality monitoring, and use this information to conduct a project-specific risk analysis, to identify alternative management practices (see the Phase 1 guidelines for further details, NRMMC–EPHC–AHMC 2006). To ensure consistency across different water sources for reuse, this document frequently refers to the guidance provided in the Phase 1 guidelines.

To maximise its usefulness to nonspecialist project developers, this document follows a conventional project development process. Chapters 2 and 3 include sections on the standard approach, project design and operations and maintenance. This structure differs from that of Phase 1 of the guidelines, which was designed more for water industry specialists. Appendix 1 of this document explains how a specialist reader familiar with the risk management framework in the Phase 1 guidelines can link the two sets of guidelines. Figure 1.1 provides a flowchart for the use of these guidelines.

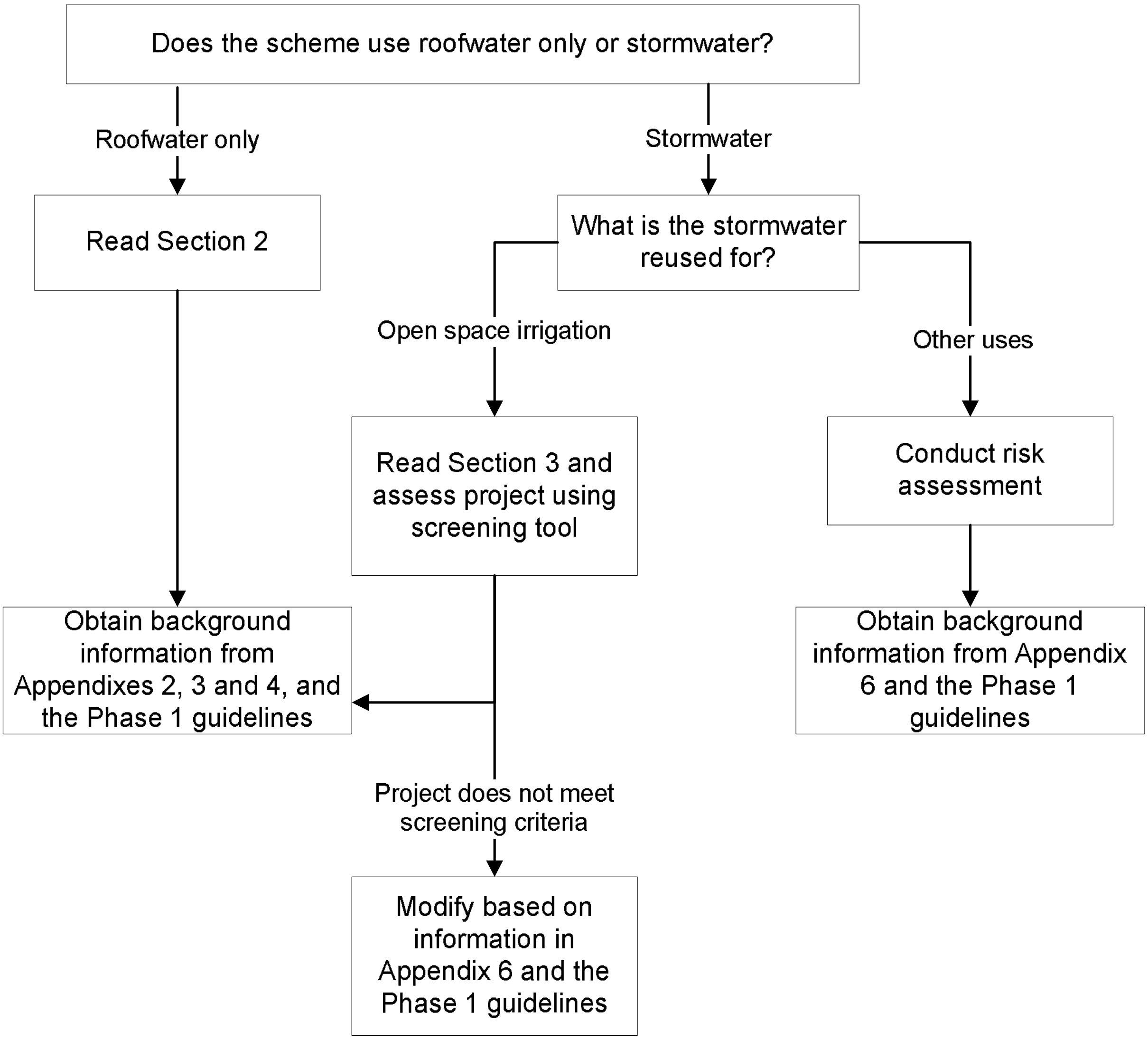


Figure 1.1 Structure and use of these guidelines

Chapter 2 describes a standard approach to managing health and environmental risks from roofwater reuse projects, including planning, design, maintenance and monitoring. This applies to roofwater schemes where the roofwater is stored in a tank and used on-site for landscape watering and toilet flushing.

Chapter 3 describes a standard approach to managing health and environmental risks, including planning, design, maintenance and monitoring, arising from a small-to-medium sized stormwater reuse project involving the irrigation of public open spaces — this is currently the most common type of stormwater reuse scheme. This chapter enables users to easily assess whether their stormwater reuse scheme has low health and environmental risks when standard management practices are used (effectively a ‘deemed to comply’ approach). It also allows users to identify where additional investigation is needed if certain aspects of their project present higher risks.

Appendixes provide detailed information on:

- the risk management framework (Appendix 1)
- the water-quality data used to develop the guidelines (Appendix 2)
- public health management considerations (Appendix 3)
- environmental risk management considerations (Appendix 4)
- additional risk management actions for stormwater reuse schemes outside the standard scheme described in Chapter 3; this information is generally presented as tier 1 and 2 actions, where a tier 1 action involves a relatively straightforward investigation and a tier 2 investigation is more detailed, allowing the level of the investigation to reflect the magnitude of the risk (Appendix 5)
- other applications (Appendix 6).

The information given in Appendixes 2–4 is intended to support the planning, design, operation and maintenance of roofwater and stormwater reuse schemes; it is intended for a more specialist audience, familiar with the Phase 1 guidelines.

2 Roofwater reuse

2.1 Application of standard approach

This section describes a standard approach that can be adopted for managing health and environmental risks from a roofwater collection scheme from buildings larger than a residential dwelling, such as:

- community halls (eg scout halls)
- public buildings
- schools
- commercial buildings (eg shopping centres, office blocks and warehouses).

Information on managing health risks associated with rainwater tanks for residential dwellings is provided in the *Guidance on Use of Rainwater Tanks* (enHealth 2004) and the *Rainwater Tank Design and Installation Handbook* (Standards Australia 2008). The approach in this section can, however, be used for a communal residential roofwater scheme where a single entity, such as a body corporate, manages the collection of roofwater from multiple residential dwellings for storage in one or more covered tanks and distribution for nonpotable uses.

This approach applies where the roofwater is **not** used as drinking water — suitable uses include garden watering, irrigation, toilet flushing, vehicle washing, firefighting and clothes washing — and where the roofwater is stored in a covered tank rather than an open storage (see Section A5.5 for information on open storages).

While there are many similarities between residential roofwater systems and those from larger nonresidential buildings, important differences that may affect the level of risk to human health include:

- potentially greater exposure to larger, sensitive populations (eg schools, nursing homes)
- liabilities associated with the supply of water by an organisation, rather than by a homeowner for household uses
- greater risk of cross-connections (ie the roofwater pipes being inadvertently connected to the potable water system) due to larger networks and more complicated systems
- more complex arrangements, with different people involved in planning, design and maintenance
- increased potential for access to roofwater by people unfamiliar with the system (eg more visitor access compared to access by household residents)
- generally larger roof areas, increasing the area for bird or animal droppings.

Thus, although most actions to minimise health risks from nonresidential schemes and residential reuse are similar, additional actions may be necessary to manage the risks identified above. These actions (described in Sections 2.2–2.4) have a strong emphasis on prevention and involve a number of different steps to prevent risks (often termed ‘multiple barriers’ in the water sector).

However, there is no requirement to follow this standard approach. Alternative risk management practices can be used where these achieve the same health and environmental risk management outcomes.

2.2 Preparatory steps

2.2.1 Organisational support

The organisation that owns or maintains the building whose roof is to be used to collect roofwater should be committed to the appropriate management of water collection, storage and reuse. Maintenance of the roofwater system is required to effectively manage health and environmental risks. Thus, before deciding to proceed with a project, the organisation needs to ensure that adequate funding is allocated for long-term effective maintenance. Such maintenance should be carried out by a nominated suitable person within the organisation or by an external contractor, such as a suitably qualified plumber. The organisation should also be committed to using monitoring data to improve the scheme's performance where required.

2.2.2 Legal requirements

Before starting the project, the local council or other regulatory authority should be contacted to determine whether there are any specific requirements that need to be met for roofwater harvesting schemes. The guidelines in this document do not override state and territory or council requirements.

2.2.3 Roof characteristics

The particular characteristics of a roof affect roofwater quality. Before starting the project, it is recommended that the roof be inspected. Ideally, the roof should not have:

- public access (roofs with maintenance access are acceptable)
- vehicular access
- structures above the roof that may rust or corrode (eg unpainted metal or concrete), or provide a resting place for birds
- discharge, overflow or bleed-off pipes from roof-mounted appliances, such as airconditioning units, hot water services and solar heaters
- a flue from a slow combustion heater that is not installed in accordance with the relevant Australian standard
- a chimney or flue from an industrial process within or adjacent to the building
- exposure to chemical sprays from processes within the building (eg spray painting) that may be deposited on the roof
- significant atmospheric deposition of pollutants (eg from industrial sources or from aerial spraying)
- vegetation growing on the roof (eg a 'green roof').

These characteristics may result in significant increases in pathogen levels or chemical concentrations, which may increase health risks. If a roof has these characteristics, roofwater quality should be monitored for relevant contaminants, and any associated health and environmental risks should be assessed before proceeding with the project.

Any lead flashing or exposed areas painted with lead-based paints should be painted with a non-lead-based paint or otherwise sealed. Asbestos roofing material should, as far as is practicable, be left undisturbed since fibres can be released into the air by actions such as cutting, grinding or drilling. High-pressure roof cleaning methods should also be avoided. Where the roof catchment area has deteriorated badly, it should be replaced with asbestos-free substitutes (enHealth 2004).

Roofwater quality can be further protected by excluding:

- copper roofing material (see also Section 2.4)
- overhanging vegetation that may attract birds and drop debris onto the roof
- bitumen-based materials or lead-based paints
- exposure to preservative-treated wood.

2.3 Project design

The design of a roofwater collection system can minimise health risks; relevant design aspects include the storage tank, gutters, pipework and the connection between the tank and the mainswater supply.

Disinfection of roofwater is not required for the uses noted in Section 2.1, provided the system design and maintenance controls noted in Sections 2.3 and 2.4 are implemented. However, an individual scheme operator may choose to include disinfection to provide an additional safety barrier.

2.3.1 Tanks

Tanks for storing roofwater are available in a range of suitable materials, including galvanised steel, fibreglass, polyethylene and concrete, and may be rigid or flexible. The main requirements for these storages for nonpotable roofwater use are that they are structurally sound, watertight and light-proof; that they incorporate access openings for monitoring and maintenance; and that any openings are appropriately screened, to minimise the potential for mosquito-borne diseases (see below). The sizing of a tank and its roof area to meet particular water supply needs is beyond the scope of this document.

The following guidance relating to the design and manufacturing of potable rainwater tanks (Standards Australia 2008) may be followed to meet or exceed the requirements for nonpotable roofwater storage:

- above-ground polyethylene tanks may be designed and manufactured in accordance with Australian Standard/New Zealand Standard (AS/NZS) 4766:2006 *Polyethylene Storage Tanks for Water and Chemicals*
- tanks manufactured from other materials may meet the requirements of Australian Technical Standard (ATS) 5200.026–2004 *Technical Specification for Plumbing and*

Drainage Products — Cold Water Storage Tanks, AS/NZS 1546.1 *On-site Domestic Wastewater Treatment Units—Septic Tanks*, or AS 3735-2001 *Concrete Structures Retaining Liquids*, as applicable

- tanks may be lined with a coating that meets the requirements of AS 5200.000 *Technical Specification for Plumbing and Drainage Products*.

Overflows from above-ground tanks and vents should be provided with a securely fastened vermin and insect-proof screen mesh, with holes less than 1.6 mm in diameter. Where a tank receives roofwater directly from a downpipe, the tank inlet should be provided with a screen to prevent leaf entry, and a robust insect-proof mesh to prevent entry of mosquitoes and other insects.

The access openings for above-ground tanks should have a close-fitting, impervious lid to prevent the entry of animals, insects and rubbish. Access and inspection openings for underground tanks should be either watertight or raised above ground level, to prevent the entry of surface runoff.

If an underground tank is buried in contaminated land, or near petroleum or chemical storage tanks or septic tanks, the tank needs to be designed to prevent any contamination of the roofwater.

Where the overflow pipe from an underground tank is connected to a stormwater system, the overflow should be designed to prevent any stormwater surcharging back into the tank.

2.3.2 Gutters

Gutters should not be rusty or corroded and should freely drain to the downpipe/s used to collect the roofwater (ie there should be no ponding of water in the gutter or downpipes).

Roof drainage systems should be designed in accordance with AS/NZS 3500.3 *Plumbing and Drainage — Stormwater Drainage*. To avoid ponding of water in gutters or downpipes, the fall on eaves, gutters or downpipes should be at least 1:500 (0.2%) and at least 1:200 (0.5%) for box gutters and internal guttering. Leaf-protection devices can be installed on gutters where needed.

2.3.3 Pipework and connections to mainswater

Pipework connecting the tank to plumbing fixtures should comply with AS/NZS 3500.1 Plumbing and Drainage — Water Services, and any local requirements, including:

- marking the pipe with the word 'RAINWATER', in capital letters
- where the roofwater system includes a connection to the mainswater supply (eg for top-up supply), ensuring that reliable and, ideally, testable backflow prevention systems (or an appropriate air gap) are in place to prevent roofwater entering the mainswater supply network.

Where roofwater is used to supply essential services, such as toilet flushing, an appropriate backup water supply, such as top-up from mainswater, needs to be included, to ensure that services will continue to function when there is inadequate rainfall to meet demand or the roofwater harvesting system fails.

A 'DO NOT DRINK' sign with appropriate symbols should be installed next to the tap in place of the recommendations for tap signage contained in AS/NZS 3500.1 *Plumbing and Drainage — Water Services*. Signs should comply with AS 1319 *Safety Signs for the Occupational Environment*. These signs are particularly important where a building also has external taps connected to the drinking water system.

Where sensitive groups could be exposed, additional controls to reduce the likelihood of exposure should be considered, such as locating external taps approximately 1.5 m above the ground. Sensitive groups include people who come from a non-English speaking background or who might not understand or follow signage (eg in childcare centres and health-care facilities).

2.4 Operations, maintenance and monitoring

Where sensitive groups are likely to be exposed, garden watering and irrigation using roofwater should be carried out at times and locations that reasonably minimise the chances of public contact with the roofwater. As with any irrigation scheme, the irrigation rate should meet the needs of the irrigated plants, and not cause excessive runoff or soil saturation.

If the roofwater is to be used for garden watering or irrigation, environmentally hazardous chemicals, such as roof-cleansing biocides, should not be used.

Irrigation or garden watering using roofwater from copper or zinc-coated roofs — including galvanised roofs or structures with exposed galvanised or zinc-containing materials (eg galvanised or zinc–aluminium roofing material, galvanised bracing and antenna supports) should generally be limited to an application rate of less than 300 mm/year.

Soils in the irrigation area should be monitored after 10 years and then after every 5 years to test whether copper and zinc levels have reached potentially hazardous levels (see Appendix 4). Specific monitoring requirements may apply in sensitive environments, such as an area where groundwater is a source for domestic consumption.

Alternatively, where roofwater from copper or zinc-coated roofs is used, roofwater quality monitoring could be carried out before use. Where this monitoring indicates that the environmental risk is low, the recommended limits to application rates would not apply.

Indicative inspection and maintenance actions for roofwater reuse systems are given in Table 2.1. A maintenance schedule should be set up during the design phase, and an inspection and maintenance log prepared to enable staff or contractors to sign off on completion of the activities. Where the pipework of the roofwater scheme is complex (ie more complex than that for a simple residential rainwater tank scheme), drawings showing the pipework and the backflow prevention devices should be kept with the maintenance log. This is important for effective maintenance, particularly to ensure that critical knowledge is not lost with staff changes.

Table 2.1 Inspection and maintenance of roofwater reuse systems

Indicative frequency	Inspection and criteria	Maintenance action (where required)
Quarterly	Check whether any tree branches overhang the roof or are likely to grow to overhang the roof	If safe and where permitted, consider pruning back overhanging branches
	Check that access covers to storage tanks are closed	Secure open access covers to prevent risk of entry
	Check that screens on inlets, overflows and other openings do not have holes and are securely fastened	Repair defective screens to keep out mosquitoes
	Inspect tank water for presence of rats, birds, frogs, lizards or other animals	Remove infestations, identify point of entry and close using gnaw-proof mesh with holes no greater than 2 cm in diameter
	Inspect tank water for presence of mosquito larvae (inspect more frequently based on local requirements in subtropical and tropical northern Australia)	Identify point of entry and close with insect-proof mesh with holes no greater than 1.6 mm in diameter
	Inspect gutters for leaf accumulation and ponding	Clean leaves from gutters; remove more regularly if required. If water is ponding, repair gutter to ensure water flows to downpipe
	Check signage at external roofwater taps	Replace or repair the missing or damaged signage
	Check first-flush diverter if present	Clean first-flush diverter; repair and replace if necessary
	Check health of irrigation area and irrigated grass or plants	Investigate observed adverse impacts that could be due to irrigation
Every year	Check for cross-connections and inappropriate tappings by checking visible plumbing fittings, alternatively turning off supplies. Also check after any plumbing work	Remove cross-connections and inappropriate tappings
	Check condition of roof and coatings	Investigate and resolve apparent changes to roof condition, such as loss of material coatings

Table 2.1 (continued)

Indicative frequency	Inspection and criteria	Maintenance action (where required)
Every 3 years	Drain, clean out and check the condition of the tank walls and roof to ensure no holes have arisen due to tank deterioration	Repair tank defects
	Check sediment levels in the tank	Organise a suitable contractor to remove accumulated sediment if levels are threatening to block tank outlets or are affecting water quality
	Undertake a systematic review of operational control of risks to the system	Identify the reason for any problems identified and take actions to prevent failures occurring in future
After 10 years and then every 5 years	Monitor soil copper and zinc levels	Stop roofwater irrigation if levels exceed criteria
After 20 years and then every 5 years	Monitor the effectiveness of any irrigation equipment over 20 years old for clogging due to algal growth	Clean or replace any clogged equipment

Note: These recommendations do not supersede any relevant state or territory requirements.

Maintenance should also include inspection and follow up on any complaints or concerns raised that could indicate problems with the system.

Monitoring should be designed to identify any problems with the system's operations (eg potentially system-related health problems where a reasonably static population is exposed, such as childcare facilities, and effects on plants watered by roofwater). However, it is not necessary to undertake routine monitoring of the quality of roofwater used for garden watering, toilet flushing and laundry use.

2.5 Nonresidential roofwater reuse checklist

This checklist summarises the key health and environmental risk management actions for a nonresidential roofwater scheme where there is no intentional drinking or contact with roofwater.

- o Planning and other regulatory requirements are met.
- o The operating organisation is committed to the safe collection and use of roofwater, including ensuring appropriate operation and maintenance.

- The likelihood of accidental drinking of roofwater is minimised through appropriate signage and tap design.
- Backflow prevention devices protect the public water supply off-site.
- Reliable insect-proofing prevents mosquitoes breeding in tanks.
- Backup water supplies are available for essential services.
- Time, method and location of any roofwater irrigation are selected to reasonably minimise public contact with the roofwater and avoid runoff or soil saturation.
- Roof-cleansing biocides or environmentally hazardous chemicals are not used on the roof.
- Irrigation or garden watering using roofwater from copper or zinc roofs is avoided unless roofwater quality monitoring is undertaken or irrigation is limited, unless soil monitoring is carried out.
- Risk management actions are documented.
- Appropriate maintenance is carried out.

3 Stormwater reuse

3.1 Reuse application

This section describes a standard approach that can be adopted for managing the health and environmental risks from an urban stormwater reuse scheme involving the irrigation of small-to-medium scale open-space irrigation schemes, such as:

- playing fields
- golf courses
- bowling greens
- parks and gardens.

There is no requirement to follow this standard approach. Alternative risk management practices can be used to achieve the same health and environmental risk management outcomes, as described in Appendixes 3 and 4, and the Phase 1 guidelines (NRMMC–EPHC–AHMC 2006).

For large schemes, schemes with other applications and schemes where stormwater is supplied to a third party, a risk assessment should be carried out, as described in Appendix 6, which links to the Phase 1 guidelines (NRMMC–EPHC–AHMC 2006). A risk assessment should also be done when the primary purpose is open-space irrigation but possible ancillary uses result in higher public exposure (eg toilet flushing in the amenities building of a sports field). Applications other than irrigation of public open spaces include:

- toilet flushing
- washing machine use
- car washing
- roadmaking or dust control
- street cleaning
- firefighting
- water features and ponds
- food crop irrigation (home grown)
- food crop irrigation (commercial)
- agricultural uses (crops other than food)
- dual reticulation
- industrial uses.

Stormwater quality varies considerably between storm events, and between catchments (see Appendix 2). This variability is greater than that observed in roofwater quality. The approach outlined here is relatively conservative, and an individual operator could undertake site-specific monitoring to assess whether less conservative risk management actions would be appropriate. This should involve reference pathogen monitoring (see Appendix 3), because no statistically valid relationship has been found between levels of pathogens and of indicator bacteria such as *Escherichia coli* (*E. coli)* (see Appendix 2).

The approach involves:

- using a project screening tool to assess whether a stormwater public, open-space irrigation project can be readily designed to manage associated health and environmental risks
- implementing the standard risk management actions outlined in Sections 3.2–3.4
- carrying out any additional investigations triggered by the screening tool, and implementing any associated risk management actions.

The project screening tool is presented in Table 3.1 and its derivation is described in Appendix 5. Use of the tool involves:

- collecting data and information about the reuse project being considered
- identifying any other risks that need to be managed beyond those readily managed by the standard approach (managing these additional risks requires additional investigations, as detailed in Appendix 5).

Figure 3.1 illustrates how to use the project screening tool. Other risk management actions may be required to meet statutory requirements or other project objectives on a case-by-case basis.

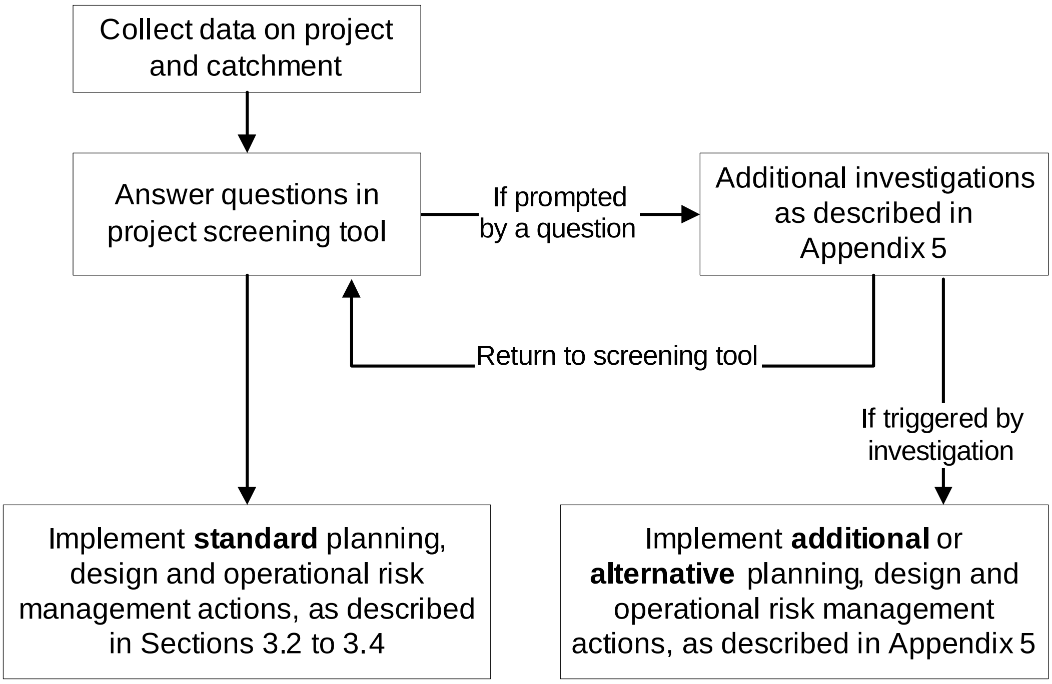


Figure 3.1 How to use the project screening tool

Table 3.1 Project screening tool checklist for stormwater reuse in public, open-space irrigation

Topic	Question	Response
Purpose (intended end uses of the stormwater)	1. Does the scheme involve stormwater irrigation of public parks and gardens, roadsides or sporting facilities (including golf courses)?	q Yes — next question q No — see Appendix 6
The catchment	2. Is the catchment land use limited to residential or commercial uses, with no significant[a] additional pollution sources, such as: • agricultural or industrial land use • a significant proportion of the catchment comprising corroding roofs • extensive construction activity, eroding stream banks or other significant sources of sediment • on-site sewage management systems (eg septic tanks) • wastewater (eg sewage) treatment plants discharging into the catchment • contaminated sites or areas with acid sulphate soils?	q Yes — next question q No or not known — see Section A5.1
	3. Is the number of sewer overflows reported by the local water utility in the catchment relatively low, that is, below 14 per 100 km of sewer pipe per year as an average over the past five years?	q Yes — next question q No or not known — see Section A5.2
	4. Are there any other stormwater harvesting or water extraction schemes in the catchment?	q Yes or not known — see Section A 5.3 q No — next question
The stormwater	5. Will the amount of stormwater withdrawn from the scheme be less than 10% of the mean annual stormwater runoff volume from the catchment above the collection point?	q Yes — next question q No — see Section A5.3
	6. Is the stormwater drain where the stormwater is collected free from tidal influence, and is the catchment free from significant[a] areas of high soil salinity (eg > 2dS/m) or known salty lakes?	q Yes — next question q No — see Section A5.4

Table 3.1 (continued)

Topic	Question	Response
The proposed water storage	7. Will the irrigation water be stored in a tank (either underground or above ground)?	q Yes — next question q No –see Section 3.3.3 and Section A5.5
	8. Will stormwater be collected by pumping from a waterway or water body?	q Yes — next question q No — see Section A5.6
	9. Is the irrigation area outside any designated (by utility, council or water resources agency) vulnerable groundwater protection zones including groundwater protection zones for town water supply bores?	q Yes — next question q No or not known — see Section A5.7
	10. Are the characteristics of the irrigation area relatively favourable, that is: • slope (for sprinkler irrigation) <6% • slope (for trickle, drip or microspray irrigation) <10% • landform — either crests, convex slopes and plains • no large surface rock outcrops • soil salinity (0–70 cm) <2 dS/m (2000 µS/cm) • soil salinity (70–100 cm) <4 dS/m (4000 µS/cm) • depth to top of seasonal high water table >3 m • depth to bedrock or hardpan >1 m • soil saturated hydraulic conductivity (0–100 cm) 20–80 mm/hour • available soil water holding capacity >100 mm/m • nonsodic soil; for example, based on Emerson soil aggregate test (0–100 cm, either class 4, 5, 6, 7, 8, or sodicity meter test) • no acid sulphate soils?	q Yes — last question q No or not known — see Section A5.8

a In this context, a significant pollution source is one that can be expected to significantly increase the levels of pathogens or relevant chemical contaminants above those expected to be found in an average residential catchment.

Most of the answers to the above questions can be obtained from the local council, local sewerage authority or state and territory government departments responsible for environment and natural resource management. Information on sewer overflows can also be obtained from the National Water Commission's (NWC's) *National Performance Reports* (NWC 2007ab) or similar state documents (eg DWE NSW 2007). Some site-specific investigations may be required, particularly to obtain irrigation area information.

If a scheme's proponent or operator cannot readily obtain some or all of this information (eg catchment information), site-specific monitoring can be carried out (see Section A5.1). However, the cost of adequate monitoring (ie of sufficient statistical and methodological quality) may well exceed the cost of obtaining the services of a suitable person to collect the information to complete the project screening tool. The interpretation of the monitoring data will also require suitable expertise.

3.2 Preparatory steps

3.2.1 Organisational support

The organisation that will operate the stormwater reuse scheme should be committed to the appropriate and ongoing management of the health and environmental risks. The organisation should either nominate suitably qualified staff to maintain the system, or arrange for maintenance to be contracted out by suitably qualified contractors.

Achieving organisational commitment is simpler where the scheme's operator is also the scheme's developer. If the staff members that are likely to be involved in operating a scheme are also involved in the scheme's development, operational risk management actions are more likely to be appropriate and able to be accommodated within the organisation's operating budget.

An organisation considering a stormwater reuse scheme should also ensure that ongoing funding is available for the proposed scheme's operations and maintenance, before a final decision is made to proceed with the project.

Where stormwater reuse schemes are to be constructed as part of a new urban or commercial development project, the developer is normally responsible for the scheme's design and construction. Responsibility for operations is often transferred to a separate organisation (eg council, water utility, golf course or body corporate) following construction. The scheme's operator should be involved in the development of the scheme, to ensure that the proposed risk management actions for the operational aspects of the scheme and their financial implications are acceptable. The developer and operator should prepare a written agreement detailing risk management roles and responsibilities.

A similar arrangement on agreed risk management roles and responsibilities should be developed in circumstances where one organisation collects, treats and distributes the stormwater for reuse by another organisation. This should be noted in the scheme management plan and reviewed regularly.

3.2.2 Legal requirements

Before starting the project, the local council or other regulatory authority should be contacted to determine whether there are any specific requirements for stormwater reuse schemes, including requirements for planning and operational approval. The scheme should be developed and operated to meet any such requirements. These guidelines do not override any state, territory or council requirements.

3.2.3 Planning approval

The authority responsible for issuing planning approvals for a stormwater reuse scheme (commonly a local council) should seek information from applicants relating to health and environmental risk management, including:

- how public health and safety risks will be addressed during the design and operation of the system
- how environmental impacts will be considered during construction
- how the system will be managed on an ongoing basis
- what (if any) risks or financial obligations will be transferred to council if it operates the scheme (eg operations, maintenance, monitoring and reporting costs).

The planning authority’s development consent for a stormwater reuse scheme should include conditions relating to managing health and environmental risks, including:

- requiring appropriate management arrangements to be in place if the local council is not the scheme’s operator (eg a club-operated golf course or a body corporate)
- implementing an environmental management plan (or similar) to manage construction impacts on the environment
- implementing an operating plan for the scheme, including regular reviews and updates of the plan
- reporting monitoring results (including any exceedences — see Section 3.4.12) and implementing any corrective actions.

3.3 Project design

3.3.1 Stormwater extraction

The potential direct environmental impacts of pumping stormwater from a natural watercourse or waterway for reuse are:

- drawing aquatic fauna into the pump
- local erosion around the pump site.

Intake of aquatic fauna can be minimised by screening the pump intake or installing screening around the pump sump. Screening of pump intakes is common, to avoid pump blockages. Potential environmental risks associated with other forms of stormwater extraction and online storages (where stormwater flows directly into the storage) are discussed in Appendix 5.

3.3.2 Stormwater quality risk management

Stormwater harvesting schemes should include stormwater treatment to minimise operational risks, with additional treatment possibly used to manage health and environmental risks.

In addition, a scheme should incorporate a minimum 72-hour buffer time between the collection of stormwater and its release for irrigation. This is intended to achieve two objectives:

- averaging (or equalising) the concentrations of pollutants and pathogens before reuse or further treatment, to minimise any effects on the quality of irrigation water from any spikes in the concentration of the raw stormwater (eg to minimise any ‘first flush effect’) and to optimise the performance of subsequent treatment processes such as disinfection
- a contingency arrangement to stop the stormwater from being used if there is a spill or an unexpected water quality event (eg major sewer overflow) in the catchment.

This buffer is recommended because it takes into account the common variability in raw stormwater quality and the limited control that a scheme operator usually has on catchment activities that could affect stormwater quality. The 72-hour period should provide a suitable time for operator notification and response (see Section 3.4.6); longer or shorter periods may apply in specific circumstances.

Depending on the design of the scheme, there are different ways to achieve a buffer. Where a separate (eg offline) storage is provided before treatment, the scheme’s storage volume should be sufficient to hold a minimum of 72 hour’s worth of irrigation water at maximum demand. Alternatively, the residence time in any online constructed wetland or pond used to pretreat the stormwater should have a minimum average residence time of 72 hours for at least 90% of the time (preferably 95%). This can also apply where a wetland is used to pretreat stormwater before aquifer injection in a managed aquifer recharge scheme.

If a water quality incident occurs, the water in an offline storage should be treated (if required) and discharged. For an online constructed pond or wetland, pumping of water for the irrigation scheme should not recommence until the water-quality issue has been resolved (eg through dilution or treatment).

Treatment for operational risks

The potential operational risks relating to stormwater quality are:

- coarse material (or gross pollutants) such as sediment and leaves entering the scheme and potentially blocking pipes, irrigation nozzles or drip irrigation systems, or damaging pumps
- high loadings of organic matter (eg leaves and grass clippings) resulting in reduced dissolved oxygen levels during decomposition, potentially creating odours and releasing pollutants from sediments
- high nitrogen and phosphorus levels supporting algal growth in open storages, potentially increasing turbidity and possibly reaching bloom levels, and biofilms clogging irrigation equipment
- high iron concentrations potentially blocking irrigation systems over time and impairing the effectiveness of the disinfection system

- high hardness (ie high levels of calcium carbonate) of stormwater, which can block irrigation systems over time.

The treatment criteria for managing operational risks will depend on the nature of the scheme. Advice on design criteria could be sought from the manufacturers of pumps and irrigations system components likely to be sensitive to stormwater pollution. A further consideration is the expected design life of sensitive elements (eg irrigation nozzles or drippers). Table 3.2 provides an indication of potentially suitable treatment criteria for public, open-space irrigation, in the absence of product-specific information (most elements are likely to have a design life of less than 20 years).

Table 3.2 Indicative stormwater treatment criteria for public, open-space irrigation — managing operational risks

Parameter	Stormwater treatment criteria	
	Design life up to 20 years	**Design life up to 100 years**
Suspended solids	<50 mg/L	<30 mg/L
Coarse particles	<2 mm diameter	<1 mm diameter
Iron (total)[a]	<10 mg/L	<0.2 mg/L
Phosphorus (total)[a]	<0.8 mg/L	<0.05 mg/L
Hardness ($CaCO_3$)[a]	<350 mg/L	<350 mg/L

a Derived from ANZECC–ARMCANZ (2000a).

The form of the pretreatment for coarse particles and, to some degree, suspended solids will depend on the intake arrangements for the scheme. Where a pump intake is used, a screen is likely to be most appropriate. In circumstances where stormwater is diverted into the scheme, a gross pollutant trap is likely to be appropriate (refer to Engineers Australia 2006 for further information on gross pollutant traps).

Iron and phosphorus concentrations are unlikely to be of concern where the irrigation equipment has a short design life, based on the median concentration levels in Appendix 2. Treatment is likely to be required for elements with a longer life, potentially using a stormwater treatment measure such as a detention pond or constructed wetland (see Engineers Australia 2006), or other treatment process. A biofilter can be used in stormwater treatment, but usually reduces runoff volumes, which may affect inflows to the scheme. Hardness is unlikely to be an issue in most urban catchments unless water-quality monitoring indicates a local problem.

Treatment for environmental risks

Additional treatment is not generally needed to minimise environmental risks where stormwater is sourced from a predominantly residential catchment. Section A5.3 has information relevant to managing environmental risks where stormwater extraction exceeds 10% of the average annual runoff volume.

Treatment for health risks

Where stormwater from a sewered residential catchment is used for public, open-space irrigation, health risks can be managed by either of the following:

- using on-site access controls to minimise exposure to irrigation water (see Section 3.4.10)
- providing additional stormwater treatment (ie beyond that required for managing operational risks).

Treatment criteria

Table 3.3 presents the recommended stormwater treatment criteria where no access controls are used. Appendix 3 describes the derivation of these criteria and contains criteria for other applications.

The recommendations in Table 3.3 apply where there has been no catchment-specific assessment of the health risks posed by the quality of the stormwater. Where such a risk assessment has been carried out, alternative risk management practices can be used (eg lower stormwater treatment criteria may apply where microbial source tracking has found negligible human sources of pathogens in a catchment).

The disinfection and turbidity criteria in this table could be considered to be less stringent than those in the Phase 1 guidelines (NRMMC–EPHC–AHMC 2006) for wastewater irrigation. The reason for this is that levels of faecal-derived microbial indicators and pathogens in stormwater are commonly less than 1% of those found in sewage (based on the ratio of the mean *E. coli* concentrations from Table A2.4 and the corresponding concentration in raw sewage from the Phase 1 guidelines). This means that less stringent treatment or exposure control requirements will achieve the same degree of health risk management.

Table 3.3 Stormwater treatment criteria for public, open-space irrigation (no access control) — managing health risks

Parameter	Stormwater treatment criteria
Disinfection	• >1.5 $\log_{10}$ (96%) reduction[a] of viruses and bacteria • >0.8 $\log_{10}$ (82%) reduction[a] of protozoan parasites • *E. coli* <10 colony forming units (CFU)/100 mL (median)
Turbidity	• <25 nephelometric turbidity units (NTU) (median) • 100 NTU (95th percentile) provided the disinfection system is designed for such water quality and that, during operation, the disinfection system can maintain an effective dose by using up all disinfectant demand and providing free disinfectant residual and/or provides adequate UV dose even in the presence of elevated turbidity and UV absorbing materials
Iron	• <9.6 mg/L[b] (median)

a Refer to the Glossary for information on log reductions.
b This is the impact threshold concentration for ferrous iron from US EPA (2006) — total iron in urban stormwater is expected to be ferrous iron, because stormwater is normally well oxygenated.

Due to the relatively low reduction in pathogen levels required relative to those for wastewater, the turbidity criteria is less stringent than noted in the Phase 1 guidelines (NRMMC–EPHC–AHMC 2006). As noted in Appendix 3, elevated turbidity levels can reduce disinfection effectiveness; however, given the lower log reductions required, turbidity impacts are less important. The criteria for stormwater are derived from evidence of disinfection capability in turbid surface waters, where the pathogens are largely in suspension and the turbidity is derived from material other than sewage floccs.

In most schemes, the iron criteria are unlikely to result in the need for stormwater treatment, because the 95^{th} percentile total iron level in Appendix 2 is approximately half of the noted criteria. Any reduction in iron levels is likely to be required only where very high iron levels are known to occur within a catchment.

Disinfection

For most small-to-medium sized schemes, ultraviolet (UV) disinfection is the most practical and commonly used disinfection technique for achieving the required log reductions, although other techniques can also be used (eg chlorination or ozonation), as detailed in the Phase 1 guidelines (NRMMC–EPHC–AHMC 2006). Any UV disinfection unit should be validated or should meet the requirements of a suitable standard (eg National Sanitation Foundation/American National Standards Institute (NSF/ANSI) 55-2007 *Ultraviolet Microbiological Water Treatment Units*). Disinfection by chlorination is also suitable for stormwater reuse schemes, particularly for larger schemes. Chlorine disinfection to meet the protozoa targets is likely to require a relatively high Ct value (disinfectant concentration × contact time), because inactivation of protozoa (particularly *Cryptosporidium*) requires higher levels of chlorine disinfection than bacteria and viruses.

The log reductions noted in Table 3.3 effectively provide the design criteria for the disinfection system. Suppliers of commercial disinfection systems have normally tested and validated the log reductions achieved by their products. There is no requirement to monitor pathogen log reductions for each scheme (see Section A3.4).

Most disinfection systems do not achieve the same degree of log reduction for bacteria, viruses and protozoa. Commonly, levels of bacteria are reduced more readily than those of viruses or protozoa. Therefore, a disinfection system designed to achieve a 1.5 log reduction of viruses, protozoan parasites and bacteria will normally achieve a greater reduction of bacteria. When potential disinfection systems are being evaluated, it is important to confirm that the system achieves the reduction required across all of the pathogen groups.

The retention of indicator bacteria in conventional stormwater treatment measures (eg constructed wetlands) is highly variable, and no information is currently available on the retention of reference pathogens. If these measures are to be used as the only technique for managing health risks, their retention of reference pathogens or suitable surrogates must be validated (see Appendix 3); however, these measures can be used to reduce turbidity before disinfection and to manage operational risks.

Turbidity

High levels of turbidity decrease the effectiveness of UV disinfection; however, most of the information on turbidity impacts on disinfection effectiveness relates to wastewater rather than stormwater (see Appendix 3). Various techniques are available to reduce stormwater turbidity levels, including:

- many types of stormwater treatment measures, including ponds, wetlands, bioretention systems and sand filters
- stormwater storage with appropriate draw-off arrangements (eg a floating draw-off in a tank storage)
- withdrawal of stormwater from a managed aquifer recharge scheme
- an in-line filter of the type used for drinking or recycled water applications.

The most reliable of these techniques is an in-line filter; the performance of the other options is more variable, particularly in the case of the options involving open storages and stormwater treatment measures. However, an in-line filter may also be the most expensive option.

An approach that could be adopted to minimise costs is to initially use a technique other than an in-line filter. This may be a cost-effective option where the technique is proposed to meet another objective; for example, treatment to meet operational risk criteria or storage of raw stormwater. Where this approach is adopted, an allowance should be made in the design and construction of the treatment system for easily installing a filter, should subsequent monitoring indicate it is required. Turbidity monitoring would occur during the commissioning phase, and a filter would be installed if the turbidity levels exceeded the criteria noted in Table 3.2. This is likely to be a suitable approach when stormwater is collected from catchments where the soils are not dispersive and the stormwater is stored in a covered tank with a relatively long minimum hydraulic residence time (eg >2 days) to allow for sedimentation. It may also be appropriate for open storages designed to minimise wind re-suspension, where the stormwater is drawn from a location near the storage's outlet and there is a relatively long hydraulic residence time.

Alternatively, if initial filtration is not planned, the capability of the selected treatment process can be validated by an independent expert, based on verifiable, traceable information and standards (eg US EPA 2006). This can be done either through a desktop assessment (coupled with in situ monitoring during a validation after commissioning of a previously validated standard design), or through more extensive validation of a novel design before procurement.

3.3.3 Stormwater storage

Stormwater storage in tanks

The potential environmental risks associated with storing stormwater in tanks are low, and relate primarily to changes in stormwater quality during storage (the environmental impacts associated with open storages are discussed in Section A5.5). Anaerobic conditions can develop in stormwater storage tanks where the stormwater has high levels of organic matter and the residence time is long. Bacterial decomposition of organic matter can lead to odour problems. Unless the stormwater has high organic loading (eg from a catchment with high sewer overflows), potential impacts can be managed by appropriate operations and maintenance (see Section 3.4).

To minimise the risks of mosquito-borne disease, tanks storing stormwater should be designed with the same features as described for rainwater tanks (see Section 2.3), including:

- close-fitting, impervious lids on maintenance access holes
- vermin-proof and insect-proof mesh on overflows and vents.

Stormwater storage in open storages

Stormwater may be stored in online open storages such as constructed wetlands and ponds, and offline open storages (eg turkey's nest dams). Additional risk management actions are usually needed to manage the additional potential health and environmental risks. These are detailed in Section A5.5 and include:

- requiring an additional 1 log reduction of *Campylobacter* concentrations unless faecal inputs from waterbirds are controlled
- minimising the potential for mosquito breeding
- minimising the likelihood of resuspending deposited sediment in the storage, to avoid increasing turbidity levels
- reducing nitrogen and phosphorus concentrations and/or designing the storage with a short hydraulic residence time, to minimise algal growth
- assessing the environmental impacts of any online storage, particularly if located on a natural creek
- undertaking additional monitoring to ensure that the additional controls are being effectively implemented.

Stormwater storage through managed aquifer recharge

The *Australian Guidelines for Water Recycling: Managed Aquifer Recharge* (NRMMC–EPHC–NHMRC 2009) provides guidance on aquifer storage in a managed aquifer recharge scheme.

3.3.4 Distribution pipework

The distribution pipework for a stormwater irrigation scheme should minimise the potential for contamination between the final treatment facility (eg disinfection) and the end use. This is usually achieved by employing a piped distribution system.

The likelihood of accidental cross-connections between the stormwater distribution network and the mainswater system, or of inappropriate connections to the stormwater pipe system, should be minimised. This is particularly important for schemes using mainswater as a supplementary water supply. To achieve this, the distribution system should incorporate the following elements:

- Where mainswater is used as supplementary water, an external, visible air gap should be incorporated between the mainswater system and the stormwater system.

- Where practicable, the stormwater distribution scheme should be operated at lower pressure than the mainswater system.
- An appropriate testable backflow prevention device or approved air gap should be installed at the meter.
- Underground and above-ground pipes in a stormwater distribution system should be colour-coded (eg purple). The top of each underground pipe should be marked with identification tape warning that the pipe contains recycled or reclaimed water and is not suitable for drinking.
- Hose taps for dual-reticulation schemes should have a removable handle and a different connection to that used for mainswater supply (eg nonstandard inlet thread).
- Signs with symbols should be provided, reading, for example, ‘Recycled water — not for drinking’. The sign should also include relevant symbols indicating that the supply is not for drinking purposes. For sign design, refer to Australian Standard (AS) 1319–1994 *Safety Signs for the Occupational Environment*.
- All external taps should be fitted with hose connection vacuum breakers.
- Flush valves in surface boxes should be installed to allow periodic flushing for system cleaning. Cross-connections should be inspected during installation.

For detailed information on the design of the distribution system’s plumbing see the Phase 1 guidelines (NRMMC–EPHC–AHMC 2006) and AS/NZS 3500.1 *Plumbing and Drainage — Part 1: Water Services*.

The pipework for a stormwater reuse scheme should also be designed to incorporate appropriate flow meters and sampling taps, to ensure monitoring is safe, efficient and representative.

3.3.5 Irrigation system design

Managing health and environmental risks from stormwater irrigation should be considered during the design of the irrigation system, particularly application rates and spray arrangements where access to the irrigation area is controlled. Drippers (surface or subsurface especially) can also minimise human exposure (Table 3.2) and the level of stormwater treatment that is required.

Calculating the appropriate application rate is important to minimise surface runoff, and impacts on groundwater and soils (eg soil saturation). The application rates should take into account the site characteristics (particularly soils) and the vegetation to be irrigated. Stormwater should be applied uniformly and at a rate less than the nominal soil infiltration rate, to avoid surface runoff.

Where practical, signage should be displayed at all public access points to areas irrigated with stormwater, warning not to drink the water. In public access areas where untreated spray irrigation is used, facilities such as drinking water fountains, swimming pools and picnic tables should be placed outside the area irrigated by treated stormwater, or be protected from drift and direct spraying.

Where spray irrigation with restricted access is used to manage exposure to the stormwater, the irrigation system should be designed to include:

- clear delineation of the irrigation area, for example, using fencing or vegetative borders
- signs, including words and pictures, on all designated entry points to the irrigation area, warning the public that the water in use is not for drinking and that the irrigated area must not be entered from the time irrigation begins until the irrigated area is dry
- a minimum 25 m buffer from the irrigation scheme's wetted perimeter to the nearest point of public access and spray drift control using low-throw sprinklers (180° inward throw), vegetation screening or anemometer switching.

These arrangements are adequate to manage the additional health risks potentially associated with open storages, as noted in Section 3.3.3, when combined with the access controls in Section 3.4.9.

Where drip irrigation of garden beds is proposed, this provides effective access control provided appropriate advisory signs are erected. This is based on the assumption that people may be in the area during the irrigation, but are unlikely to enter garden beds.

3.4 Operations, maintenance and monitoring

3.4.1 Qualified staff

Only appropriately qualified staff should manage and operate the scheme. Depending on the nature of the scheme, plumbers, electricians and specialist technicians may all be involved in operations. These staff should be trained in relevant aspects of the scheme's operations and should follow operational procedures.

If an organisation does not have the capacity to operate part or the entire scheme, external contractors should be suitably qualified, and should be informed about operational procedures and protocols.

The operator should maintain details of competencies, qualifications, licences, training programs undertaken, training needs identified and training records for employees and contractors.

3.4.2 Scheme management plan

A scheme management plan should be prepared during the design phase, to describe the health and environmental risk management actions to be implemented during operations. This will ensure critical knowledge is not lost with staff changes. The plan should highlight the roles and responsibilities of relevant parties, and provide a framework for appropriate operation. It should be made available to all staff involved in operations. The content and extent of the management plan will vary, depending on the nature and scale of the scheme, but could include the information in Table 3.4.

Table 3.4 Indicative contents of a scheme management plan

Section	Contents
Background	Statutory requirements Relevant permits or approvals Description, process flow diagram and map of the scheme, including the location of public warning signs and all underground pipes Water quality and treatment objectives against which monitoring data is measured
Roles and responsibilities	How responsibilities are shared between treated stormwater suppliers and end users (if applicable) Responsibilities of any third parties (eg councils)
Operations	Information on operating plant and equipment Information on operating the irrigation scheme (if applicable), such as loading rates, access restrictions and irrigation timing Procedures for responding to noncompliance with scheme objectives (eg water-quality criteria) Qualifications of personnel involved in the scheme's operations
Maintenance	Inspection schedules Maintenance requirements Statements of safe working methods to protect workers Asset management procedures
Incident (emergency) response (contingency) actions	Incident response protocols Incident communications procedures List of key stakeholders with current, verified contact details
Monitoring	Operational monitoring requirements, including sampling methods Reporting procedures
Decommissioning	Proposed arrangements for the safe decommissioning of the scheme

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

3.4.3 Scheme commissioning, validation and verification

To prove a scheme is operating as designed, it should go through a three-phase process of commissioning, validation and verification (NRMMC–EPHC–AHMC 2006).

Commissioning

Commissioning refers to fine tuning and testing the operation of all equipment and the scheme as a whole. The objective is to define the routine operating conditions of the scheme for the long term, and to confirm that the equipment and systems operate as intended. Contractual performance payments are often related to successful completion of commissioning. Stormwater should be diverted during the commissioning phase and not used for the intended application, or should be used only under highly controlled conditions during commissioning.

Validation

Validation constitutes the initial check that the system is working as intended, and is undertaken before schemes are considered ready for use. The validation phase is particularly important for stormwater reuse schemes that involve treatment, as this is a relatively new approach to water management and there is a degree of uncertainty associated with some aspects of scheme design (eg disinfection).

During this validation period, the scheme operates normally for a certain period (typically from one to three months) and further testing is performed for quality assurance purposes. The treated stormwater is diverted and is either not applied to its intended end uses or is only used for a strictly controlled and limited set of interim uses. Frequent monitoring and testing of the equipment, water quality and other key aspects of the scheme should be carried out (Appendix 3), and action taken to address any identified problems.

If treatment is required, validation should be undertaken to confirm that the treatment system used allows the scheme to meet the required quality criteria. The performance indicators that will be monitored during routine operation (Section 3.4.11) should be monitored more frequently over the validation period, during which at least 20 samples of the treated water should be tested for *E. coli*. Sampling should occur on different days of the week, at different times during the day and, most importantly, under different hydrological conditions (eg varying periods after storms). Validation testing needs to demonstrate median *E. coli* concentrations of <10 CFU/100 mL.

If treatment is not required and risk management is based on access restrictions during irrigation, the efficacy of the restrictions should be checked by surveying the irrigation area and walking the irrigation lines during test irrigation runs, to confirm that all the required restrictions are operating as intended.

Verification

If validation is satisfactory, a scheme can become fully operational. Verification monitoring is then undertaken in a similar fashion to the validation monitoring, but typically at a lower frequency. Verification monitoring is likely to include inspection of the exposure controls for all schemes, as well as stormwater quality monitoring for schemes involving treatment. Further discussion of verification monitoring is included in Section 3.4.11.

3.4.4 Catchment surveillance

Potential health and environmental risks to a stormwater harvesting scheme from its stormwater catchment should be addressed during the project’s design phase. During the operational phase, catchment management activities should focus on catchment surveillance to identify any changed catchment activities that may add to the risks that were identified in the design phase.

If any additional risks are identified, arrangements should be made to mitigate the risks or to modify the scheme's risk management actions. There should be regular liaison with the local council or the catchment manager, to help identify any potential new hazards that may present a risk to the scheme.

3.4.5 Managing chemicals

Some chemicals used in stormwater harvesting and reuse schemes may adversely affect the quality of treated stormwater or the receiving environment (eg chlorine for disinfection). These chemicals should be evaluated to determine how likely they are to contaminate the scheme and affect its integrity (eg determine corrosion potential). All chemicals used in treatment processes should be securely stored and placed in an area protected by a low wall to prevent the spread of liquids (ie bunded) as appropriate, to avoid spills or leakage to waters.

3.4.6 Incident response

By their nature, most incidents and emergencies are difficult to predict in terms of their nature and timing; therefore, a contingency planning approach to management is required.

Some of the types of incident that could influence a stormwater harvesting and reuse scheme are:

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

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

For serious incidents, the scheme's operator should document appropriate procedures in a response plan. Operational staff should receive training in following the plan, and the plan should be put into practice and regularly reviewed. A communications procedure should form part of such a plan. Depending on the nature of the scheme and the incident, the procedure should nominate a person to communicate information to any end users of the treated stormwater, as well as to the relevant regulatory stakeholders. The notification should summarise the nature of the incident and the actions to be taken. Following the incident, once the scheme's operations have returned to normal, all parties initially notified should be advised of any corrective and preventive actions.

As part of the incident response arrangements, the scheme's operator should arrange with the relevant regulatory stakeholders to be notified of any major chemical spills within the catchment, and with the water utility to be notified of any sewer overflows. If notification of sewer overflows is not possible, stormwater collection or supply should be avoided during large storm events when wet weather overflows are more likely to occur. Water utilities can typically identify the design criteria that apply to their sewerage system and the size of storm event that would be expected to lead to a sewer overflow. In the case of spills or sewer overflows within the catchment, or algal blooms in the storage, the operator should consider suspending the supply of stormwater for end uses.

3.4.7 Occupational health and safety

The potential health risks to workers in stormwater harvesting and reuse schemes can be minimised by:

- training workers (staff and any contractors) on health risks and appropriate risk management activities
- considering providing immunisation against hepatitis A (depending on the risk)
- avoiding drinking treated stormwater — mainswater should be provided
- installing a washbasin that provides mainswater at worker amenities
- prohibiting eating, drinking or smoking while working with treated stormwater
- promoting hand washing with soap and mainswater after working with treated stormwater
- ensuring prompt cleaning of any wounds with antiseptic, followed by a medical dressing
- providing appropriate personal protective equipment
- avoiding high exposure to treated stormwater; for example, by minimising access to irrigation areas during irrigation of untreated stormwater
- protecting against hazardous treatment materials, and electrical and mechanical hazards such as from pumps
- protecting against slip hazards and hazards from open water bodies.

3.4.8 Managing storage tanks

Stormwater storage tanks need to be monitored and maintained in a similar manner to roofwater storage tanks. Table 3.5 shows details of recommended inspection and management practices for managing health and environmental risks.

Odours from stormwater storage tanks or from irrigated stormwater are most likely when storage times are long. Should the odours become problematic, management options include storing little or no stormwater during periods of limited demand or long retention (eg winter), or installing odour controls or aerators in the tank. In the unlikely event of serious odour problems, organic matter loads (eg leaves) can be reduced before storage of water by installing a gross pollutant trap or biofilter.

Table 3.5 Standard stormwater scheme monitoring

Scheme type	Frequency	Monitoring	Action
All schemes	Quarterly and in response to notifications	Check condition of catchment, irrigation area and irrigated plants and grass	Undertake corrective actions
		Check irrigation areas for signs of erosion, underwatering, waterlogging or surface runoff	Modify irrigation practices
	Annually and in response to blockages	Check lines for blockages and leaks	Clear blockages and flush/clean lines; repair leaks
	Annually and in response to notifications and new connections	Check for cross-connections by checking visible plumbing fittings, alternately turning off supplies	Shut down system immediately and rectify problems
	Triennially and following any incidents	Undertake a systematic review of operational control of risks to the system	Determine the reason for any problems identified during inspections and take actions to prevent failures occurring in future
All schemes with tanks	Annually and in response to notifications	Check access covers to storage tanks are closed	Repair any defects
		Check that screens on inlets, overflows and other openings do not have holes and are securely fastened	Repair any defective screens
		Inspect tank water for mosquito larvae (inspect more frequently in subtropical and tropical northern Australia based on local requirements)	Treat tanks containing larvae with kerosene or medical paraffin
	Triennially or as appropriate	Drain, clean and inspect storage tanks	Repair any defects

Table 3.5 (continued)

Scheme type	Frequency	Monitoring	Action
Unrestricted irrigation	Weekly[a]	Verification of disinfection system performance using *E. coli*	Follow up results ≥100 CFU/100 mL by re-testing and investigation of likely pathogen sources
	Continuous	Efficacy of treatment system performance (eg turbidity and ultraviolet dose for disinfection)[b]	Shut down system immediately and rectify problems
Restricted irrigation	Weekly	Efficacy of irrigation restrictions (eg fencing of irrigation areas)	Rectify problems

a If weekly sampling over a three-month period indicates that the median *E. coli* levels are eg <10 CFU/100 mL, the monitoring frequency may be reduced to quarterly. Weekly monitoring should recommence for three months after any result ≥100 CFU/100 mL.
b This is particularly important for systems where the stormwater to be disinfected has high turbidity levels.

3.4.9 Access control

Control of access to irrigation areas can be used to adequately manage health risks when no specific treatment to manage health risks is implemented. These access restrictions do not apply to operations staff (Section 3.4.7) or where stormwater is treated to meet the criteria set out in Table 3.2. Access controls are not required where untreated or treated stormwater irrigation is carried out using subsurface or drip irrigation.

Suitable approaches for controlling access to spray irrigation areas include:

- irrigating at times when there is no intended, permitted or organised public access to the irrigation area and the likelihood of persons being present within the area is low (eg late at night)
- implementing an appropriate withholding period to allow the irrigation area to dry before access is permitted (depending on the application rate, soil conditions and climate, this withholding period is typically between one and four hours in temperate zones).

These controls should also achieve an additional 1-log reduction in pathogen levels above those for the standard scheme, should this be required through recommendations in Appendix 5.

3.4.10 Irrigation scheduling

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

Irrigation scheduling and monitoring should minimise the risk of over-irrigating or excessive pooling of water on the soil surface.

The application of the correct amount of treated stormwater to avoid runoff can be controlled by manual or automated techniques. For example, the soil moisture deficit can be easily computed using monthly average evapotranspiration and actual rainfall events. Irrigation is then applied according to the size of the deficit. The irrigator will need to know how much water is delivered by the irrigation system over a given area. Soil moisture monitors linked to a computer system can also be used to determine when irrigation is needed. Both manual and automated methods are likely to give false results under certain circumstances. Whatever method is chosen, regular checks of moisture in the topsoil should be made before irrigation (to ensure that the soil is dry and needs irrigating) and after irrigation (to check that watering has been adequate but not excessive).

3.4.11 Operational monitoring

Monitoring and inspections should be implemented during the scheme's operations to ensure that public health and environmental risks are being appropriately managed. Table 3.4 provides guidance on appropriate routine operational monitoring parameters and their monitoring frequency (see Appendix 5 for additional monitoring recommendations for open storages).

Maintenance should also include inspection and follow up on any complaints or concerns raised that could indicate problems with the system.

The key indicators of treatment system performance will be different for each system, and should be advised by the treatment system designer and supplier. For UV disinfection, key performance indicators are likely to include turbidity and UV intensity. Indications of inadequate treatment system performance should lead to the immediate cessation of supply of the irrigation water, while any problems are identified and resolved. Specialist services may be required to help identify and repair some treatment system problems.

Irrigation restriction methods will be different for each scheme and should be stated in the scheme management plan. Restrictions (which should be checked) include:

- any subsurface irrigation should be at least 100 mm below the surface level
- directional sprays should throw correctly
- microspray or low-throw sprinklers should not discharge excessively
- irrigation lines should not leak
- signage should be in place
- irrigation timers should operate correctly.

Any shortcomings in the irrigation restrictions should be promptly remedied.

Every year, the scheme's operator should check that there have been no major changes in the nature of the catchment that might create new risks (eg new industrial developments or construction sites), that the irrigation area is not becoming inundated, and plants are not being damaged. Adverse changes in the nature of the catchment or the effects of irrigation should be promptly investigated, to identify and resolve any problems. Specialist services may be required to help explain unanticipated irrigation effects in some cases.

3.4.12 Reporting

Monitoring results and other information on scheme performance should be reported to key internal and external stakeholders (eg the consent authority) at least yearly and after any incident, or to meet any regulatory requirements. This allows the operator and the consent authority to assess the ongoing performance of the scheme, in particular by comparing monitoring results to the scheme's stormwater quality criteria. The appropriate follow-up actions needed where systems are not performing adequately should be identified. Where there is no consent authority, an annual written report should be provided to the chief executive of the organisation managing the scheme, or the responsible senior manager.

3.4.13 Record keeping

All monitoring results should be retained for a suitable period. The minimum storage period is that required to meet relevant regulatory or development consent requirements and to satisfy auditing needs. The managers of the system should determine how long records need to be stored past this minimum period.

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

3.4.14 Auditing scheme operations

The Phase 1 guidelines recommend that both internal and external auditing of each recycled wastewater scheme is undertaken (NRMMC–EPHC–AHMC 2006). A less rigorous auditing regime is considered appropriate for stormwater recycling schemes, given the generally lower risks associated with using stormwater rather than sewage as an initial water source. However, based on experience of auditing household plumbing and on-site sewage management systems, some auditing is warranted.

The auditing should establish how well scheme operators are complying with treatment and irrigation controls. As with many other water-related auditing programs, external auditing can be undertaken by approved third-party inspectors or directly by local or state government staff.

A scheme's operator should arrange for a regular audit of the access controls, as part of a 'due diligence' approach to risk management. The audit can be undertaken by the operator of another scheme or another suitably experienced person. The frequency of the audits can be determined by exposure risk, for example, higher risk schemes (eg with larger exposed populations and with children or the elderly among the exposed) being inspected quarterly and lower risk schemes every two to three years.

For stormwater irrigation schemes with unrestricted access, scheme-by-scheme auditing is essential. Regulatory agencies should place all registered stormwater irrigation schemes with unrestricted access on a programmed inspection regime. Targeted auditing and advice may be required to follow up any issues that emerge.

3.4.15 Continuous improvement

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

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

3.5 Additional risk management actions for projects other than irrigation of public open spaces

Additional or modified risk management actions may be needed, as identified during the investigations described in Appendix 5. These additional risk management actions need to be implemented on a project-specific basis in addition to, or in place of, the standard control measures.

3.6 Stormwater irrigation scheme checklist

The checklist below summarises the key elements of the health and environmental risk management actions for a stormwater reuse irrigation scheme.

- o Applicable planning and other regulatory requirements are met.
- o The organisation is committed to the safe reuse of stormwater, including ensuring appropriate operation and maintenance.
- o Stormwater extraction does not adversely increase upstream flood levels or impact on stream flows.
- o Stormwater is treated (including disinfection) if there are no restrictions on access to the irrigation area.
- o Appropriate plumbing controls and signage are used.
- o Irrigation systems are designed to deliver water efficiently and uniformly.
- o Appropriate monitoring occurs during the validation phase.

- Appropriately qualified staff or contractors operate the scheme in accordance with a scheme management plan, including following appropriate incident response and workplace safety procedures.
- Appropriate catchment management arrangements are in place with the relevant stakeholders.
- Controls on access to the irrigation area are effectively implemented, if required.
- Irrigation scheduling, rates, uniformity and water delivery to irrigation areas are monitored.
- Operation of the scheme is independently audited annually where access to the irrigation area is unrestricted, and triennially where access to the irrigation area is restricted.
- Appropriate monitoring, reporting and record-keeping procedures are followed.

Appendix 1 Risk management framework

The risk management approach given here is based on the 12-element risk management framework on which Phase 1 of the water recycling guidelines is based (NRMMC–EPHC–AHMC 2006). Details are given in Chapter 2 of the Phase 1 guidelines. Table A1.1 lists the 12 elements, and shows how they have been included in these guidelines for reuse of roofwater and stormwater.

Table A1.1 Application of risk management framework to roofwater and stormwater reuse

Element	Description	Location in document	
		Roofwater	**Stormwater**
1	Commitment to the responsible use and management of recycled water quality	Section 2.2.1	Section 3.2.1
2	Assessment of the recycled water system	Appendixes 3 and 4	Appendixes 3 and 4
3	Preventive measures for recycled water management	Sections 2.2.3, 2.3 and 2.4, Appendixes 3 and 4	Section 3.2 and Appendixes 3 and 4
4	Operational procedures and process control	Section 2.4	Section 3.4
5	Verification of recycled water quality and environmental sustainability	Section 2.4	Section 3.4
6	Management of incidents and emergencies	Section 2.4	Section 3.4
7	Employee awareness and training	Section 2.2.1	Sections 3.4 and 3.2.1
8	Community involvement and awareness	Section 2.3	Section 3.3
9	Validation, research and development	Not applicable	Section 3.4
10	Documentation and reporting	Section 2.4	Section 3.4
11	Evaluation and audit	Section 2.4	Section 3.4
12	Review and continual improvement	Section 2.4	Section 3.4

Appendix 2 Stormwater and roofwater quality

A2.1 Stormwater

A2.1.1 Stormwater quality and land use

The levels of chemicals in stormwater runoff are strongly related to a catchment's land use, particularly the proportion of the catchment that is impervious. Other factors also influence pollutant concentrations, with apparently similar land uses yielding different pollutant loads. Duncan (1999) compared pollutant characteristics in urban stormwater from different land uses and found that the variation in pollutant concentrations between land uses (eg between residential and industrial land) was considerably less than an order of magnitude. Nutrient levels were lower in commercial and industrial catchments than in residential areas, while the opposite applies to heavy metal concentrations. Concentrations of chemicals in an urban river with a partly nonurban catchment may be lower than those from a totally urbanised catchment. Chemical concentrations in stormwater can also be affected by spills or illegal dumping of chemicals.

Variation in stormwater contaminant levels is likely to have significant implications for environmental management. However, in terms of reuse, such variation is relevant primarily where above-average levels of contaminants present a high environmental or public health risk. Data from Duncan (1999) and Makepeace et al (1995) can be used to assess whether more intense land uses (eg commercial or industrial) will affect environmental risks (eg through high concentrations of metals).

Levels of faecal indicator bacteria — such as *Escherichia coli* (*E.* coli) and thermotolerant (faecal) coliforms — between catchments and between storm events within a catchment can vary by many orders of magnitude. The review by Duncan (1999) noted that, on average, thermotolerant coliform levels were approximately one order of magnitude lower in commercial or industrial areas than in residential catchments. A more recent study found that lower coliform levels were attributed to an absence of domestic animals in commercial or industrial areas (McCarthy et al 2006).

The microbial quality of stormwater from surface runoff (eg car parks) is likely to be better than that of stormwater collected from a drain, which is likely to be contaminated by sewer leakage or overflows. Although few data are available, pathogen levels in surface runoff are likely to be somewhere between those in roofwater and those in stormwater drains. Surface runoff pathogen loads are likely to be higher than those in roofwater, due to faecal inputs from animals, particularly those associated with humans (eg cats and dogs). If a scheme developer considered that the approach outlined in Chapter 3 was too conservative for a surface runoff harvesting project, they could undertake their own pathogen monitoring program, although the costs would be high.

A2.1.2 Stormwater monitoring

Any monitoring of chemical constituents in stormwater should focus on parameters likely to reach the threshold of concern described in Appendix 4 (eg approaching the long-term trigger value). This risk-based approach to monitoring design avoids the expense of monitoring for chemicals that are unlikely to be relevant for the environmental risk assessment.

With respect to microbial contaminants, there is no simple statistical correlation between faecal indicator bacteria and human pathogen concentrations in stormwater. Concurrent monitoring of faecal indicator bacteria (eg *E. coli*) and pathogens has generally found a poor correlation between the levels of these microorganisms in both stormwater (eg Schroeder et al 2002, Lemarchand and Lebaron 2003, Jiang 2004, Rajal et al 2005, Signor et al 2005, AWQC 2008a) and combined sewer overflows (Arnone and Walling 2006).

This lack of a simple relationship is to be expected, given that faecal indicator bacteria in stormwater are derived from both wildlife and sewage, whereas human pathogens are derived primarily from sewage and the faeces of some warm-blooded animals. Hence, monitoring of indicator bacteria for a specific project is unlikely to yield information on pathogen concentrations that can directly inform a health risk assessment with reasonable certainty.

Direct monitoring of pathogens is likely to be more useful, although the detection, enumeration and infectivity assessment of pathogens in environmental water samples is complex and costly, with a relatively long analytical testing period. While the design of a monitoring program will be specific to each project, the monitoring should involve sampling during the rising limb, peak, and falling limb of the hydrograph, to ensure that the sampling is reasonably representative of the water quality throughout a storm event. A minimum of three events (preferably five to six events) should be sampled, with the sampling covering events ranging from small to medium size, and possibly large events (most stormwater for reuse is collected from small-to-medium sized events). Some dry weather sampling is also recommended where the scheme will use dry weather flows.

A2.2 Roofwater

A2.2.1 Roofwater quality

Roofing material heavily influences the contaminants in roofwater. Metal roofs generate higher levels of metals than ceramic tiled roofs. Elevated zinc levels are common for metal roofing (Yaziz et al 1989, Thomas and Greene 1993, Chang et al 2004, Morrow et al 2007).

Pathogen levels in roofwater are usually lower than those recorded in stormwater, with pathogens mainly sourced from faeces of birds and small animals. *Campylobacter* is the most common reference pathogen detected in roofwater, with *Cryptosporidium* (Savill et al 2001, Simmons et al 2001, Schets et al 2007) and *Salmonella* detected occasionally. As for stormwater (and for the same reasons) there is no simple statistical correlation between indicator bacteria (eg *E. coli*) and human pathogen concentrations. The preferred approach is direct pathogen monitoring, focusing on the most relevant pathogens commonly detected in roofwater (eg *Campylobacter*).

A2.2.2 Roofwater monitoring

Where chemical constituent levels in roofwater are monitored, this should occur throughout a storm event. The sampling should preferably be flow-weighted, because high concentrations have been reported early in a storm event (at 'first flush') when runoff volumes (and hence loads) are low. As roofwater will be stored before use, this storage will effectively equalise roofwater concentrations in storage — any first-flush effect is therefore of little relevance.

A2.3 Data analysis

A2.3.1 Overview

An extensive range of Australian-sourced stormwater contaminant data, both published and unpublished, was collated to characterise general roofwater and stormwater quality, potential contaminants and their expected ranges of concentration. These data were used to derive the summary statistics given in Section A2.3.3.

There is a lack of Australian and, to a lesser degree, international data for some parameters (eg boron and herbicide levels) compared to the data available for sewage. This affects health and environmental risk assessment, and highlights the importance of monitoring for identifying unexpected environmental impacts.

A2.3.2 Data analysis

The data was initially categorised into source catchment types and runoff conditions (ie dry weather, wet weather or not specified). The preliminary list of source catchment types included agricultural, forest or natural, industrial, mixed-urban or rural roads, roofs, rural, and urban.

The collated data revealed many combinations of source catchment types, contaminants and types of flow for which no data were available. In a subsequent step these were grouped, irrespective of runoff conditions, into the following source catchment categories:

- all roofs (Tables A2.1 and A2.2)
- urban (Tables A2.3 and A2.4).

Some data sources indicated that stormwater was sampled from urban, road or industrial catchments; however, due to the lack of data and of clarity in the descriptions of the source catchment attributes, these categories were pooled into the urban dataset. Source catchment types defined as agricultural, forest or natural, and rural were considered to be outside the scope of these urban stormwater reuse guidelines. Examination of the source catchment data indicated that most were from urban catchments. Data for roofs with and without zinc were not separated.

A2.3.3 Characterisation of concentration ranges

Multiple studies have been combined to develop the roofwater quality summary statistics, and the physical and chemical urban stormwater quality summary statistics. To enable these multiple studies to be combined, collated data on stormwater were used to develop lognormal probability density functions for each parameter recorded as present in Australian stormwater. Distributions were fitted with the distribution-fitting software package *Riskview* (software distributed by Palisade Corporation, Newfield, NY, 2002). Due to the great variation in reporting of data values and statistics, the identification of minimum, maximum and average values was somewhat subjective. For each parameter, the distribution-fitting procedure involved calculating means of all reported minimum values, means of all reported maximum values and means of all reported central tendencies (usually a mean or median value).

Averaged minimums were considered to represent the lower bound data or 5th percentile; average maximums, the upper bound data or 95th percentile; while average data were considered to represent an estimate of the central tendency. A standard lognormal distribution has a mean and standard deviation that are approximately equivalent, and this assumption was useful in determining the level of skewness of the lognormal distribution for each parameter. Once a particular distribution was selected for the particular parameter in question, a range of statistics (eg percentiles) were computed using the Monte Carlo simulation software package @*RISK* (software distributed by Palisade Corporation, Newfield, NY, 2002).

The values derived from this analysis are presented in Table A2.1 (roofwater quality) and Table A2.3 (urban stormwater quality). Table A2.3 includes microbial data that has been reported here for completeness, but was not used to directly inform the health risk assessment due to its inadequacy. Previous Australian and international studies were inadequate to properly characterise urban stormwater quality with respect to microbial characteristics. The best data available were for an unsewered urban area (Aldgate Creek, near Adelaide — Roser and Ashbolt 2007), whereas these guidelines consider only sewered urban areas. Therefore, a new study was commissioned to provide suitable data to support these guidelines (AWQC 2008a).

For the microbial urban stormwater quality summary statistics, a single study was used to provide the values. The study gathered data from 59 samples, covering four sites in Sydney representing sewered residential area urban stormwater. Three of these sites are areas with relatively high sewer overflows (Sydney Water Corporation 1998). Between the four sites, 11 dry weather and 48 wet weather samples were collected. The wet weather samples were collected from four storm events for each of the four sites, with sampling during the early, mid and late hydrograph stages. The data was considered to be representative of stormwater quality through the range of conditions within which water would be harvested.

For both roofwater and urban stormwater, upper percentile values were used in deriving the microbial water quality summary statistics for the health risk assessment, such that the interpretation of the data was conservative.

Compared to median concentrations in sewage noted in the Phase 1 guidelines (NRMMC–EPHC–AHMC 2006), median stormwater concentrations (Table A2.1) are lower for nutrients, pH, salinity and ions, and higher for most metals.

Table A2.1 Lognormal summary statistics for roofwater quality

Contaminant	Unit	Mean	SD	Percentile				
				5th	25th	50th	75th	95th
Bacteria — indicators								
Enterococci	#/100 mL	671	1079	29	142	343	770	2326
Thermotolerant (faecal) coliforms	#/100 mL	93.0	107.5	7.0	28.3	59.9	117.1	286.7
Heterotrophic plate count	#/100 mL	20185	23533	1331	5904	12855	25486	62876
Total coliforms	#/100 mL	1875	2212	123	546	1190	2365	5855
Metals								
Arsenic	mg/L	0.005	0.002	0.003	0.004	0.004	0.006	0.008
Cadmium	mg/L	0.0005	0.0003	0.0002	0.0003	0.0004	0.0006	0.0010
Chromium	mg/L	0.012	0.012	0.002	0.005	0.008	0.015	0.034
Copper	mg/L	0.185	0.224	0.013	0.056	0.120	0.234	0.570
Iron	mg/L	0.115	0.077	0.055	0.071	0.093	0.132	0.248
Lead	mg/L	0.079	0.041	0.056	0.060	0.067	0.082	0.137
Nickel	mg/L	0.016	0.018	0.001	0.005	0.011	0.020	0.049
Strontium	mg/L	0.017	0.018	0.002	0.006	0.011	0.021	0.050
Zinc[a]	mg/L	2.45	1.97	0.33	1.09	1.97	3.26	6.20
Nutrients								
Total nitrogen	mg/L	1.53	0.81	0.67	0.99	1.33	1.85	3.04
Total phosphorus	mg/L	0.122	0.078	0.047	0.072	0.102	0.147	0.260
Physicochemical indicators								
pH		6.42	0.61	5.46	5.99	6.39	6.81	7.47
Suspended solids	mg/L	17.7	13.7	3.1	8.3	14.2	23.0	43.5
Turbidity	NTU	2.48	1.21	0.78	1.62	2.33	3.18	4.67

NTU = nephelometric turbidity unit; SD = standard deviation.
a Includes data from zinc-containing roof materials. Separate data for roofs with and without zinc are not available.

Table A2.2 Data sources by contaminant for stormwater quality — roof catchments

Contaminant	Reference[a]							
	1	2	3	4	5	6	7	8
Bacteria — indicators								ü
Enterococci			ü	ü	ü			ü
Thermotolerant (faecal) coliforms	ü							ü
Heterotrophic plate count	ü							ü
Total coliforms	ü							
Metals								
Arsenic		ü						ü
Cadmium		ü	ü	ü			ü	
Chromium		ü				ü		
Copper	ü	ü	ü	ü			ü	ü
Iron		ü				ü	ü	
Lead	ü	ü	ü	ü		ü	ü	ü
Nickel		ü				ü		
Strontium		ü						
Zinc[b]		ü	ü	ü			ü	ü
Nutrients								
Total nitrogen				ü				
Total phosphorus			ü	ü				
Physicochemical indicators								
pH	ü		ü				ü	ü
Suspended solids					ü		ü	
Turbidity	ü		ü				ü	ü

a References:
1. Jayaratne et al (2006)
2. Chapman et al (2006)
3. Duncan (1999)
4. Fletcher et al (2004)
5. Gardner et al (2004)
6. Magyar et al (2006)
7. Mitchell et al (2002)
8. Simmons et al (2001).

b Includes data from zinc-containing roof materials. Separate data for roofs with and without zinc are not available.

Table A2.3 Lognormal summary statistics for untreated stormwater quality — urban catchments[a]

Contaminant	Unit	Mean	SD	Percentile				
				5th	25th	50th	75th	95th
Pathogens								
Campylobacter (bacteria)	#/100 mL	3.31	1.97	1.00	1.93	2.89	4.21	7.02
Cryptosporidium (protozoa)	#/10 L	176	211	12	52	112	222	546
Giardia (protozoa)	#/10 L	1.81	2.08	0.12	0.55	1.17	2.29	5.55
Bacteria — indicators								
Coliforms	#/100 mL	97665	170197	3369	17668	44884	106860	355988
Clostridium perfringens	#/100 mL	925	1 016	103	315	614	1 153	2 748
E coli	#/100 mL	59339	71939	3835	17203	37511	74564	184382
Enterococci	#/100 mL	13792	10928	1621	6043	11229	18586	34465
Faecal coliforms	#/100 mL	69429	82740	4694	20440	44168	87235	215568
Faecal streptococci	#/100 mL	29771	21717	3829	13991	25212	40317	70894
Somatic coliphages	#/100 mL	17530	20917	1154	5088	11115	22083	54704
Metals								
Aluminium	mg/L	1.19	0.60	0.49	0.78	1.07	1.47	2.29
Arsenic	mg/L	0.009	0.001	0.006	0.008	0.009	0.009	0.011
Barium	mg/L	0.028	0.005	0.021	0.025	0.028	0.031	0.038
Cadmium	mg/L	0.0198	0.0242	0.0015	0.0061	0.0127	0.0248	0.0606
Chromium	mg/L	0.009	0.005	0.002	0.005	0.008	0.011	0.017
Copper	mg/L	0.055	0.047	0.012	0.025	0.041	0.068	0.141
Iron	mg/L	2.842	1.246	1.126	1.956	2.674	3.540	5.100
Lead	mg/L	0.073	0.048	0.017	0.040	0.063	0.095	0.162
Manganese	mg/L	0.111	0.046	0.054	0.079	0.103	0.134	0.197

Table A2.3 (continued)

Contaminant	Unit	Mean	SD	Percentile				
				5th	25th	50th	75th	95th
Mercury	µg/L	0.218	0.105	0.080	0.143	0.201	0.273	0.411
Nickel	mg/L	0.009	0.004	0.004	0.007	0.009	0.011	0.017
Zinc	mg/L	0.293	0.153	0.080	0.183	0.272	0.379	0.570
Nutrients								
Oxidised nitrogen	mg/L	0.680	0.446	0.132	0.361	0.592	0.900	1.523
Total dissolved nitrogen	mgL	3.28	2.61	0.68	1.55	2.59	4.19	8.22
Total kjeldahl nitrogen	mg/L	2.84	4.14	0.60	0.95	1.59	3.04	8.82
Total organic nitrogen	mg/L	0.623	0.828	0.160	0.233	0.367	0.669	1.874
Total nitrogen	mg/L	3.09	2.33	0.62	1.52	2.51	4.00	7.46
Filtered reactive phosphorus	mg/L	0.664	0.762	0.050	0.204	0.430	0.839	2.037
Total phosphorus	mg/L	0.480	0.413	0.075	0.207	0.367	0.620	1.261
Organics								
Polycyclic aromatic hydrocarbons	µg/L	0.262	0.306	0.017	0.078	0.168	0.331	0.811

Table A2.3 (continued)

Contaminant	Unit	Mean	SD	Percentile				
				5th	25th	50th	75th	95th
Physico-chemical indicators								
Ammonia	mg/L	1.135	1.187	0.102	0.394	0.793	1.464	3.281
Bicarbonate alkalinity as $CaCO_3$	mg/L	35.21	3.36	29.99	32.87	35.04	37.37	40.97
Biochemical oxygen demand	mg/l	54.28	45.58	6.56	22.87	42.53	72.03	140.77
Chemical oxygen demand	mg/L	57.67	17.22	32.90	45.41	55.75	67.85	88.72
Chloride	mg/L	11.40	1.05	9.75	10.67	11.35	12.08	13.20
Oil and grease	mg/L	13.13	8.11	3.43	7.45	11.47	16.93	28.25
pH		6.35	0.54	5.50	5.98	6.33	6.70	7.27
Sodium	mg/L	10.63	2.82	6.58	8.62	10.31	12.29	15.72
Suspended solids	mg/L	99.73	83.60	19.01	45.41	77.24	127.19	254.47
Total dissolved solids	mg/L	139.6	17.30	112.89	127.44	138.54	150.58	169.60
Total organic carbon	mg/L	16.90	3.33	11.99	14.54	16.60	18.92	22.80
Turbidity	NTU	50.93	40.46	7.98	23.21	40.74	66.78	127.79

NTU = nephelometric turbidity unit; SD = standard deviation.
a Excludes data from AWQC (2008a).
Note: component nitrogen and phosphorus concentrations may be greater than total nitrogen and phosphorus due to a statistical aberration.

Table A2.4 Stormwater quality summary statistics from untreated sewered urban catchments in Sydney

Contaminant	Unit	Count	Detects	Mean	SD	Percentile					
						5th	25th	50th	75th	95th	Max
Pathogens											
Campylobacter	MPN/L	59	2	<2	<2	<2	<2	<2	<2	<2	15
Cryptosporidium oocysts, confirmed, recovery-corrected	Oocysts/ 10 L	59	22	27	34	<2	<5	<13	36	102	138
Cryptosporidium parvum or *C. hominis*	Detected /10 L	59	5	n/a	n/a	<1	<1	<1	<1	≥1	≥ 1
Cryptosporidium oocysts, confirmed, recovery-corrected for samples where *C. parvum* or *C. hominis* were detected	Oocysts/ 10 L	59	5	6	12	1	1	2	4	18	69
Giardia oocysts, confirmed, recovery-corrected	Cysts/10 L	59	11	101	340	<5	<17	<25	<57	220	2,531
Adenovirus, by cell culture	PFU/10 L	59	0	n/a	n/a	<1	<1	<1	<1	<1	< 1
Adenovirus, by PCR	Detected /10 L	59	2	n/a	n/a	<1	<1	<1	<1	<1	≥ 1
Polyomavirus, by PCR	Detected /10 L	59	7	n/a	n/a	<1	<1	<1	<1	≥1	≥ 1
Enterovirus, by PCR	Detected /10 L	59	13	n/a	n/a	<1	<1	<1	<1	≥1	≥ 1
Norovirus, by PCR	Detected /10 L	59	0	n/a	n/a	<1	<1	<1	<1	<1	< 1
Indicators											
E. coli	MPN/100 mL	58	58	35 961	105 996	61	1 700	5 800	15 750	240 000	690 000
Enterococci	CFU/100 mL	59	59	3 095	4 610	26	100	740	3 950	12 100	20 000
Clostridium perfringens spores	CFU/100 mL	59	42	322	422	<5	<50	140	475	905	2 200
FRNA coliphage	PFU/L	59	11	55	277	<1	<1	<1	<1	180	2 110
Physicochemical											
Ammonia	mg/L	59	59	0.3	0.4	0.0	0.1	0.1	0.3	1.0	2.4
Colour	Hazen	59	59	41.3	19.7	20.9	28.0	34.0	48.0	85.0	102.0
Dissolved oxygen	mg/L	59	59	6.4	2.5	0.8	5.5	7.1	8.1	8.9	10.7
Total kjeldahl nitrogen	mg/L	59	59	1.4	0.8	0.6	0.9	1.1	1.6	3.2	4.5
Total suspended solids	mg/L	59	59	31.9	37.2	4.9	10.0	20.0	33.5	118.2	192.0
Turbidity	NTU	59	59	37.3	45.4	1.7	8.5	20.0	45.0	121.0	250.0
UV transmissivity	%	59	59	56.8	13.6	28.8	47.4	61.7	66.2	71.8	83.4

CFU = colony forming unit; FRNA = functional ribonucleic acid; MPN = most probable number; n/a = not applicable; NTU = nephelometric turbidity unit; PCR = polymerase chain reaction; PFU = plaque forming unit; SD = standard deviation; UV = ultraviolet.
Source: AWQC (2008a).

Table A2.5 Data sources by contaminant for stormwater quality — urban catchments

Contaminant	Reference[a]																	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Pathogens																		
Campylobacter (bacteria)																	ü	ü
Cryptosporidium (protozoa)																	ü	ü
Giardia (protozoa)																	ü	ü
Adenovirus (virus)																		ü
Enterovirus (virus)																		ü
Norovirus (virus)																		ü
Polyomavirus (virus)																		ü
Bacteria — indicators																		
Clostridium perfringens																	ü	ü
Coliforms															ü			
Enterococci															ü		ü	ü
E. coli															ü		ü	ü
Faecal coliforms	ü	ü			ü				ü	ü	ü			ü				
Faecal streptococci										ü								
FRNA coliphages																		ü
Somatic coliphages																	ü	
Metals																		
Aluminium								ü				ü			ü			
Arsenic			ü					ü				ü		ü	ü			
Barium														ü				
Cadmium			ü					ü		ü	ü	ü		ü	ü			
Chromium			ü				ü	ü		ü		ü		ü	ü			
Copper			ü					ü		ü	ü	ü		ü	ü			
Iron							ü	ü		ü		ü			ü			
Lead			ü					ü		ü	ü	ü		ü	ü			
Manganese							ü	ü		ü		ü		ü	ü			
Mercury							ü			ü				ü	ü			

Table A2.5 (continued)

Contaminant	Reference[a]																	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Nickel			ü				ü	ü		ü		ü		ü	ü			
Zinc			ü					ü		ü	ü	ü		ü	ü			
Nutrients																		
Ammonia	ü	ü	ü		ü	ü	ü		ü					ü	ü			
Oxidised nitrogen	ü	ü			ü	ü	ü		ü					ü	ü			
Total dissolved nitrogen						ü												
Total kjeldahl nitrogen							ü		ü					ü	ü			ü
Total organic nitrogen															ü			
Total nitrogen	ü	ü	ü	ü	ü	ü		ü	ü	ü	ü		ü	ü	ü	ü		
Filtered reactive phosphorus	ü	ü	ü			ü	ü							ü	ü			
Total phosphorus	ü	ü	ü	ü	ü	ü		ü	ü	ü	ü		ü	ü	ü	ü	ü	
Organics																		
Polycyclic aromatic hydrocarbons														ü				
Physicochemical indicators																		
Bicarbonate alkalinity as $CaCO_3$														ü				
Biochemical oxygen demand							ü			ü				ü				
Chemical oxygen demand							ü			ü				ü				
Chloride														ü				
Colour																		ü
Dissolved oxygen																		ü
Oil and grease										ü	ü			ü				
pH							ü			ü							ü	
Sodium														ü				
Suspended solids	ü	ü	ü	ü	ü	ü		ü	ü	ü	ü		ü	ü	ü	ü		ü

Table A2.5 (continued)

Contaminant	Reference[a]																	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Total dissolved solids							ü							ü				
Total organic carbon							ü			ü				ü			ü	
Turbidity							ü			ü					ü		ü	ü
UV transmissivity																		ü

a References:
1. AWT (1997)
2. AWT (2001)
3. BCC (2004), cited in Mitchell et al (2006)
4. Chiew and Scanlon (2001)
5. Coad (2001)
6. Fletcher et al (2004)
7. DEC NSW (2006)
8. Deletic and Fletcher (2004)
9. DLWC NSW (no date)
10. Duncan (1999)
11. Fletcher et al (2004)
12. Flower (2005), cited in Mitchell et al (2006)
13. Francey et al (in press)
14. Kogarah Council, unpublished monitoring data (2007)
15. J Argus, Department of Water, Western Australia, pers comm., 2007
16. Peljo and Fletcher (2002)
17. Roser and Ashbolt (2007) – Aldgate Creek catchment
18. AWQC (2008a).

Note: Studies 1–17 were used to develop water quality criteria for the physical and chemical characteristics; study 18 was used to develop water quality criteria for the microbial characteristics.

Appendix 3 Health risk assessment and management

A3.1 General approach

The approach to health risk assessment and management for stormwater and roofwater reuse is the same as that adopted for wastewater and grey water reuse in the Phase 1 guidelines (NRMMC–EPHC–AHMC 2006), although the quality of the source water differs.

The quantitative assessment of microbial health-based risks involves the following stages:

- *Hazard identification* — identifying the hazards likely to be present (ie pathogens) in the source water, their concentration and their effects on human health. For consistency with the Phase 1 guidelines, *Cryptosporidium*, *Campylobacter jejuni* and human rotavirus were selected as the three reference pathogens and, as in the Phase 1 guidelines, the 95^{th} percentile of the reported concentrations was used for the risk assessment.
- *Determination of dose–response* — establishing the relationship between the dose of the hazard and the incidence or likelihood of illness.
- *Exposure assessment* — estimating the size and nature of the population likely to be exposed to the hazard.
- *Risk characterisation* — combining the information on the level of the hazard, dose–response and exposure, to calculate the risk.

To compare different risks to human health, Australia's water recycling guidelines use a unit of risk called a 'disability adjusted life year' (DALY), which can be used to:

- define the acceptable level of risk to public health
- compare impacts from different hazards; for example, those that cause acute impacts (eg a brief episode of diarrhoea) and those that cause chronic impacts (eg arthritis)
- ensure that control efforts are directed at hazards with the greatest potential impacts on public health.

Australia's water recycling guidelines use a level of one-millionth of a DALY per person per year as a measure of the acceptable risk to human health. This is roughly equivalent to one person in a thousand contracting diarrhoea in one year as a result of a water recycling scheme. The observed incidence of diarrhoea in Australia is far higher, at just under one case per person per year.

As explained in the Phase 1 guidelines (NRMMC–EPHC–AHMC 2006), acceptable risk can be used to set health-based targets; that is, the 'goal-posts' or 'benchmarks' that have to be met by each recycled water scheme to ensure that risk remains at or below an acceptable level.

The assumptions made about microbial water quality in these guidelines are considered to be the most supportable, given current evidence. However, the evidence on roofwater and stormwater is limited compared to that for sewage quality; therefore, conservative assumptions have been made.

The assessment of chemical hazards for stormwater reuse followed the same approach as in the Phase 1 guidelines, by assessing the levels of contaminants in stormwater and their relative levels compared to the *Australian Drinking Water Guidelines* (NHMRC–NRMMC 2004) and then accounting for the reduced exposure compared to drinking water.

The approach to health risk management outlined in these guidelines is based on the situation where a specific health risk assessment has not been carried out. Where this has occurred (eg for firefighting), the results from the specific risk assessment can be adopted.

There are no known reports of disease associated with stormwater reuse to date. Most schemes incorporate some form of treatment (eg constructed wetlands or biofiltration) and many schemes in Adelaide involve managed aquifer recharge, which is likely to further reduce pathogen levels (although there has been no known monitoring of these reductions). In addition, irrigation is often undertaken when the irrigated areas are not used by the public (effectively informal access control). These schemes effectively implement controls similar to those in these guidelines.

A3.2 Reference pathogen levels

Due to a lack of suitable data from separately sewered residential catchments in Australia or overseas, a special stormwater quality monitoring project was undertaken to support the development of these guidelines (AWQC 2008a). The results of this study were used to derive reference pathogen levels in Australian urban stormwater.

Data sourced from the AWQC (2008a) study were transformed into a form suitable to support data analysis, by setting results that reported below detection limits to a value of one half the detection limit (for all relevant samples for all determinants) and by correcting results for the recovery efficiency of the methodology used for analysis (for protozoan parasite oocyst counts).

Where sufficient numerical data were available, an interpolated 95th percentile was carried forward to provide the summary statistic for the health risk assessment. This approach was adopted for deriving the *Cryptosporidium* protozoan parasite reference pathogen concentration in stormwater for these guidelines, which was based on the interpolated 95th percentile of the confirmed oocyst counts in samples containing either *C. parvum* or *C. hominis*: 18 oocysts per 10 L (Table A2.4). The 95th percentile concentration of confirmed oocysts from all samples was higher, at 102 oocysts per 10 L. However, in urban stormwater there is evidence that most samples do not contain human infectious oocyst genotypes; rather, they contain genotypes that infect other animals. For instance, recent data from Jiang (2004) studying three United States sewered urban stormwater catchments found that only about 5% of around 100 *Cryptosporidium* oocyst types characterised were potentially human infective. Therefore, the lower value of 18 oocysts per 10 L selected for the health risk assessment was considered appropriate and conservative.

Where there were insufficient numerical data to derive an interpolated 95th percentile, or where the interpolated 95th percentile was below the detection limit, the maximum observed value was carried forward to provide the summary statistic for the health risk assessment. This approach was adopted for deriving the *Campylobacter* bacterial reference pathogen concentration in stormwater for these guidelines, which was based on the maximum observed value: 15 MPN/L (Table A2.4). Although this value was quite conservative, in practice, bacterial pathogen reduction is never the limiting factor in water recycling because the much more robust viral and protozoan pathogens inevitably limit the treatment or end-use restrictions required.

Where no numerical data were reported due to all samples being reported as 'none detected', 10 times the detection limit was considered to represent a conservative summary statistic for the health risk assessment. This approach was adopted for deriving the infectious adenovirus viral reference pathogen concentration in stormwater for these guidelines, which was based on 10 times the assay detection limit: 1/L (Table A2.4). It would have been defensible to use twice the assay detection limit, were it not for the fact that virus assays do not yield 100% recovery; 10% recovery is more realistic. Furthermore, the presence or absence results from the PCR (polymerase chain reaction) assays did reveal the presence of viral nucleic acid in a small proportion of samples, albeit at unknown concentrations, and not necessarily from viruses that were still viable.

Table A3.1 summarises the reference pathogen concentrations used for the health risk assessment. By way of comparison, the 95th percentile concentrations of *Cryptosporidium* and *Campylobacter* from the unsewered peri-urban Aldgate Creek catchment near Adelaide (Roser and Ashbolt 2007) reported in Table A2.3 (55/L and 70/L respectively) are marginally higher than the values adopted in Table A3.1 for stormwater from an urban sewered catchment. This indicates the influence of suspected septic tank leakage in the Aldgate Creek catchment.

Further, a study of urban stormwater in the urban Lake Parramatta Creek catchment in Sydney (Roser and Ashbolt 2005) did not detect these pathogens (three samples). Neither of these studies monitored adenovirus or rotavirus. The only study located that monitored rotavirus in urban stormwater was one by Schroeder et al (2002) in Southern California, United States, where the virus was not detected in 97 samples.

Table A3.1 Reference pathogen levels in stormwater

Reference pathogen	Pathogen used	Concentration used for the health risk assessment (#/L)[a]
Rotavirus	Infectious adenovirus	1
Cryptosporidium	*Cryptosporidium parvum or C. hominis*	1.8
Campylobacter jejuni	*Campylobacter* spp.	15

a The units in this table are #/L compared with the units for these pathogens in Table A2.5 of #/10 L or #/100 mL.

These default values were used to determine the required reductions in reference pathogen levels described in Section A3.3.1. Project-specific data on pathogen concentrations can be used as an alternative to the default values to calculate the required reductions, using the calculation method described in Section A3.3.1.

A3.3 Stormwater microbial risk assessment and management

A3.3.1 Required reductions

The tolerable reference pathogen doses quoted in the Phase 1 guidelines are shown in Table A3.2.

Table A3.2 Tolerable dose of reference pathogens

Reference pathogen	Tolerable dose
Rotavirus	0.0025 infectious virions/person/year
Cryptosporidium	0.016 infectious oocysts/person/year
Campylobacter jejuni	0.038 infectious bacteria/person/year

Table A3.3 lists the calculated tolerable concentrations in stormwater for various end uses, including municipal irrigation. These concentrations were calculated by dividing the tolerable dose (Table A3.2) by the estimated annual exposure volume per person per year from Table 3.3 from the Phase 1 guidelines for various uses. As noted in the Phase 1 guidelines, the exposure volumes are default values that can be used where project-specific information is not available. The reduction required is calculated from the reduction required to reduce the pathogen levels in stormwater (Table A3.1) to the noted tolerable concentrations.

While these guidelines are primarily intended to apply for new schemes, the approach outlined in this section can be used to assess the effectiveness of controls for existing schemes, particularly those where disinfection is not used (ie where the treatment process involves constructed wetlands followed by managed aquifer recharge). This approach would involve monitoring reference pathogen levels in the stormwater before use (ie post-treatment and storage) and comparing the 95^{th} percentile levels to the tolerable concentrations given in Table A3.3 that apply to the specific application. Health risks from pathogens should be adequately controlled where the monitored concentrations are lower than the tolerable concentrations. This approach is recommended over a risk assessment based on indicator bacteria, for example, *Escherichia coli* (*E. coli*), due to the poor correlation between indicator bacteria and reference pathogen levels discussed earlier.

Table A3.3 Tolerable pathogen levels and required reductions for stormwater reuse

Use	Reference pathogen	Tolerable concentration (infectious units per L)	Required reduction	
Municipal, including open-space irrigation and nonpotable construction activities (eg dust suppression, earthworks compaction) (exposure = 50 mL/person/year)	Rotavirus	0.050	95.0%	1.3 log
	Cryptosporidium	0.32	82.2%	0.8 log
	Campylobacter jejuni	0.76	95.9%	1.3 log
Dual reticulation for indoor and outdoor use (eg toilet flushing, laundry use, irrigating garden food crops, ornamental garden watering) (exposure = 670 mL/person/year)	Rotavirus	0.0037	99.6%	2.4 log
	Cryptosporidium	0.024	98.7%	1.9 log
	Campylobacter jejuni	0.057	99.6%	2.4 log
Firefighting (exposure = 1000 mL/person/year)	Rotavirus	0.0025	99.8%	2.6 log
	Cryptosporidium	0.016	99.1%	2.1 log
	Campylobacter jejuni	0.038	99.8%	2.6 log
Commercial food crops (exposure = 490 mL/person/year)	Rotavirus	0.0051	99.5%	2.3 log
	Cryptosporidium	0.033	98.2%	1.7 log
	Campylobacter jejuni	0.078	99.5%	2.3 log
Non-food crops (eg trees, turf, woodlots, flowers) (exposure = 50 mL/person/year)	Rotavirus	0.050	95.0%	1.3 log
	Cryptosporidium	0.32	82.2%	0.8 log
	Campylobacter jejuni	0.76	95.9%	1.3 log

A3.3.2 Stormwater microbial health risk management

The required reductions in pathogen levels can be achieved by stormwater treatment, on-site exposure controls, or a combination of both. The Phase 1 guidelines provide guidance on the indicative log reduction in pathogen levels that can be achieved for various forms of treatment and on-site preventive measures (Phase 1 guidelines, Tables 3.4 and 3.5 respectively). The log reductions required for stormwater reuse are approximately 2.5–4 log lower than for wastewater use for the same applications; consequently, the on-site controls and treatment requirements are reduced.

On-site exposure reduction

The on-site preventive measures used in the Phase 1 guidelines are applicable to stormwater reuse. Control measures can generally be combined to achieve greater exposure reductions. The most practical options for a stormwater reuse project are shown in Table A3.4. This table notes the control measures that apply to exposure at the irrigation area and off-site exposure. As these exposures may apply to different populations, the reduction benefits should not be added for different exposed populations.

There is limited information on the effectiveness of the estimates of microbial hazard reductions given in Table A3.4, and further research is required on this aspect. Where this type of preventive measure is applied, it is essential that the application is supported by education of users, and monitored using surveillance and auditing.

Table A3.4 Indicative exposure reductions provided by on-site preventive measures

Control measure	Reduction in exposure to pathogens	
	On-site exposure	**Off-site exposure**
Drip irrigation of crops	2 log	
Subsurface irrigation of above-ground crops	4 log	
Withholding periods for irrigation of parks/sports grounds (1–4 hours)	1 log	
Spray drift control (microsprinklers, anemometer systems, inward-throwing sprinklers, etc)		1 log
Drip irrigation of plants/shrubs	4 log	
Subsurface irrigation of plants/shrubs or grassed areas	5–6 logs	
No public access during irrigation	2 log	
No public access during irrigation and limited contact following irrigation (eg food crop irrigation rather than public open space)	3 log	
Buffer zones (25–30 m)		1 log

Source: Modified from the Phase 1 guidelines. (NRMMC–EPHC–AHMC 2006)

Stormwater treatment

No data on the effectiveness of conventional stormwater treatment measures in reducing levels of reference pathogens were located. Limited data were available on bacterial removal, largely limited to indicator bacteria (*E. coli* and thermotolerant coliforms). These data indicate a wide range of performance:

- The Center for Watershed Protection (2007) found that retention of faecal coliforms and *E. coli* from a range of different stormwater treatment measures ranged from negative retention (ie outflow concentrations higher than inflow concentrations) up to 99% retention (2 log).
- Farrell and Scheckenberger (2003) and the Stormwater Assessment Monitoring and Performance Program (2005) also identified variable performance from ponds and wetlands, with an average *E. coli* retention of 90%.

The negative retention is likely to be due to faecal input from birds or animals (eg birds on a constructed wetland).

The available data indicate that the observed retention for *E. coli* in ponds and wetlands is slightly higher and is more consistent than for faecal coliform retention, although there are considerably more faecal coliform studies.

The most reliable stormwater treatment measures for indicator bacterial reduction are constructed surface-flow wetlands and wet ponds (ie those that have a permanent body of water). Retention using filters and swales is often poor and can be negative (Centre for Watershed Protection 2007), although *E. coli* retention of up to 70% using bioretention systems has been observed (Hunt et al 2008).

There is also limited information on the relationship between the reductions in bacterial indicators and design parameters for stormwater treatment measures, which would enable a treatment measure to be designed to achieve a particular retention. The monitoring data indicates that a constructed wetland or pond designed to achieve a reasonable reduction in the loads of conventional stormwater pollutants is likely to achieve an *E. coli* reduction of 0.5–1.0 log (68–90%).

The estimated removal for *Campylobacter* and *Cryptosporidium* is expected to be less than 0.5 log, assuming that the ratio between the *E. coli* removal and indicative removals for surface-flow wetlands from the Phase 1 guidelines is applied (Table 3.4). No data on virus removals in wetlands was available in the Phase 1 guidelines to estimate removals in stormwater wetlands; however, the removal is also expected to be less than 0.5 log.

Given this uncertainty, a conservative approach is to assume that conventional stormwater treatment measures do not reduce the levels of reference pathogens.

The pathogen reductions achieved by most wastewater treatment systems are expected to be greater and more consistent when treating wastewater than stormwater. This is due largely to the more variable quality and quantity of stormwater inflows and the higher concentrations of pathogens in wastewater. Except for disinfection and filtration, log reductions from the Phase 1 guidelines for most wastewater treatment systems should not be used as an indication of equivalent stormwater treatment effectiveness, because they are likely to represent overestimates.

The most appropriate approach to stormwater treatment for small-to-medium reuse schemes is disinfection, possibly preceded by filtration for turbidity control (see Section A3.4). Large schemes involving dual reticulation may need to incorporate more sophisticated treatment, such as membrane filtration, reverse osmosis or lagoon storage with disinfection.

Table A3.5 presents an indicative range of log reduction reported in the literature for various water and wastewater treatment techniques relevant to stormwater treatment. This information is typically based on removal efficiency demonstrated by laboratory challenge testing; however, operational monitoring may not be sensitive enough to demonstrate these log removals. Further research in this area could provide greater confidence in the sensitivity of operational monitoring for these systems. This table is intended to be informative and should not be used as the design basis for schemes. Scheme proponents should validate the treatment technology for the specific application and operational conditions (ie they should demonstrate that they will work).

Table A3.5 Indicative log reductions of reference pathogens in wastewater after different treatments

	Indicative log reductions		
Treatment	**Viruses (including rotavirus virions)**	**Protozoa (including *Cryptosporidium* oocysts)**	**Bacterial pathogens (including *Campylobacter* cells)**
Dual-media filtration with coagulation	0.5–3.0	1.5–2.5	0–1.0
Membrane filtration	2.5–>6.0	>6.0	3.5–>6.0
Reverse osmosis	>6.0	>6.0	>6.0
Chlorination	1.0–3.0	0–0.5	2.0–6.0
Ozonation	3.0–6.0	–	2.0–6.0
Ultraviolet light	>1.0 adenovirus >3.0 enterovirus, rotavirus[a]	>3.0	2.0–>4.0 *Campylobacter* 3.0–4.0[b]

– = no data available.
a Cotton et al (2001).
b Butler et al (1987).
Source: Phase 1 guidelines.

Ultraviolet (UV) light is currently the most common disinfection treatment used for stormwater harvesting schemes (Hatt et al 2004, DEC NSW 2006), and should achieve the required log reduction for municipal irrigation. Filtration followed by reasonable chlorination may not achieve the required reduction for *Cryptosporidium* oocysts for municipal irrigation. Ozone treatment is relatively expensive, and media filtration alone (ie without prior coagulation) is unlikely to achieve the pathogen reductions necessary for municipal irrigation. UV is likely to remain the preferred disinfection technique for stormwater reuse, at least for small-to-medium sized schemes. Practicable levels of UV disinfection are effective on protozoan parasites, whereas practicable levels of chlorine disinfection are not.

Table A3.6 indicates a number of treatment or on-site exposure controls that could be used to achieve the required reductions. The UV dose recommended in Table A3.6 for treatment involving UV should provide the appropriate log reduction of the most resistant of the enteric viruses — adenovirus type 41 (Baxter et al 2007), with much higher reductions for most other viruses. The UV dose recommended is therefore able to meet requirements for removal of protozoa and bacteria. The influence of turbidity on UV disinfection is discussed in Section A3.4.

The postdisinfection *E. coli* levels in Table A3.6 are based on the median *E. coli* concentration from Appendix 2 (≈10^4 MPN/100 mL) reduced by the log reduction required for virus reduction for the specific application, plus an additional reduction of approximately 1.5 log, to account for UV disinfection, for example, reducing *E. coli* more readily than rotavirus (Chang et al 1985, Nasser et al 2006). This also provides a factor of safety given the uncertainty in stormwater pathogen levels.

The *E. coli* criterion is an indication of disinfection effectiveness and not a direct indicator of residual health risks. It is therefore higher in stormwater that is to be used for irrigation than for wastewater in the Phase 1 guidelines, because the log reductions are lower, even though the *E. coli* levels are higher in sewage.

Table A3.6 Potential combinations of treatment processes and on-site controls for designated uses of stormwater

Use	Log reduction targets[a]	Indicative treatment process[b]	Log reductions achievable by treatment[a]	On-site preventive measures	Indicative exposure reduction (log reductions)	Water quality criteria
Option 1A: Municipal use, with unrestricted access — open spaces, sports grounds, golf courses, and nonpotable construction uses (eg dust suppression) OR Irrigation of non-food crops	V 1.3 P 0.8 B 1.3	Filtration (if required) and disinfection	≥1.5 >>4.0 >>4.0	No specific measures		• Turbidity: <25 NTU (median), <100 NTU (95th percentile) • *E. coli* <10/100 mL
Option 1B: Municipal use, with restricted access and application	V 1.3 P 0.8 B 1.3	No treatment	0	Restrict public access during irrigation Minimum 25–30 m buffer to nearest point of public access and spray drift control	2.0 (on-site) 2.0 (off-site)	Not applicable

Table A3.6 (continued)

Use	Log reduction targets[a]	Indicative treatment process[b]	Log reductions achievable by treatment[a]	On-site preventive measures	Indicative exposure reduction (log reductions)	Water quality criteria
Option 1C: Municipal use, with drip irrigation	V 1.3 P 0.8 B 1.3	No treatment	0	Drip irrigation of plants	4.0	Not applicable
Option 2: Dual reticulation with indoor and outdoor use OR Irrigation of commercial food crops	V 2.4 P 1.9 B 2.4	Filtration (if required) and disinfection	≥2.5 >>4.0 >>4.0	Strengthened cross-connection controls required including ongoing education of householders and plumbers (for dual reticulation)		• Turbidity: <25 NTU (maximum), <10 NTU (95th percentile), <2 NTU (target) • *E. coli* <1/100 mL

NTU = nephelometric turbidity units; UV = ultraviolet.
a Given as 'V', 'P' or 'B', where V = virus, represented by adenovirus type 41 for UV, which is more resistant and better characterised than rotavirus; P = protozoa, represented by *Cryptosporidium* spp. oocysts; B = bacteria, represented by *E. coli*, which is more resistant and better characterised than *Campylobacter*.
b Indicative UV doses given are based on US EPA (2006) and refer to validated doses taking into consideration RED bias and other factors.

Turbidity levels for effective filtration to remove *Cryptosporidium* oocysts are considerably more stringent than those required for effective disinfection. Typically, turbidity needs to be of the order 0.1 NTU target and 0.3 NTU 95th percentile to achieve 2-log reduction of protozoan parasites, and coagulation would be essential for filtration to be effective. Prolonged ponding in storage tanks or holding ponds (designed to minimise short-circuiting) can reduce parasites to levels where simple chlorination will inactivate the remaining bacterial and viral pathogens. However, in the absence of ponding, chlorine alone will be inadequate because it is ineffective on some important encysted parasites.

If filtration is used in place of ponding, it must meet stringent parasite removal requirements and not be used simply to reduce turbidity to improve subsequent disinfection. Free chlorine is, however, highly effective on all relevant viruses and bacteria. Combined chlorine treatment (eg monochloramine, often termed chloramination) is also effective, but requires long contact times (many hours, at least) to be effective on viruses.

For chlorine-insensitive protozoa, either undisturbed waste stabilisation lagoon ponding or filtration (or both) can be used as pretreatment processes before chlorination. Based on unpublished observations from water management agencies and experience with waste stabilisation ponds used in sewage treatment, a 25-day ponding period would be expected to provide greater than 1.5 log reduction of viable infectious *Cryptosporidium* oocysts under Australian temperature and insolation conditions (insolation is a measure of solar radiation energy received on a given surface area in a given time). This is the level of reduction required by the Phase 1 guidelines. If ponding is used, the stored water must be undisturbed throughout the ponding period. Water removal must not disturb the settled sediment containing ova, cysts and oocysts. Ponding may only be practical for large schemes with high exposures.

A3.4 Influence of turbidity on disinfection of stormwater

Following some storm events, turbidity and often levels of organics in stormwater are too high for disinfection without some form of pretreatment. Therefore, if there is an intention to use stormwater for unrestricted irrigation, or other relatively high exposure uses, one of the most difficult issues is reducing turbidity, and to a lesser extent, organics. Both can interfere with disinfection through effects such as physical shielding by turbidity and through UV or oxidant absorption and reaction by organics.

Where a stormwater reuse system includes substantial tormwater storage before disinfection, short-term peaks in inflow stormwater turbidity are unlikely to influence average turbidity levels. This is due to the storage equalising turbidity levels, with some reduction in turbidity likely, due to sedimentation. Turbidities above 1.5 NTU can reduce the effectiveness of disinfection (LeChevallier et al 1991). Historically, the default recommended turbidity levels for effective disinfection are less than 1 NTU for drinking water (NHMRC–NRMMC 2004) and less than 2 NTU for recycled water (NRMMC–EPHC–AHMC 2006).

In practice, chlorine or other oxidants (eg chloramine, ozone, chlorine dioxide or hydrogen peroxide) and UV disinfection systems can provide adequate disinfection at turbidities above this level, for example, at 10 NTU or more. However, disinfection can only be effective at these higher turbidities if the material that gives rise to the turbidity does not rapidly absorb the UV irradiation or quench the oxidant, and does not consist of particles that entrap pathogens, shielding them from disinfection.

Evidence on the effects of absorbance and quenching on disinfection comes from a range of unpublished disinfection trials and from published studies. For example, adding kaolin (natural clay) to water to simulate increasing turbidities due to clay from natural runoff, and then adding microorganisms, has relatively little effect on disinfection with chlorine at turbidities of 1–5 NTU (Barbeau et al 2004). Kaolin does not exert a chlorine demand. Effects at higher turbidities were not evaluated but, based on the results presented and on unpublished experiences of water management agencies, the effect would be expected to continue at slightly higher turbidities. A number of agencies have found that chlorine disinfection of drinking water supplies remains effective at tens of NTU, provided the disinfectant demand does not quench the disinfectant, and free disinfectant residual remains present (unpublished data).

Similar experiments involving the seeding of microorganisms into natural waters — with natural sediment added to vary turbidities — has demonstrated that turbidities in the range 1–10 NTU can be adequately disinfected using UV, with the turbidity not reducing the effectiveness of disinfection provided the UV disinfection system can increase its dose to compensate for the scattering and absorbance (Passantino et al 2004). Once again, effects at higher turbidities were not evaluated but, based on the results presented and on unpublished experiences of water management agencies, any effects would be expected to continue at slightly higher turbidities.

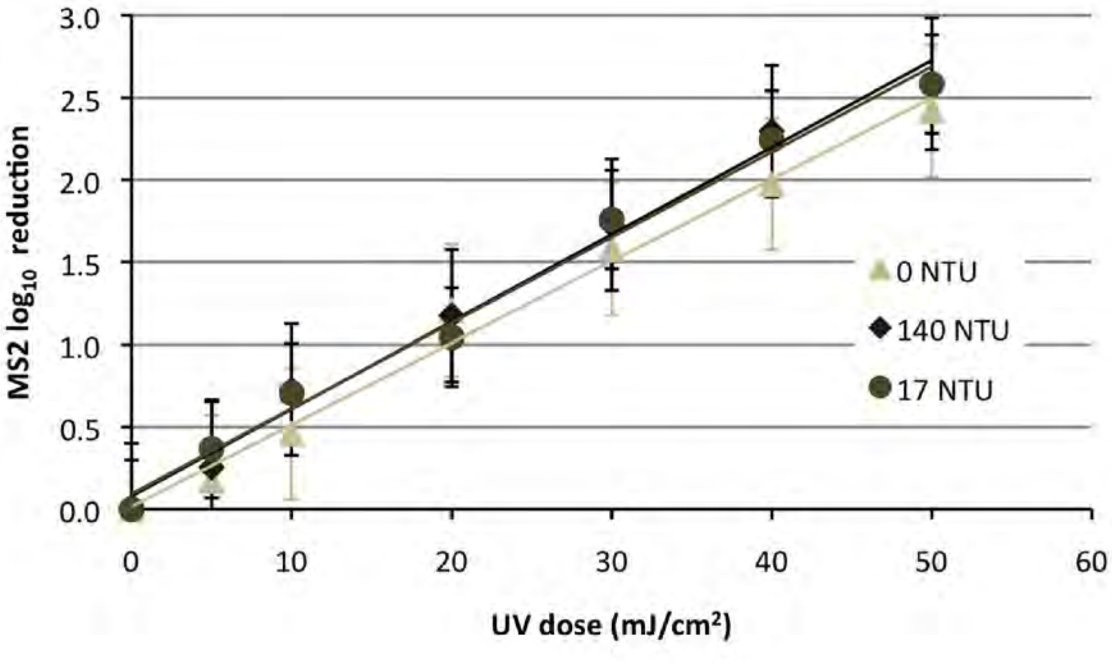
A study of UV disinfection in stormwater with elevated turbidity undertaken specifically to support the development of these guidelines (AWQC 2008b) showed that, provided the disinfection system can provide a sufficient UV dose to compensate for the increased UV absorbance and scatter, effective disinfection can be maintained. Figures A3.1–A3.3 summarise the results of the study for MS2 coliphage (as a viral surrogate), *Cryptosporidium* oocysts (as a protozoan reference pathogen) and *E. coli* (as a bacterial surrogate), respectively. In conducting this trial, the UV exposure period was increased as turbidity increased to compensate for the effects of scatter and absorbance, and to provide a consistent dose.

The results demonstrate that the UV dosing was effective even at elevated turbidities up to 140 NTU for all three reference pathogen groups. In practice, viral disinfection is typically the limiting factor for UV disinfection. Therefore, for the MS2 coliphage the experiment was completed for seven turbidity ranges, and in duplicate, with the full results for the MS2 trial given in Figure A3.4. For reference, the physical and chemical properties of the test water are given in Table A3.7.

Table A3.7 Characteristics of test water

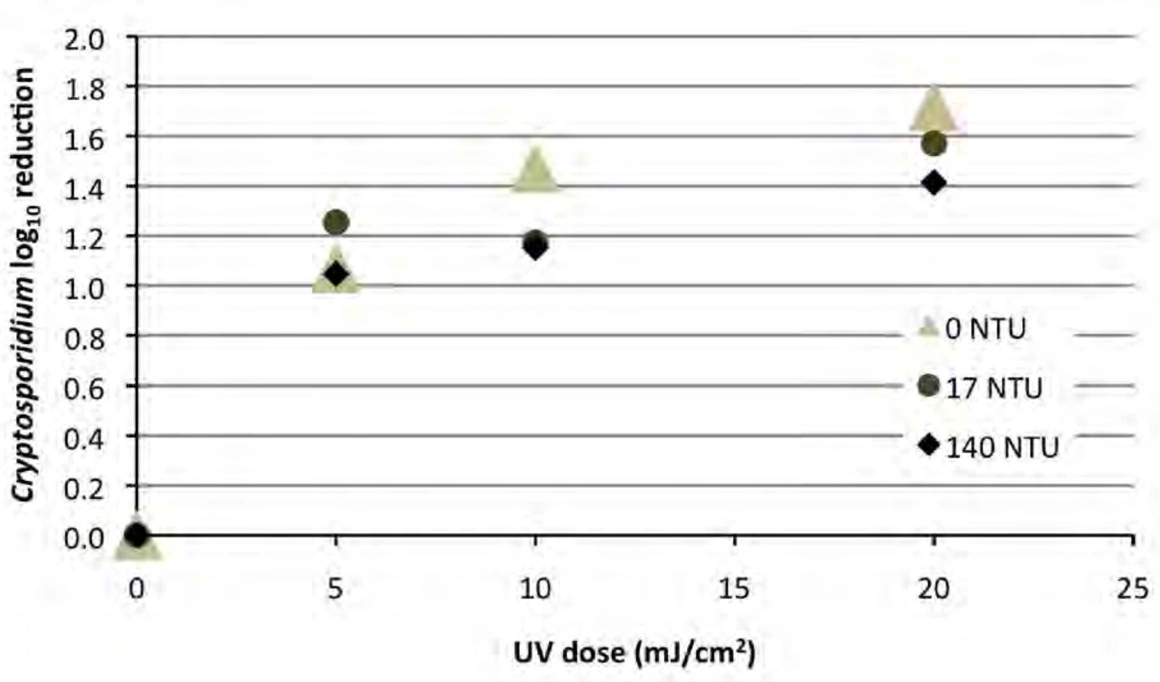
Target turbidity (NTU)	Transmittance 254 nm (%)	Total suspended solids (mg/L)	Turbidity (NTU)	Colour 456 nm (HU)	Ammonia as N (mg/L)	TKN as N (mg/L)
5	87.7	2	3.9	8	0.012	0.17
10	71.4	2	8.6	27	<0.005	0.45
20	70.6	10	17	27	<0.005	0.44
50	71.3	28	56	24	0.008	0.52
100	70.3	76	140	31	<0.005	0.84

HU = Hazen Units; N = nitrogen; NTU = nephelometric turbidity units; TKN = total kjeldahl nitrogen.
Source: AWQC (2008b).



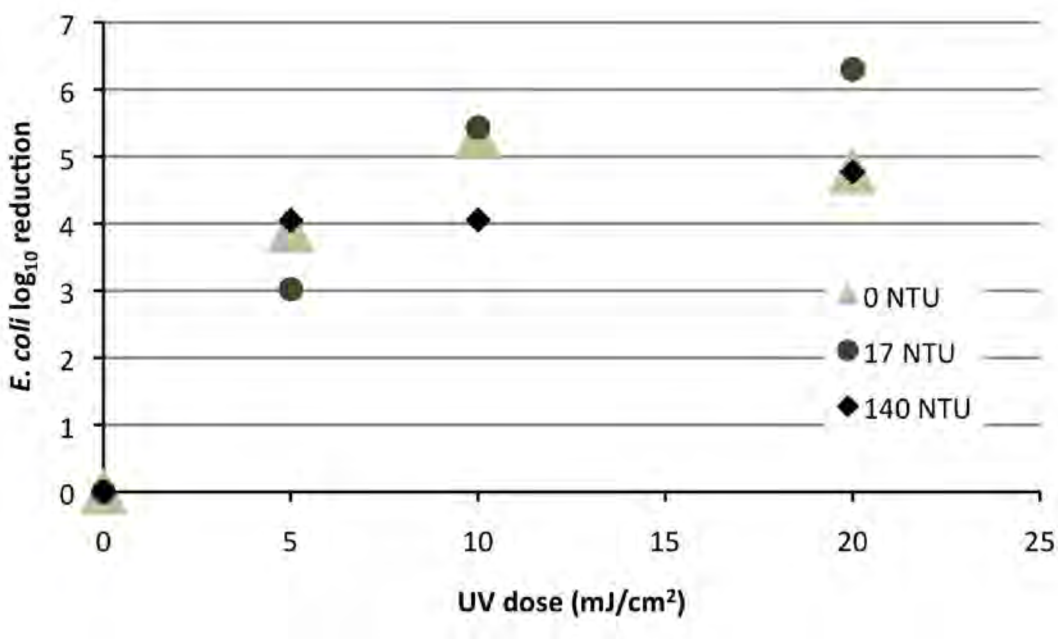
Note: Results are the average of two samples; error bars are one pooled standard deviation; best-fitting linear trendlines are shown.
Source: AWQC (2008b).

Figure A3.1 MS2 coliphage dose–response curves for UV disinfection for three turbidities



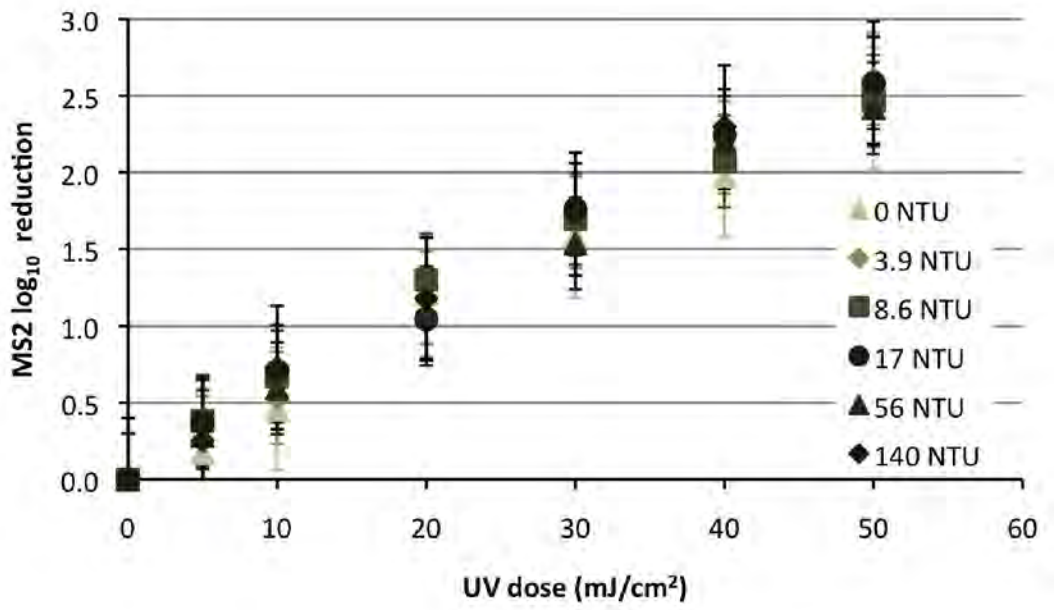
Note: Results are from one sample.
Source: AWQC (2008b).

Figure A3.2 ***Cryptosporidium*** **dose–response curves for UV disinfection for three turbidities**



Note: Results are from one sample.
Source: AWQC (2008b).

Figure A3.3 ***E. coli*** **dose–response curves for UV disinfection for three turbidities**



Note: Results are an average of two samples and error bars are one pooled standard deviation.
Source: AWQC (2008b).

Figure A3.4 MS2 coliphage dose–response curves for UV disinfection for six turbidities

There are two difficulties in assuming that the above results will hold in more natural conditions.

The first issue is the loss of disinfectant dose due to excessive turbidity and organics. This can be handled by appropriate design. During the experimental conditions described above, showing that increased turbidity is tolerable, the UV or chlorine doses were not overwhelmed by the turbidity. For example, natural kaolin or sediments were added that might not have been significantly UV absorbing or chlorine quenching. However, in natural waters, increased turbidity in the range 1–10 NTU typically does mean that a higher disinfectant dose is needed to get the same effect, because turbidity reduces disinfectant effectiveness through effects such as scattering, shielding and some absorbance (eg Christensen and Linden 2003).

In practice, UV and chlorine disinfection systems can either be designed to dose in the presence of significant turbidity and organic matter at all times (ie overdosing during periods of low turbidity), or can be set to respond automatically, to compensate for the effects of increased turbidity and organic matter through automated intensity or residual feedback dosing. Recent evidence from a study commissioned to support these guidelines (AWQC 2008b) is consistent with previously unpublished observations that, if appropriately designed, disinfectant systems can respond by detecting and increasing disinfectant doses to counter quenching and absorbance. Therefore, if it is intended to disinfect stormwater with elevated organics without ponding or treatment (eg filtration), and with turbidities >10 NTU, it is vital that the disinfection system is designed appropriately and is operated to maintain performance.

The second issue, shielding, needs to be evaluated empirically. In natural settings, where microorganisms are naturally present and held within particles, rather than seeded as single organisms artificially, even relatively low turbidity increases can significantly reduce disinfection effectiveness in some circumstances. Due to the relatively low concentrations of naturally occurring microbial faecal indicators and pathogens in normal drinking water sources, most studies on naturally occurring microorganisms are based on wastewater.

Studies on secondary treated wastewater show that turbidity does interfere with UV inactivation, with tailing (ie plateauing) often being observed once inactivation of about 2 $\log_{10}$ has been achieved (Keller et al 2003). This effect appears to be the result of the entrapment of microorganisms within particles greater than 5 µm in diameter (Madge and Jensen 2006). Similar particle protection effects have been demonstrated in artificial water that had been amended to simulate natural water (Mamane and Linden 2006ab).

Unpublished studies by water management agencies have often shown similar tailing effects in oxidant-disinfected wastewater. If the elevated turbidity includes particles of faecal origin, or contains entrapped faecal pathogens (eg as a result of a conventional aerated wastewater treatment processes creating floccs), it is likely that disinfection would be relatively ineffective unless filtration first removed the particles from the stormwater.

On the other hand, if the turbidity is typically derived from sources other than faecal, or flocculated faecal, material and is not expected to entrap pathogens, then — provided the disinfection system can compensate for increased UV absorbance and scattering, or oxidant demand — several log inactivation of susceptible pathogens should be achievable, even at elevated turbidities.

Stormwaters differ with respect to the actual nature of the particles causing turbidity; thus, it is not possible to make a general statement about a safe turbidity cutoff at which sufficient log inactivation of susceptible pathogens can be achieved. The extent of turbidity reduction required for a particular disinfection technique to be effective depends on the nature of the turbidity, but also on the power and design of the disinfection process. Properly operated water and wastewater filtration processes can be used to reduce turbidity sufficiently for disinfection to be effective. However, such technologies may prove prohibitively costly for small stormwater schemes; also, the technical capacity required to select and operate such systems may be lacking.

It may be possible, in some circumstances, to demonstrate reasonable disinfection effectiveness (eg 2–3 log reductions) at higher turbidities, even at up to 100 NTU, in specific circumstances. However, it cannot be assumed that disinfection will work without empirical validation testing during commissioning and ongoing verification testing over the long term. Some means of controlling concentrations of turbidity and organics is needed for any stormwater disinfection system, at least some of the time, particularly after storm events of intermediate-to-high magnitude.

Simple ways to reduce turbidity and organics that can be applied to stormwater free of larger, fresh faecal particles include extended ponding, ponding enhanced by flocculation, wetland treatment or sand, or strainer polishing filtration. Such simple methods may lower turbidity and organics enough to allow disinfection to be effective.

The following recommendations summarise approaches to stormwater disinfection that can be used for unrestricted irrigation:

- Treated stormwater with turbidity 0–2 NTU (95th percentile), with occasional short-term peaks (turbidity <5 NTU) can be disinfected using standardised, validated processes. The installation of standardised processes that have been previously validated (off-site or at another site) for similar quality surface water disinfection, can obviate the need for site-specific, in situ validation testing. Ongoing verification testing during operation (weekly *E. coli* monitoring) is required.
- Treated stormwater with elevated turbidity, typically below 25 NTU, with occasional short-term peaks of up to 100 NTU, can be disinfected, provided the disinfection system can respond by increasing the dose to compensate for absorbance and scattering (in the case of UV), and quenching (in the case of an oxidant, such as chlorine). The stormwater can also be disinfected provided it has been screened, filtered or ponded to remove larger faecal particles. Actual proof of treatability should be attained through in situ process validation during the commissioning phase, and confirmed through ongoing verification.

The disinfection processes should be validated using *E. coli* monitoring, both before and after disinfection, to determine effectiveness of disinfection. Validation testing would need to be undertaken in conditions representative of the water to be supplied. Additional validation testing may be necessary to represent conditions present after the shortest interval following storm events at which irrigation would be expected to begin. Ongoing verification testing during operation (weekly *E. coli* monitoring) is required.

In some cases, untreated stormwater with extreme turbidity may not be amenable to disinfection. If disinfection is to be relied upon for the treatment of stormwater with turbidities over 100 NTU, there is a need for a scheme-specific, specialist validation to be undertaken and overseen by an independent, suitably qualified professional engineer or scientist. This requirement is part of Element 9 of the risk management framework given in the Phase 1 guidelines (NRMMC–EPHC–AHMC 2006). Data on disinfection of high-turbidity stormwater are lacking, and further research in this area is warranted. In addition to undertaking a specialist validation, ongoing verification testing during operation (weekly *E. coli* monitoring) is required.

Since pathogens are acutely hazardous, even short periods of disinfection failure are not tolerable. All disinfection systems should be automated and designed with continuous, automated operational monitoring indicating the disinfectant dose. Water production should automatically shut down if disinfection is not effective.

A3.5 Chemical hazards

Any consumption of stormwater and roofwater destined for irrigation will be restricted to sporadic, isolated incidental consumption of small amounts of water. The total exposures and risks are likely to be low, and adverse outcomes are likely to be limited to those associated with acute-acting hazards.

Under the Phase 1 guidelines, health risks from chemicals arising from wastewater recycling were considered to be low, not requiring targeted treatment. Stormwater would not be expected to be particularly chemically hazardous when compared to sewage. Hazardous chemicals are routinely discharged to sewage in domestic waste and as ‘trade waste’, whereas chemical hazards in stormwater, arising from open environments, would ordinarily be far below acutely hazardous concentrations for sporadic, small-volume exposures (see Appendix 2). Therefore, as for the Phase 1 guidelines, the exposure controls required to adequately manage microbial health risks from low-exposure uses of recycled wastewater are considered adequate to manage chemical health risks for the equivalent uses of reused stormwater.

A3.6 Roofwater

A3.6.1 Hazard identification

The approach adopted for assessing risks associated with roofwater was largely identical to that adopted for stormwater, but with an important difference in hazard identification for microbial contaminants. Roofwater was assumed to be free from sewage contamination, but was assumed to contain bird and small animal faeces, which is an established source of human-infectious zoonotic *Campylobacter* and *Salmonella* bacteria. Human-infectious viral and protozoan pathogens were assumed to be present at negligible concentrations relative to the bacterial pathogens.

Epidemiological studies of health risks from rainwater have focused on drinking rainwater, where the exposure is higher than for the uses addressed in these guidelines (Sinclair et al 2005, Heyworth et al 2006). No epidemiological studies of nonpotable use of rainwater were found.

Metal (eg lead) levels in roofwater can exceed drinking water guideline values, sometimes by an order of magnitude. However, these guideline values relate to lifetime exposures from drinking, involving hundreds of litres per year. Reported exceedences of the drinking water guideline values were not sufficient to exceed tolerable exposure levels for small exposure volumes of several litres per year. Chemical health risks were not considered significant for nonpotable uses. In general, roofwater was not considered to contain hazardous chemical concentrations high enough to present health risks when used for low exposure uses.

The recommendations in Section 2.2.3 regarding sealing areas exposed to lead paint or flashing are intended to reduce roof sources of lead in the roofwater. It is acknowledged that there are atmospheric sources of lead that will contribute to roofwater lead concentrations (Magyar et al 2008, Huston et al 2009).

A3.6.2 Pathogen concentrations

Pathogen concentrations in roofwater were predicted based on microbial indicator data and pathogen monitoring data from roofwater.

Pathogen data alone was considered insufficient to be used to predict pathogen concentrations in roofwater, due to the lack of sound data, particularly for the reference pathogens. Most pathogen monitoring results for roofwater are expressed as ‘not detected’ for most reference pathogens (eg Sinclair et al 2005, Schets et al 2007, Simmons et al (2001). Data below detection limits cannot readily be described using conventional statistical approaches, and these data were not used in deriving concentrations (Table A2.1).

In contrast, extensive microbial indicator data are available (eg thermotolerant coliform concentrations, Table A2.1), which indicate the concentration of faecal-derived microbial material suspended in roofwater. Since the principal microbial pathogens of concern are also derived from faecal material, microbial indicator concentrations can be used to help predict pathogen concentrations.

In the Phase 1 guidelines (NRMMCC–EPHC–AHMC 2006), the ratio of observed mean *E. coli* concentrations in sewage to those in grey water was used to estimate the reduction in the levels of reference pathogens required to meet the health targets. For consistency between Phases 1 and 2 of the guidelines, the approach of using a ratio of measured concentrations of microbial indicators to estimate pathogen concentrations was extended to roofwater.

Microbial faecal indicator counts in grey water are human-derived and, in roofwater, are likely to be almost entirely derived from wildlife. The approach adopted in these guidelines is therefore highly conservative.

Bacterial pathogen concentrations in roofwater were predicted using the conservative pathogen to indicator ratios derived from sewage, and indicator levels in roofwater.

The possible significance of domestic roofwater used for drinking as a source of enteric pathogens and a cause of gastroenteritis is currently under study. The findings from this research may have implications for both hazard identification and the concentration assumptions in these guidelines. There are many pathogens, particularly protozoan parasites (some of which are often termed ‘emerging pathogens’) that may be significantly associated with roofwater ingestion and whose identification may change the findings of this risk assessment. However, at present, confirmed waterborne disease outbreaks from conventional roofwater systems appear to be associated primarily with bacterial pathogens. Provided exposure controls are sufficient to reduce the risks from bacterial pathogens to tolerable levels, the lower risks from other pathogens are considered to be adequately managed.

The 95th percentile concentrations of microbial indicators in Australian sewage were derived from the same dataset as that used in the Phase 1 guidelines to derive sewage reference pathogen levels. The resulting 95th percentile levels of the microbial indicators are summarised in Table A3.8. This table also contains the ratio between the microbial indicator levels in sewage and the corresponding 95th percentile levels of these indicators in roofwater in Appendix 2 (Table A2.1).

Table A3.8 Sewage microbial indicator concentrations and corresponding ratios with roofwater

Indicator	Sewage 95th percentile level (CFU or MPN/L)	Sewage/roofwater ratio
E. coli or thermotolerant (faecal) coliforms	2.9×10^8	1.0×10^5

CFU = colony forming units; MPN = most probable number.

The concentration of the 95th percentile reference pathogens in roofwater are shown in Table A3.9 and were estimated using the following equation:

[roofwater reference pathogen level] = [sewage reference pathogen level]/[indicator ratio]

where:

- sewage reference pathogen levels were those from Section 3.5.2 of the Phase 1 guidelines
- indicator ratio is the sewage/roofwater ratio for the corresponding indicator from Table A3.8 above.

Table A3.9 Estimated reference pathogen (*Campylobacter jejuni*) levels in roofwater

Reference pathogen	Indicator ratio used	Estimated 95th percentile level (/L)	
		Estimated from ratio	**Estimated from data**
Campylobacter jejuni	*E. coli*	0.07	<2.0[a]

a The 95th percentile from pathogen monitoring is unknown because it is below the detection limit of the assays used. Such predominantly left-censored data are not amenable to conventional statistical analysis and were not analysed for Table A2.1. The value shown is based on halving the relevant detection limit.

To provide a conservative approach to risk assessment, the highest pathogen concentration of the two independently derived estimates noted in Table A3.9 would ordinarily be adopted for the risk assessment. The *Campylobacter* estimate from the data is higher than that from the ratio method, these being conservative values, due to the detection limits of the assays used. The detection limit of the least sensitive assay among the highest quality and most relevant studies reported in Table A3.3 (K Power, NSW Health, 2007, pers comm) has been used to set the limit. The detection limit for this assay is one cultivable unit per 250 mL; therefore, by convention, one-half the detection limit was set as the value for reporting, or one cultivable unit per 500 mL, (ie 2/L).

In practice, such concentration estimates are highly conservative. Both ratio and direct measurement methods have limitations:

- Ratio methods suffer from the absence of a conventional statistical correlation between pathogens and indicators in stormwater.
- Direct assessment methods suffer from:
  - the small dataset sizes available
  - the high error rates in pathogen testing
  - the smaller number of sites tested
  - the high detection limits of the assays (typically only assaying volumes of between 250 mL and 2 L), particularly for roofwater.

It was considered that the direct assessment method yielded values that were too conservative, and that the use of the ratio method would be more reliable. The ratio method is based on a broader microbial indicator dataset and assumes the same ratio between microbial indicators and human infective pathogens, as is found in fresh sewage. This assumption is likely to be so conservative (in spite of the poor statistical correlation between pathogens and indicators) that it is considered the more reliable of the two possible evidence-based values given in Table A3.9, even though it is the lower of the two.

A3.6.3 Required reductions

The control requirements needed to maintain exposure within safe levels were derived using the tolerable pathogen doses given in the Phase 1 guidelines (shown here in Table A3.2). Table A3.10 lists the calculated tolerable concentrations in roofwater for various end uses (including municipal irrigation), calculated by dividing the tolerable dose by the estimated annual exposure volume from the Phase 1 guidelines. Most of the log reductions required are negative; that is, with the exposure controls in place, no treatment is required.

For the equivalent of dual-reticulation indoor and outdoor use, the log reduction required is 0.08 $\log_{10}$ units, or 17.2%. However, even in this case, treatment is not necessarily required provided the exposure controls can be maintained. The 95th percentile *Campylobacter* concentrations used to derive these log reduction requirements assume that the ratio of bacterial human-infective pathogens to indicators is the same in roofwater as in sewage.

Pathogens other than the reference pathogens may also be present in roofwater, such as *Legionella* bacteria (CRC for Water Quality and Treatment 2008). Management of the risks associated with the reference pathogens is considered adequate to manage the health risks from all pathogens.

Table A3.10 Tolerable pathogen levels and required reductions for different uses of roofwater

Use	Reference pathogen	Tolerable concentrate-ion (infectious units per L)	Required reduction (or safety margin)	
Equivalent of municipal, including open-space irrigation, dust suppression (exposure = 50 mL/ person/year)	*Campylobacter jejuni*	0.76	Not required	(–1.1 $\log_{10}$)
	Implications			Treatment not required[a]
Equivalent of dual reticulation for indoor and outdoor use (exposure = 670 mL/ person/year)	*Campylobacter jejuni*	0.057	17.2%	0.1 $\log_{10}$
	Implications			Treatment not required[ab]
Equivalent of commercial food crops (exposure = 490 mL/ person/year)	*Campylobacter jejuni*	0.078	Not required	(–0.1 $\log_{10}$)
	Implications			Treatment not required[a]
Equivalent of non-food crops (eg trees, turf, woodlots, flowers) (exposure = 50 mL/ person/ year)	*Campylobacter jejuni*	0.76	Not required	(–1.1 $\log_{10}$)
	Implications			Treatment not required[a]
Equivalent of firefighting (exposure = 1000 mL/ person/year)	*Campylobacter jejuni*	0.38	45%	0.25 $\log_{10}$
	Implications			Treatment not required[ab]

a Treatment is not required if exposure controls can be maintained as recommended.
b Even though the value is positive rather than negative, treatment is not required due to the very small log reduction predicted being outweighed by the conservatism in the estimates.

Appendix 4 Environmental risk management

A4.1 Screening assessment

A generic, screening-level environmental risk assessment was carried out on public, open-space irrigation schemes using urban stormwater and roofwater, for sites meeting the screening tool criteria (Section 3.1). The risk assessment broadly followed the processes outlined in the Phase 1 guidelines (NRMMC–EPHC–AHMC 2006), which can be used to carry out a risk assessment for schemes other than those meeting the project screening tool criteria.

For stormwater reuse, where the source water is effectively derived from the receiving waters, environmental risks to surface waters were not assessed, because the stormwater would have reached the receiving waters if not diverted for irrigation. This is in contrast with conventional wastewater effluent irrigation, where the source waters are independent of the receiving waters and an assessment of the potential impacts is therefore appropriate.

The screening-level risk assessment used the 95^{th} percentile concentrations of physicochemical contaminants from Tables A2.1 and A2.4. The 95^{th} percentile levels were used instead of the median or mean values, to provide a conservative generic risk assessment. As noted in Appendix 2, roofwater quality data are limited and insufficient data are available to differentiate between roof types; hence, the appropriateness of a conservative approach. Roof type influences concentrations of key pollutants, particularly metals (see Section A2.2).

The stormwater and roofwater concentrations were compared to the long-term trigger value levels (ANZECC–ARMCANZ 2000a) for agricultural irrigation for soil and plants as environmental end points.

For assessment of salinity risks, the leaching factor for a heavy clay soil type was used to conservatively derive average root-zone salinity, for comparison with soil tolerance criteria for sensitive crop plants. Limited data on sodium adsorption ratios (SARs) in stormwater are available to assess the likely impacts of salinity on soil structure. Lin et al (2006) reported SAR values of 0.5–1.0 in untreated Adelaide stormwater. This is likely to result in a stable soil structure for the 95^{th} percentile salinity level noted above, using the relationship between SAR, irrigation water conductivity and soil structural stability (ANZECC–ARMCANZ 2000a). Key hazards were identified as those constituents where the 95^{th} percentile level exceeded these criteria. Hydraulic loading was identified as a further key environmental hazard, because waterlogging is a hazard associated with any irrigation scheme. The resulting key environmental hazards are noted in Table A4.1.

Table A4.1 Key environmental hazards from roofwater and stormwater irrigation

Hazard	Roofwater	Stormwater
Cadmium	N/A	Yes
Copper	Yes	N/A
Hydraulic loading rate	Yes	Yes
Iron	Yes	Yes
Nitrogen	N/A	Yes
Phosphorus	Yes	Yes
Zinc	Yes	N/A

N/A = not available.

An assessment of risks to groundwater and surface water was not carried out, because the stormwater is usually sourced from the receiving surface waters. The National Environment Protection Council (NEPC 1999) groundwater irrigation levels were derived from a previous version of the Australian water quality guidelines, now superseded by ANZECC–ARMCANZ (2000a). The trigger levels used in these guidelines (derived from ANZECC–ARMCANZ 2000a) are therefore more appropriate than the NEPC levels (NEPC 1999) for assessing risks to the beneficial use of groundwater for irrigation.

The long-term trigger values were considered to be an appropriate indicator of potential soil contamination for this generic screening-level risk assessment. An assessment of potential soil contamination requires both site-specific data on existing levels of potential contaminants (eg metals) and data on loading rates from stormwater and roofwater irrigation. This would enable the soil ecological investigation levels from NEPC (1999) and the cumulative contaminant levels from ANZECC–ARMCANZ (2000a) to be used for a specific project.

Although no criteria are presented in ANZECC–ARMCANZ (2000a) for hydrocarbons in irrigation waters, the levels noted in Appendix 2 are not considered likely to present an environmental risk.

This screening assessment for stormwater reuse was based on stormwater from largely residential catchments. As noted in Section A2.1, commercial and industrial catchments can have different runoff contaminant levels. The references provided in Appendix 2 can be used to conduct a similar risk assessment for these alternative land uses; the assessment should focus on chemicals whose concentration increases with change in land use (eg metals).

In addition, SE Water (pers comm. 2008) has observed that total dissolved salts, sodium and chloride may present a slight risk of foliage damage if sprayed onto sensitive plants on hot days.

A4.2 Assessment of potential impacts from key hazards

The description of the environmental impacts (or consequences) given in Table 4.4 of the Phase 1 guidelines was used for the assessment of potential impacts from key hazards.

Nitrogen

No trigger values for nitrogen were exceeded for roofwater, and it is considered a low risk.

For stormwater, the 95th percentile nitrogen concentration was higher than the long-term trigger value. That value was based on ensuring no decrease in crop yields or quality due to excessive nitrogen concentrations during later flowering and fruiting stages of sensitive crops (see Appendix 4 of the Phase 1 guidelines). Most crop yields are generally unaffected until nitrogen concentrations in irrigation water exceed 30 mg/L (ANZECC–ARMCANZ 2000a). The 95th percentile concentration is approximately a quarter of this value. Further, the 50th percentile value is approximately half of the long-term trigger value, and the 95th percentile concentration is lower than the short-term trigger value. Consequently, the environmental impact on grass (and other nonsensitive plants) and soils due to nitrogen in stormwater is considered to be low.

In addition, the irrigated stormwater is normally sourced from the receiving waters; hence, the additional environmental impact of any stormwater returning to the water body or groundwater will be low.

Phosphorus

The roofwater 95th and 50th percentile phosphorus concentrations exceed the long-term trigger value, although they are lower than the short-term value (lower limit of specified range). The long-term trigger value is based on minimising the likelihood of algal blooms in storages or bioclogging of irrigation equipment (ANZECC–ARMCANZ 2000a). Roofwater is normally stored in a tank, where the likelihood of algal blooms is low and the associated risk is also considered low.

There is a medium risk of bioclogging of irrigation equipment when using rainwater for more than 20 years. It is not practical to reduce phosphorus levels in roofwater for domestic applications. Reducing concentrations using conventional stormwater treatment measures is unlikely to be effective, because the outflow concentrations are typically 0.15–0.2 mg/L (Schueler 2000), which is higher than the long-term trigger value of 0.05 mg/L. An on-site wastewater treatment process would be required to achieve this level, which is not practical. It is recommended that the effectiveness of the irrigation equipment be monitored regularly after 20 years to detect any bioclogging.

The 95th percentile phosphorus concentration in stormwater exceeds both the long and short-term trigger values (lower value of interim range). The recommended short-term value requires site-specific assessment, and is based on being low enough to prevent phosphorus in irrigation water overloading soil, and allowing environmentally significant concentrations of phosphorus to move from soils into water bodies.

A conservative estimate for a generic short-term trigger value for public, open-space irrigation, accounting for soil conditions, was carried out using the interim model from ANZECC–ARMCANZ (2000a). A conservatively low phosphorus soil sorption capacity for sand dunes from Kruger et al (1995) was used, with an assumed soil depth of 1 m, a soil bulk density of 1300 kg/m^3 and an irrigation rate of 0.5 m/year. No phosphorus input from fertiliser and no phosphorus removal harvesting was assumed. After a 20-year irrigation period, the resulting phosphorus short-term trigger value was estimated to be 2.6 mg/L — approximately twice the 95th percentile concentration and seven times greater than the median concentration. Hence, the likelihood of short-term (up to 20 years) impacts is low.

Where stormwater is stored in a tank, the likelihood of algal blooms is low; however, the likelihood is higher for stormwater stored in open storage rather than a tank (see Appendix 5). There is a medium risk of bioclogging of irrigation equipment using stormwater for more than 20 years. Reducing concentrations to the short-term trigger value concentration using conventional stormwater treatment measures is unlikely to be effective, although the median concentrations can be halved to around three times the short-term trigger value. This will delay bioclogging considerably beyond 20 years.

Recommended options for managing phosphorus risks to stormwater irrigation equipment are to:

- undertake no treatment and monitor the irrigation system regularly after 20 years to assess any bioclogging (ie accept a risk to the irrigation equipment)
- install stormwater treatment measures, such as constructed wetlands or biofiltration systems, to reduce phosphorus concentrations (Engineers Australia 2006) to around 0.2 mg/L, and monitor the irrigation system regularly after 40 years to assess any bioclogging (ie accept some risk to the irrigation equipment)
- implement a wastewater treatment process to reduce phosphorus levels to 0.05 mg/L (ie accept a low risk to the irrigation equipment)

Irrigated stormwater is normally sourced from the receiving waters; hence, the environmental impact of any stormwater returning to the water body will be insignificant.

Cadmium

For roofwater, the 95th percentile for cadmium did not exceed any trigger values and cadmium was considered low risk.

For stormwater, the 95th percentile cadmium concentrations exceed the long-term trigger value and are marginally higher than the short-term trigger value (the 50th percentile concentration is lower than this value). The long-term trigger value was set to prevent the uptake of cadmium into crops that may pose a threat to animal and human health, because human and animal health concerns from ingestion of cadmium-contaminated crops are triggered at concentrations lower than those likely to be toxic to plants (ANZECC–ARMCANZ 2000a). Cadmium is toxic to a range of plants at levels ranging from 0.1 mg/L to 1 mg/L (ANZECC–ARMCANZ 2000a). The 95th percentile concentration is below the lowest level that is toxic to plants. Hence, the environmental impacts from cadmium for irrigation of public open space are considered to be insignificant.

Copper

The 95th percentile copper concentrations in roofwater exceed the long-term trigger value, although the concentrations are lower than the short-term trigger value. According to ANZECC–ARMCANZ (2000a), copper toxicity from nutrient solutions has been observed at concentrations of 0.1–1.0 mg/L with concentrations of 0.03 mg/L reducing growth in one study. Elevated levels of copper in irrigation water were therefore considered as possibly directly toxic to plants. The long-term trigger value for copper was set at 0.2 mg/L, which corresponds to the 70th percentile roofwater concentration. The environmental impacts due to copper in roofwater for irrigation are therefore considered minor, and the risk low.

For stormwater, the 95th percentile for copper did not exceed any trigger values and copper was considered low risk.

Iron

The 95th percentile iron concentration in roofwater marginally exceeds the long-term trigger value, although the 50th percentile value is lower than the long-term trigger value. Both are lower than the short-term trigger value. The long-term trigger value was set primarily to minimise the potential clogging of irrigation systems, while the short-term trigger value was set to avoid concentrations of iron that may be toxic to plants (ANZECC–ARMCANZ 2000a). There is, therefore, a small chance of clogging due to iron deposition, in the unlikely event that median iron concentrations are similar to the 95th percentile value.

The 95th percentile iron concentration in stormwater exceeds the long-term trigger value, but is lower than the short-term trigger value (the 50th percentile value also exceeds the long-term trigger value). There is, therefore, a medium risk of iron clogging irrigation systems in the medium-to-long term (ie over 20 years).

Reducing iron concentrations using conventional stormwater treatment measures will only be moderately effective, because the monitored average outflow concentrations from a range of different treatment measures is 0.8 mg/L (four times the long-term trigger value) (based on data from the International Stormwater BMP Database[1]). An on-site wastewater treatment process would be required to achieve the short-term trigger value, which is not practical. Hence, it is recommended that the effectiveness of the irrigation equipment be monitored regularly after 20 years to detect any clogging, when replacement may be required.

The recommended options for managing iron risks to stormwater irrigation equipment is similar to those proposed for managing phosphorus risks, namely to:

- undertake no treatment and monitor the irrigation system regularly after around 20 years to assess any clogging (ie accept a risk to the irrigation equipment)
- install stormwater treatment measures to reduce iron concentrations (eg constructed wetlands or biofiltration systems — see Engineers Australia (2006)) to around 0.8 mg/L and monitor the irrigation system regularly after around 40 years to assess any clogging (ie accept some risk to the irrigation equipment)
- implement a wastewater treatment process to reduce iron levels to 0.05 mg/L (ie accept a low risk to the irrigation equipment).

Zinc

The 95th percentile zinc concentration in roofwater exceeds both the long-term and short-term trigger value, with the median concentration marginally lower than the long-term trigger value. The long-term and short-term trigger values for zinc were set to minimise the potential for toxicity to plants and soil microorganisms (ANZECC–ARMCANZ 2000a). Zinc is an essential micronutrient for plants, but excessive concentrations can be toxic to plants and microorganisms that live in the soil (ANZECC–ARMCANZ 2000a).

The type and condition of roofing materials influences the levels of metals in roofwater. However, insufficient data on roofwater quality are available to distinguish between roofs

[1] http://www.bmpdatabase.org

with zinc coatings and other roofs. The combined data may therefore underestimate average zinc concentrations in runoff from zinc roofs. The environmental impact of average roofwater has thus been assumed to be moderate, taking a conservative approach to account for the current uncertainty (ie the impact is likely to be low for the use of roofwater from nonmetallic roofs). No practical techniques are available to reduce zinc loads in roofwater, and low application rates and monitoring are therefore recommended.

For stormwater, the 95th percentile did not exceed any trigger values.

Hydraulic loading

As noted in the Phase 1 guidelines, where excess water is applied to the soil surface and percolates down through the soil (ie leaches), it can cause ‘hydraulic loading’ to the extent that local or regional watertables rise. When the watertable rises to within 2 m of the surface (the plant-rooting zone), soils can easily become saturated (waterlogged). This upward movement of water can also mobilise salts in the soil profile and bring them to the surface, causing ‘secondary’ salinity. Even if the water does not reach the surface, it may still affect ecosystems that depend on deep soil water or groundwaters. Waterlogging also makes oxygen less available to plant roots and to other organisms (hypoxia). Waterlogged plants usually grow very slowly, and roots become highly susceptible to infections from disease-causing organisms. Generally, irrigation systems and good irrigation practice will minimise the likelihood of any of these impacts on the environment, and the environmental impacts can be assumed to be minor and the risk low.

A4.3 Generic risk assessment

A generic environmental risk assessment for roofwater irrigation is summarised in Table A4.2, showing the key environmental hazards and the potential environmental impacts (excluding low-risk exposures). The risk assessment is based on the approach described in Chapter 4 of the Phase 1 guidelines.

The preventive measures for managing environmental risks due to copper and zinc in roofwater have been developed, based on the water-quality data in Appendix 2. A scheme operator may choose to undertake site-specific roofwater monitoring to assess whether the median copper and zinc levels are below the irrigation long-term trigger value given in ANZECC–ARMCANZ (2000a). If the median is lower than the trigger values, the environmental impact is expected to be insignificant, with the associated environmental risks being low; hence, no preventive measures are required.

First-flush diverters are used on some residential roofwater systems. However, the evidence on the presence of first flush is equivocal. Forster (1999) noted a first flush for metals in a German study, whereas Cheah et al (2007) did not observe a first flush for a recent roofwater quality study in Sydney. Should a first flush be present, concentrations are high although runoff and hence loads are low. The first flush is unlikely to have any significant effect on copper or zinc loads entering a roofwater storage system. The use of first-flush diverters is therefore not recommended as a preventive measure for these metals.

Table A4.2 Generic environmental risk assessment for municipal irrigation of roofwater

Hazard				Maximum risk — no preventive measure (ie uncontrolled)			Critical control point or control point in environmental pathway	Preventive measures	Residual risk — with preventive measures		
Use or exposure entry	Receiving environment or receptor	Environ-mental end point	Effect	Likelihood	Impact	Level of risk[a]			Likelihood	Impact	Level of risk
Copper											
Irrigation	Plants	Plants	Toxicity	Almost certain	Minor	Moderate	Source water	Roof condition management	Unlikely	Minor	Low
				Almost certain	Minor	Moderate	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Almost certain	Minor	Moderate	Irrigation	Monitoring	Unlikely	Minor	Low
	Soils	Plants	Toxicity	Almost certain	Minor	Moderate	Source water	Roof condition management	Unlikely	Minor	Low
				Almost certain	Minor	Moderate	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Almost certain	Minor	Moderate	Irrigation	Monitoring	Unlikely	Minor	Low

Table A4.2 (continued)

Hazard				Maximum risk — no preventive measure (ie uncontrolled)			Critical control point or control point in environ-mental pathway	Preventive measures	Residual risk — with preventive measures		
Use or expos-ure entry	**Receiving environ-ment or receptor**	**Environ-mental end point**	**Effect**	**Like-lihood**	**Impact**	**Level of risk[a]**			**Like-lihood**	**Impact**	**Level of risk**
Zinc											
Irrigat-ion	Plants	Plants	Toxicity	Almost certain	Minor	Moderate	Source water	Roof condition management	Unlikely	Minor	Low
				Almost certain	Minor	Moderate	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Almost certain	Minor	Moderate	Irrigation	Monitoring	Unlikely	Minor	Low
	Soils	Plants	Toxicity	Almost certain	Minor	Moderate	Source water	Roof condition management	Unlikely	Minor	Low
				Almost certain	Minor	Moderate	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Almost certain	Minor	Moderate	Irrigation	Monitoring	Unlikely	Minor	Low

Table A4.2 (continued)

Hazard				**Maximum risk — no preventive measure (ie uncontrolled)**			**Critical control point or control point in environ-mental pathway**	**Preventive measures**	**Residual risk — with preventive measures**		
Use or expos-ure entry	**Receiving environ-ment or receptor**	**Environ -mental end point**	**Effect**	**Like-lihood**	**Impact**	**Level of risk[a]**			**Like-lihood**	**Impact**	**Level of risk**
Hydraulic loading											
Irrigat-ion	Soils	Plants	Waterlo gging	Possible	Minor	Moderate	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Possible	Minor	Moderate	Soils	Site selection	Rare	Minor	Low
	Soils	Soils	Waterlo gging	Possible	Minor	Moderate	Soils	Drainage	Rare	Minor	Low
				Possible	Minor	Moderate	Ground-water	Monitoring	Unlikely	Minor	Low
	Soils	Ground water	Waterlo gging	Possible	Minor	Moderate	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Possible	Minor	Moderate	Irrigation	Monitoring	Unlikely	Minor	Low
				Possible	Minor	Moderate	Soils	Site selection	Unlikely	Minor	Low
			Salinity	Possible	Minor	Moderate	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Possible	Minor	Moderate	Ground-water	Monitoring	Unlikely	Minor	Low
				Possible	Minor	Moderate	Plants	Monitoring	Unlikely	Minor	Low

a Maximum risk is highlighted to identify risk requiring preventive measures.

The soil metal concentration trigger values in Tables A4.3 and A4.4 are the soil ecological investigation levels from NEPC (1999). These levels are lower, and hence more conservative, than the cumulative contaminant loading from ANZECC–ARMCANZ (2000a) when converted to milligrams per kilogram, based on an assumed soil accumulation zone depth of 75 mm and a soil bulk density of 1333 kg/m^3 (EPA NSW 1997). All control points, preventive measures, target criteria, critical limits, critical control points, and their verification are site and scheme specific.

Table A4.3 Copper: preventive measures for roofwater irrigation

Control points	Preventive measures	Target criteria	Verification
Source water	*Roof condition management* Avoid irrigating using roofwater from copper roofs.	No copper roofing material.	Not applicable.
Irrigation or watering	*Irrigation tools* Irrigation rates should be less than approximately 300 mm/year. Limit irrigation using roofwater to 10 years unless monitoring shows soil copper levels are below target criteria.	Median copper concentration in soil should be less than 100 mg/kg.	Soil copper concentrations are below critical limit for plants likely to be irrigated by open-space irrigation.

Table A4.4 Zinc: preventive measures for roofwater irrigation

Control points	Preventive measures	Target criteria	Verification
Source water	*Roof condition management* Avoid irrigating using roofwater from zinc-coated roofs (eg galvanised iron) or painted roofs.	No zinc-coated roofing material.	Not applicable.
Irrigation or watering	*Irrigation tools* Irrigation rates should be less than approximately 300 mm/year. Limit irrigation using roofwater to 10 years unless monitoring shows soil zinc levels are below target criteria.	Median zinc concentration in soil should be less than 200 mg/kg.	Soil zinc concentrations are below critical limit for plant toxicity.

Table A4.5 Hydraulic load preventive measures

Control points	Preventive measures	Target criteria	Verification
Irrigation	*Irrigation tools* When irrigating, apply appropriate volumes of water and use alternative irrigation methods (eg drippers) to restrict rates of water addition. Ensure irrigation scheduling methods follow best practice. Water applied must be carefully calculated to match current demand, according to standard protocols (Allen et al 1998, Christen et al 2006).	Delivery of correct water volumes.	Soil water content remains less than field capacity, except where leaching is required. If leaching is required, ensure it is minimised.
			Appropriate volumes of water are applied for plants grown, weather conditions, soils and the leaching fraction required. Calculated amount of water needed is recorded, measured on application and documented. No symptoms of waterlogging in plants. Symptoms include yellowing or decay between the veins, leaf tissue becoming soft at the base or in the centre. Wilting may occur due to root decay, damaged roots appear blackened.
Soils	*Site selection* Select sites with sufficient drainage capacity. If there is a shallow A soil horizon above a layer of impermeable clay, this may lead to waterlogging. Verify watertable is >2 m from soil surface or the lateral hydraulic conductivity of the watertable will handle required leaching fractions and irrigation rates.	Drainage capacity of specific site is appropriate.	Hydraulic conductivity of the soil profiles copes with the required leaching fraction and irrigation volume required for the plants to be grown (saturated hydraulic conductivity) at least >5 mm/hour).
		Groundwater below 2 m.	Groundwater remains below 2 m during irrigation and rain events.
	Drainage Subsoil drainage can be installed to increase infiltration rate and remove excess water.	Drainage >5 mm/hour.	Soil water content less than field capacity; drainage at least >5 mm/hour.
Ground-water	*Monitoring* Ensure watertable remains >2 m from soil surface.	Groundwater below 2 m.	Verify watertable >2 m from surface.

Note: All control points, preventive measures, target criteria, critical limits, critical control points, and their verification are site and scheme specific. The examples given in this table should be validated and verified for specific schemes.

Appendix 5 Screening stormwater reuse projects

A5.1 Catchment land use

The land use within a catchment from which stormwater is harvested for reuse can significantly affect water quality, and the scheme's potential health and environmental risks. The guidelines in Chapter 3 are based on sewered residential or commercial land use within the catchment, and the land use from which the water quality data in Appendix 2 are derived. Other land uses can increase the loads of stormwater pollutants:

- Agricultural land uses can generate relatively high pathogen and nutrient levels in runoff, particularly when land is actively fertilised (eg pasture production or market gardens) or produces excess amounts of manure (eg animal husbandry).
- Industrial land uses can result in stormwater with relatively high levels of hydrocarbon and metals.
- Stormwater runoff from major roads and freeways or tollways with high traffic volumes can contain relatively high levels of hydrocarbon and metals.
- Commercial or industrial catchments with significant areas with metal roofs (eg warehouses and factories) can generate elevated metal loads in stormwater, particularly if the roofs are in poor condition.
- Significant stream bank erosion or construction activity within a catchment can result in high levels of suspended solids and turbidity in stormwater.

A stormwater harvesting scheme's catchment may also have point sources of pollution, including:

- on-site sewerage management schemes (eg septic tanks), which can increase pathogen levels
- wastewater treatment plants, which can increase pathogen and pollutant concentrations, depending on the nature of the wastewater and the treatment system.

A5.1.1 Additional investigations and actions for nonresidential catchments

If the catchment's land use is not predominantly residential or commercial, a more detailed assessment of the implications for water quality is needed. There are two levels of investigation, referred to as tier 1 and tier 2.

Tier 1 investigation

A tier 1 assessment involves investigating whether the potential water-quality impacts of nonresidential or commercial land uses or point sources of pollution are currently adequately controlled, and whether water quality will be similar to or better than that from residential catchments. Table A5.1 identifies some potential hazards and examples of potential risk controls. This assessment should be done by an expert in water-quality management with suitable qualifications and experience.

Table A5.1 Potential hazards and hazard controls

Potential hazard in catchment	Example controls on potential hazards
Industrial land use, or major roads and freeways	Appropriately designed stormwater treatment measures are present.
	Stormwater quality controls are appropriately operated and maintained.
	Treatment measures are managed by an organised commercial and/or government entity subject to regulation and audit.
Agricultural land uses	Agricultural land uses are not expected to produce poor stormwater quality (ie no significant fertiliser application, manure generation or forestry activities).
	Where agricultural land uses could produce poor stormwater quality, appropriate stormwater-quality management practices are in place and appropriately maintained.
On-site sewage management systems	Regulatory authority requires appropriate design of on-site sewage management systems.
	Regulatory authority audits on-site sewage management systems.
Wastewater treatment plants	Wastewater treatment plant is appropriately designed, operated and maintained.
	Treatment measures are managed by an organised commercial and/or government entity subject to regulation and audit.
	Regulatory authority regulates and audits treatment plant water quality performance.
	Treatment plant includes disinfection.

If there is any uncertainty about the effectiveness of the controls on potential hazards, site-specific stormwater-quality monitoring should be carried out. Such monitoring should target the pollutants that are likely to have higher concentrations than those from an urban residential catchment, and that are relevant to potential health and environmental risks. Stormwater reuse schemes typically collect baseflows and flows from relatively small events for reuse (rather than runoff from large events); hence, the water-quality monitoring should focus on these events. This monitoring should also be carried out if there is uncertainty about the land use or the presence of point sources of pollution.

If monitoring indicates that the water quality is similar to or better than that noted in Appendix 2, no further risk management actions are required beyond the standard actions identified in Chapter 3. If the water quality is poorer than that specified in Appendix 2, a tier 2 investigation should be carried out.

In some circumstances, it may be possible for a representative of the stormwater harvesting scheme's operator to monitor the effectiveness of the controls for nonresidential catchments (eg when the operator is a local council that also has a water-quality regulatory role). Then the additional project-specific controls required are:

- to arrange inspection and monitoring controls at potential sources of hazard by a suitably competent and authorised assessor at an appropriate frequency, typically annually, to check on their efficacy
- to be prepared to take avoidance actions downstream if the controls at source became compromised, and to set up reliable communication lines facilitating such actions.

Results

Having confirmed that additional project-specific controls can be limited to source controls and avoidance response:

- o Record the additional source control and avoidance response risk management actions required and implement them during scheme creation and operation.
- o Return to the project screening tool checklist.

Tier 2 investigation

A tier 2 assessment should be carried out when there is uncertainty about:

- pollutant sources, including the impacts of nonresidential/commercial land uses
- the effectiveness of the controls on pollution sources.

This level of investigation involves site-specific water-quality monitoring and a full environmental or health risk assessment (or both) to assess the need for additional or alternative risk management measures. Additional source controls, avoidance response, treatment, or exposure controls may be required before stormwater recycling can be safely undertaken. The risk assessment should be carried out following the procedures outlined in Appendixes 2 and 3, and the Phase 1 guidelines (NRMMC–EPHC–AHMC 2006).

Results

Having completed the detailed risk assessment:

- o Record the additional risk management actions required and implement them during scheme creation and operation.
- o Return to the project screening tool checklist.

A5.2 Sewer overflows

Sewer overflows are the primary source of pathogens in stormwater from an urban, sewered catchment. Other microbes in stormwater (including indicator bacteria) come from nonhuman sources such as cats, dogs and birds. The extent and nature of sewer overflows can vary within and between sewerage systems, with overflows occurring in both dry and wet weather.

Data on the frequency of sewer overflows from 70 water utilities in Australia revealed a mean annual overflow frequency of 14.5 overflows per 100 km of sewer, with a median value of 7 overflows/100 km (NWC 2007ab). There are limitations with these data because they combine dry and wet weather overflow data, with wet weather overflows likely to have greatest impacts on stormwater quality. The distribution of overflow frequency between water utilities is skewed, with 70% of systems having below-average overflows.

The pathogen and indicator bacteria data used in these guidelines (Appendix 2) were obtained from Adelaide, Brisbane, Melbourne, Perth and Sydney. The overflow frequencies for these utilities were below the mean, with the highest value being marginally below the mean. The standard risk controls were based on these conditions.

There are likely to be additional health risks associated with stormwater reuse when the project is located in an area where the water utility has an above-average frequency of sewer overflows (>14.5/100 km/year).

While the approach outlined in this section is considered reasonable, it has limitations with respect to the potential variability in overflows across a water utility's operating area. Additional data to support a more comprehensive approach are not available. If a scheme proponent or approving agency is concerned about significantly above-average overflows being present in a subcatchment, a tier 2 assessment (see below) could be carried out.

A5.2.2 Additional investigations and actions

Tier 1 investigation

If sewer overflow rates are unknown, or are known to be moderate to high (14.5–50 overflows/100 km sewer/year), the recommended standard health risk management approach is to achieve an additional 1-log reduction for all pathogens using additional treatment or exposure controls (Appendix 2).

Results

Having assessed that an additional 1-log reduction in pathogen levels is appropriate:

- Record the additional risk management actions required and implement them during scheme creation and operation.
- Return to the project screening tool checklist.

Tier 2 investigation

There should be a more detailed tier 2 assessment where annual sewer overflow rates are known to be very high (>50 overflows/100 km/year).

The recommended approach is to quantify the additional health risks by calculating the increased contaminant concentrations based on assumed raw sewage quality (see Phase 1 guidelines) entering the stormwater, and increasing the log reduction requirements accordingly. This assessment should be done by an expert in water-quality management with suitable qualifications and experience. The tier 2 investigation can involve monitoring or modelling.

Site-specific stormwater-quality monitoring can be carried out in both wet and dry weather conditions, with the wet weather monitoring being flow weighted. This monitoring should focus on the level of the reference pathogens noted in Appendix 3 (see Section A2.1 for further information on monitoring).

If monitoring indicates that the water quality is similar to or better than that noted in Appendix 2, no further risk management actions are required beyond the standard actions identified in Chapter 3. If the water quality is poorer, a risk assessment should be carried out following the procedures outlined in Appendixes 3 and 4, the Phase 1 guidelines, and additional log reduction or management practices that have been identified.

Sewer system modelling can be used to estimate sewer overflow volumes, to compare with predicted stormwater flow volumes during the corresponding storm events. The log reduction requirements should be estimated, based on the calculated contribution of sewage to the stormwater, following the procedures in Appendix 3.

Results

Having completed the detailed risk assessment:

- Record any additional risk management actions required, and implement them during scheme creation and operation.

- Return to the project screening tool checklist.

A5.3 Water extraction

Urbanisation usually doubles runoff volumes, due to impervious surfaces decreasing the infiltration of rainfall. However, the increase varies with rainfall and soil characteristics. This increased runoff can affect the health of stream ecosystems, alter wetting–drying cycles in natural wetlands, cause bank erosion, and convey pollutants to receiving waters. Environmental benefits are usually achieved by reducing runoff volumes to predevelopment levels.

While some stormwater harvesting is environmentally beneficial, there are circumstances — mainly relating to the cumulative effects of numerous small schemes — where there are potential environmental risks.

Schemes where the environmental risks from stormwater extraction are low, and where all of the stormwater could be harvested, include those harvesting stormwater from a drain that discharges directly to:

- a beach
- a tidal waterway
- a lake (where the drain contributes only a small proportion of the inflow into the lake).

Schemes where a more detailed water balance and environmental impact assessment is needed include those:

- upstream of natural wetlands, where the wetting–drying cycle is important for the health of the wetland
- upstream of lakes or constructed wetlands, where a significant reduction in inflows may increase the risk of algal blooms
- on natural streams which collect baseflow and low flows, potentially impacting on stream ecosystem health (eg converting a perennial stream into an ephemeral stream, such as a stream channel that fills periodically through rainfall or snowmelt).

A reasonably conservative threshold has been set in the project screening tool where schemes collecting less than 10% of the annual runoff from the stormwater system do not trigger a detailed investigation. The state or territory water resource management agency may have different requirements; if so, these take precedent over this threshold.

A5.3.1 Additional investigations and actions for extractions above threshold

Tier 1 investigation

If a stormwater harvesting scheme extracts more than 10% of the average annual runoff volume or there are existing extractions within the catchment, the tier 1 assessment should be carried out. This involves identifying whether the scheme falls into a low risk category such as a beach, a tidal waterway or a lake. No further action is required if the scheme meets this criterion. A tier 2 investigation should be carried out for all other schemes.

Results

Having assessed that the environmental risks from stormwater extraction are insignificant:

- Return to the project screening tool checklist.

Tier 2 investigation

A tier 2 assessment should involve water-balance modelling of the catchment, to assess the potential impacts of the scheme on stream flow characteristics. As assessment can then be made of the potential impact of the altered stream flow characteristics on aquatic ecosystem health. Where the impact is considered to be significant, the scheme should not proceed. No further action is required if the impact is expected to be minimal. Fletcher et al (2006) describes a suitable approach.

Results

Having assessed the environmental risks from stormwater extraction:

- If necessary, modify the scheme to reduce extractions to an acceptable level.
- Return to the project screening tool checklist.

A5.4 Salinity

Elevated salinity levels can impact on plant productivity and soil structure (ANZECC–ARMCANZ 2000a). Salinity levels in stormwater from residential catchments are relatively low (Appendix 2); hence, irrigation impacts are considered insignificant (Appendix 4).

Salinity levels will be higher than those noted in Appendix 2 when:

- the stormwater drain is subject to tidal influence
- there are point sources of salinity
- salt-degraded land soil is a problem
- salty water bodies might overflow into the catchment area.

A5.4.1 Additional investigations and actions for salinity management

Tier 1 investigation

Tier 1 investigations are not applicable for salinity management.

Tier 2 investigation

A tier 2 assessment for tidally influenced drains involves site-specific salinity monitoring, including monitoring at high tide. Site-specific monitoring is also required in areas with high soil salinity. State or territory natural resource management agencies may have salinity hazard maps available for the proposed irrigation area, to help assess the likelihood of salinity impacts.

The results can be compared against the criteria in ANZECC–ARMCANZ (2000a) to assess the suitability of the stormwater for irrigation.

Elevated salinity in stormwater is difficult to reduce by treatment. One approach is to mix potable water with stormwater to dilute salinity. An alternative approach is to grow salt-tolerant plants and grasses in the irrigation area (see ANZECC–ARMCANZ 2000a).

If the point source is one where it is possible to prevent salt entering the stormwater, such source control measures should be implemented. Appendix 4 of the Phase 1 guidelines describes other potential preventive measures that can be considered, should salinity levels exceed the criteria.

Results

Having confirmed that additional project-specific controls can be implemented:

- Record any additional risk management actions required and implement them during scheme creation and operation.
- Return to the project screening tool checklist.

A5.5 Open storages

The health and environmental risks arising from the use of open storages (ponds, dams, etc) for storing stormwater are potentially higher than those from storing stormwater in a tank. This is due to potential hazards from:

- additional inputs of faecal matter into the stored stormwater from waterbirds
- mosquito breeding in the storage and the resulting risk of mosquito-borne disease
- public safety hazards of an open water body
- algal blooms (eutrophication) in the storage
- increased turbidity
- environmental impacts of a storage located directly on a stormwater drain or waterway.

Impacts of waterbirds

Waterbirds, such as ducks and herons, may provide faecal input into the stored water (Albureesh et al 2004). This can significantly increase the levels of indicator bacteria, with levels of thermotolerant coliforms increased by 10–100-fold. However, the increase in the level of pathogens is usually considerably less than the increased indicator bacteria levels; the microbial inputs are nonpathogenic, with the likely exception of *Campylobacter* and possibly *Salmonella* (Appendix 2).

The low levels of human infectious strains of bacterial pathogens that might be introduced by wild birds do not present a significant additional risk to health for nonpotable uses. However, if the birds present are known to be feeding extensively on neighbouring human refuse tips or fresh sewage sludge, it is possible that some small additional risks might arise, and these should be taken into consideration (Canning et al 2007).

The impact of the waterbird faecal inputs will vary, depending on factors such as the ratio of the surface area to storage volume (shallow storages are likely to be more susceptible to impacts) and the residence time.

Water Futures (pers comm, 2007) studied the impact of faecal inputs from waterbirds on sewage treatment plant lagoons. While an increase of up to 100-fold in thermotolerant coliforms was noted, no significant increase in health risks was predicted compared with background levels. This is logical because the environment being irrigated by the water would typically be exposed to the same faecal inputs from birds as nearby water bodies.

The attractiveness of a storage to waterbirds is difficult to predict. One approach is to minimise the attractiveness and then monitor waterbird numbers, with high numbers triggering further action. This can be done by incorporating such features as relatively steep side slopes on the storage (eg 2 units horizontal:1 unit vertical), no macrophytes or other aquatic plants, no structures or roosting trees, and depths of more than 0.5 m.

Should high numbers of waterbirds be regularly observed in the storage, potential responses include:

- undertaking a detailed health risk assessment, supported by appropriate monitoring
- installing netting above the storage
- incorporating an additional 1-log reduction in *Campylobacter* levels in the treatment system or additional access controls (see Section 3.4.9), which is likely to be a conservative response; a disinfection system designed to achieve the target virus and protozoa reductions should achieve this additional bacteria log reduction.

Mosquito breeding

Minimising mosquito breeding in storages is particularly important in temperate and tropical regions, to minimise mosquito-borne diseases. Mosquito breeding can be reduced through the incorporation of specific design features (Queensland Health 2002, Moreton Bay Waterways and Catchments Partnership 2006) such as:

- locating the storage in an area where the prevailing wind direction will increase wave action, because this prevents larvae from breathing and female mosquitoes from laying eggs

- ensuring a minimum operating depth of 0.3 m (preferably 0.6 m) to hinder mosquito breeding
- designing the storage to minimise the growth of emergent aquatic plants, because this will reduce mosquito breeding, allow predators to reach mosquito larvae and increase wave action
- incorporating, where possible, a steep bank slope, preferably greater than 3 units horizontal:1 unit vertical; a slope of up to 8 units horizontal:1 unit vertical is often used, but steep edges may be unacceptable for public safety reasons
- selecting bank vegetation that does not vigorously invade the storage, and designing the bank gradient to minimise the vigorous growth of vegetation
- designing the layout to avoid stagnant isolated areas of water
- providing a deep pool of permanent water elsewhere (for long dry periods or in situations where water levels are artificially lowered), so that mosquito predators can seek refuge and maintain a presence in the wetland
- facilitating water level fluctuations that disturb the breeding cycle of some mosquito species (although this may improve conditions for other mosquito species)
- providing an underwater topography that achieves regular wetting and drying, and draws water down evenly, avoiding isolated pools
- providing ready access for field operators to monitor and treat mosquito larvae
- ensuring that maintenance procedures do not result in wheel rut and other localised depressions that create isolated pools when water levels fall.

Not all these features will be appropriate for every situation.

Water weeds, such as water hyacinth and salvinia, can provide a breeding medium for mosquito species whose larvae attach to these plants under water. These weeds should be removed immediately if encountered. Recommended monitoring is noted in Table A5.2.

Some of the management approaches to minimise mosquito breeding may conflict with those to minimise turbidity and maximise public safety (ie side slopes on storages). These requirements will need to be balanced on a site-specific basis.

Public safety

The public safety requirements for a storage vary from site to site. More rigorous provisions should be adopted where public access is available, particularly where there is access by children.

Brisbane City Council (BCC 2001) recommend fencing where the water depth is greater than 150 mm and the maximum batter slope (backwards receding slope) is greater than 5 horizontal units:1 vertical unit. Where a storage has vertical edges, Moreton Bay Waterways and Catchments Partnership (2006) recommends that a safety fence or barrier be erected on top of concrete or stone walls where:

- there is a risk of serious injury in the event of a fall (more than 0.5 m high and too steep to comfortably walk up or down, or the lower surface has sharp or jagged edges)

- there is a high pedestrian or vehicular exposure (on footpaths, near bikeways, near playing or sporting fields, or near swings and playgrounds)
- there are water ponds to a depth greater than 300 mm on a constructed surface of concrete or stone
- the water is expected to contain concentrated pollutants
- there are mowed grassed areas abutting the asset.

The recommended type of fence or barrier is a:

- pool fence when there is a chance of drowning or infection from the storage, and the surrounding area is specifically intended for use by small children (swings, playgrounds, sporting fields, etc)
- galvanised tubular handrail (in accordance with relevant Australian Standards) without chainwire elsewhere
- hedge of dense vegetation at least 2 m wide and 1.2 m high, if vandalism is not a concern.

Algal blooms

Stormwater is generally high in nutrients (nitrogen and phosphorus) and, under certain circumstances, stormwater storages may suffer from excessive vascular plant and algal growth (eutrophication). Algal blooms in particular are problematic, and may cause blockage of treatment systems, filters and irrigation equipment. If the algal bloom is caused by toxin-producing species, algal toxins in the water can pose a serious health risk. As the water is not to be used for drinking, the health risk arises from people coming into contact with the water during irrigation, maintenance work by ground staff, or by members of the public playing or swimming in the storage.

Management strategies include source control, hazard reduction through additional treatment to reduce nutrient levels (primarily phosphorus), turbidity management, and restriction of light sources; in the event of a bloom, strategies also include warning signage and access restrictions. Water-quality monitoring is an important part of a risk management program, and guidance on this topic is given in Chapter 5 of the Phase 1 guidelines. To ensure that eutrophication risks are appropriately managed, an assessment of the potential for algal growth and the possible need for additional treatment is required. The Phase 1 guidelines include tables listing control points, preventive measures, target criteria and verification for nitrogen (Table A4.9) and phosphorus (Table A4.12) management.

Assuming that there are no significant additional pollution sources — such as industrial, on-site sewage management systems, and sewage treatment plant discharges — in the stormwater catchment, the most significant factor determining the risk of algal blooms in the storage is the residence time of water. Long residence times and low mixing rates are commonly associated with increased risk of algal blooms, particularly in summer. Engineers Australia (2006) specifies guideline residence times considered protective against the risk of algal blooms. For water bodies with the following summer water temperatures, the 20th percentile residence time should not exceed:

- 50 days (15°C)
- 30 days (20°C)
- 20 days (25°C).

Other ways to help minimise the risk of algal blooms include:

- incorporating such features as gross pollutant and sediment traps, buffer strips, vegetated swales and bioretention systems in drainage lines directing flow to the storage
- treating the water flowing into constructed wetland and pond storages, to promote factors such as sedimentation, filtration, chemical adsorption and biological uptake.

Further guidance on stormwater storage water-quality management is given in Engineers Australia (2006).

Prebloom levels of algae may influence turbidity.

Increased turbidity

Elevated turbidity levels can impair the effectiveness of disinfection systems and block irrigation system components. Storage of stormwater normally reduces turbidity levels; however, increased turbidity can occur in certain circumstances, such as resuspension of sediments due to wind action, scouring of sediments by high-velocity inflows and bank erosion.

The following features should be considered in storage design, particularly when disinfection is used:

- Aligning the storage to minimise its exposure to prevailing winds (eg the long axis of a rectangular storage should be approximately at right angles to the prevailing wind direction).
- Planting dense shrubs and trees around the edge of the storage, particularly the areas exposed to prevailing winds.
- Incorporating energy dissipaters in the design of the inlet structure.
- Locating the outlet structure away from the inlet structure.
- Planting the banks of the storage to minimise erosion.
- Lining the storage if soils are dispersive.

Online storages

Stormwater storages can be constructed online, directly on a drain or urban creek, rather than offline (eg turkey's nest dam). The main potential environmental impact with all online storages is increasing upstream flood levels. This may affect upstream infrastructure, as well as riparian vegetation along an urban stream. Other potential effects on natural streams include hindering fish passage, affecting the connectivity of aquatic ecosystems and eroding downstream banks.

The potential environmental impacts need to be assessed on a site-specific basis, and appropriate mitigation measures implemented. It is important that the relevant state or territory natural resource management agency is consulted during the design phase of any online storage on a natural stream, because permits or approvals may be required.

Table A5.2 Recommended additional monitoring for open storages

Frequency	Monitoring	Correction
Annually and in response to notifications	Integrity of any netting to prevent waterbird access to storages	Fix holes in netting
	Excessive growth of aquatic plants or water weeds in storages	Remove excessive plants or weeds
Quarterly and in response to notifications	Assess for presence of high numbers of mosquitoes	Control mosquitoes using appropriate chemicals, assess effectiveness of design features for minimising mosquitoes and correct if required
	Assess the integrity of any fencing around the storage	Repair any defects
Monthly (excluding winter) and in response to notifications	Assess the storage for the presence of any algae	Suspend operations, investigate nature of algae; if toxic, implement management options such as aeration and assess need for nutrient management practices
Monthly and in response to notifications	Visual assessment of turbidity levels	Monitor turbidity if levels appear excessive, assess effectiveness of control measures such as bank stabilisation and energy dissipaters
Monthly	Assess waterbird numbers in storage	If waterbird numbers are significant, undertake health risk assessment, implement practices to reduce attractiveness of storage, or implement additional treatment
Annually and following major storms	Integrity of spillway and downstream stream bank integrity for online storages	Stabilise any eroding areas

Tier 1 investigation

Waterbirds — either install netting or adopt an additional 1 log reduction in pathogen levels. A tier 2 investigation could be carried out to assess the health risks in detail.

Mosquito breeding — adopt appropriate design features to minimise breeding and implement appropriate monitoring (tier 2 investigation not required).

Public safety — adopt appropriate design features to minimise public safety risks (tier 2 investigation involves a safety risk assessment).

Algal blooms — if the 20th percentile summer residence times do not exceed those recommended above, no further action is likely to be needed. If residence times do exceed these levels, it may still be possible to design the storage system to have a similar low risk of algal blooms through the implementation of other measures (eg shandying with freshwater, shading, etc — see Tables A4.9 and A4.12 in the Phase 1 guidelines). However, the benefits of these measures need to be quantified to ensure that the algal bloom risk will be no higher than that for risk categories for summer residence times. If this is not possible, a tier 2 investigation is needed.

Turbidity — adopt appropriate design features and appropriate monitoring to minimise turbidity. (Tier 2 investigation involves assessing the impacts on scheme operation of elevated turbidity levels).

Online storages — conduct a tier 2 investigation.

Results

Having confirmed that additional project-specific controls can be readily implemented:

- Record the additional source control and avoidance response risk management actions required and implement them during scheme creation and operation.
- Return to the project screening tool checklist.

Tier 2 investigation

Waterbirds — a detailed health risk assessment can be carried out to assess the risks due to pathogen inputs from waterbirds.

Public safety — a public safety risk assessment can be carried out by a suitable expert, considering the likelihood and consequence of injury.

Algal blooms —the recommendations in the tier 1 analysis are conservative. If the tier 1 guidelines cannot be met, a tier 2 investigation involving a more detailed quantitative analysis or modelling (or both) may show that greater residence times still achieve an acceptable risk of algal blooms, or that a similar acceptable risk is achieved through other measures.

Turbidity — conduct a detailed assessment of the impacts of elevated turbidity on scheme operations. This may involve assessing whether elevated turbidity impacts the effectiveness of any disinfection system.

Online storages — a site-specific assessment of the environmental risks from an online storage should be carried out. This should involve assessing potential flooding impacts and any ecological and geomorphological impacts of storages constructed on a stream.

Results

Having completed the detailed investigations:

- Record the additional risk management actions required and implement them during scheme creation and operation.
- Return to the project screening tool checklist.

A5.6 Stormwater diversion

Stormwater can be diverted into an offline storage by pumping (Chapter 3), or by constructing a low weir across a stormwater drainage pipe or channel to divert a proportion of the stormwater flows. Diversion weirs are generally not used to extract stormwater from watercourses. An increase in flood levels upstream of the weir is likely to be the most common problem, and will have potential impacts on properties, any riparian vegetation, and bank stability of watercourses. Any diversion weirs constructed on watercourses may inhibit the passage of aquatic fauna (eg fish) and sediment movement, with potential erosion impacts (see above comments on online storages).

Tier 1 investigation

A tier 1 investigation is not applicable for assessing and managing the impacts of diversions. A tier 2 investigation is warranted.

Tier 2 investigation

The specific impacts of a diversion on flood levels should be addressed by hydrological and hydraulic modelling. The impacts of diversions located on a stream need detailed ecological and geomorphological assessment.

Results

Having completed the detailed investigations:

- Record the additional risk management actions required and implement them during scheme creation and operation.
- Return to the project screening tool checklist.

A5.7 Groundwater vulnerability

Irrigation with stormwater can potentially affect groundwater quality, although the risk under normal conditions is considered insignificant. An exception may be when the irrigation area is within a groundwater vulnerability area, as designated by the relevant state and territory natural resources management authority, or within 1 km of a town water supply bore. In these circumstances, stormwater irrigation may impact on the beneficial uses of the groundwater (ARMCANZ–ANZECC 1995) and a detailed assessment is needed.

If the project involves aquifer storage and recovery, further investigation is needed. Consult the Phase 1 guidelines (NRMMC–EPHC–AHMC 2006) and the *Australian Guidelines for Water Recycling: Managed Aquifer Recharge* (NRMMC–EPHC–NHMRC 2009). Refer to the relevant guidelines to do a groundwater study.

Tier 1 investigation

A tier 1 investigation is not applicable for the impacts of stormwater irrigation on vulnerable groundwater zones. A tier 2 investigation is warranted.

Tier 2 investigation

The specific impacts of a stormwater irrigation scheme on groundwater in these areas must be assessed (see Phase 1 guidelines).

Results

Having completed the detailed investigations:

- Record the additional risk management actions required and implement them during scheme creation and operation.
- Return to the project screening tool checklist.

A5.8 Irrigation area characteristics

The landform and soil characteristics of the irrigation area can influence the extent of environmental risks from stormwater irrigation. The applicable landform and soil characteristics, their potential environmental risks and their threshold for low risks are noted in Table A5.3.

Table A5.3 Landform and soil characteristics

Characteristic	Potential impact	Low-risk threshold
Slope (for sprinkler irrigation)	Excess runoff and erosion	<6%
Slope (for trickle/drip or microspray irrigation)	Excess runoff and erosion	<10%
Landform	Erosion and seasonal waterlogging	Either crests, convex slopes or plains
Surface rock outcrop	Interference with irrigation equipment, excess risk of runoff	Nil
Soil salinity (0–70 cm)	Restricted plant growth	<2 dS/m (2000 µS/cm)
Soil salinity (70–100 cm)	Restricted plant growth	<4 dS/m (400 µS/cm)
Depth to top of seasonal high watertable	Poor aeration, restricted plant growth, effects on groundwater	>3 m
Depth to bedrock or hardpan	Restricted plant growth, excess runoff, waterlogging	>1 m
Soil saturated hydraulic conductivity (0–100 cm)	Excess runoff, waterlogging, poor infiltration	20–80 mm/hour (eg not sands or heavy clays)
Available soil water holding capacity	Little water available to plants in reserve, effects on groundwater	>100 mm/m (eg not sandy soils)
Soil sodicity (0–100 cm) (eg based on Emerson aggregate test)	Poor soil structure	Class 4, 5, 6, 7, 8 (eg soils are not dispersive)

Source: Adapted from DPI NSW (2004).

Landform information can be readily assessed from site surveys and site inspection. Ideally, the watertable depth should be assessed during a wet season by representative site sampling. Where excavation to 3 m is difficult, local knowledge and the absence of indications of the watertable to the depth of sampling (minimum of 1 m) can be used. An initial screening assessment of soil characteristics can be carried out by assessing soil type in the irrigation area, with soil monitoring carried out if there is uncertainty.

Tier 1 investigation

If there is uncertainty about soil types and their influence on environmental risks, the soil should be monitored to assess soil characteristics against the criteria noted in Table A5.3. If the criteria are not met, the application rate should be reduced to <200 mm/year, or a tier 2 investigation carried out.

Results

Having confirmed that additional project-specific controls can be limited to a low application rate:

- Record the additional risk management actions required and implement them during scheme creation and operation.
- Return to the project screening tool checklist.

Tier 2 investigation

Carry out a detailed assessment of environmental risks, using the data in Appendix 2 and the procedures in the Phase 1 guidelines (NRMMC–EPHC–AHMC 2006).

Results

Having completed the detailed risk assessment:

- Record the additional risk management actions required and implement them during scheme creation and operation.
- Return to the project screening tool checklist.

Appendix 6 Health and environmental risk management for other applications

A6.1 Potential uses of roofwater and stormwater

As noted in Chapter 1, these guidelines have been prepared to support the most common forms of roofwater and stormwater reuse, particularly public, open-stage irrigation. Roofwater and stormwater can, however, be used for a range of other applications including:

- drinking — refer to
  - enHealth (2004) for domestic roofwater drinking
  - the *Australian Drinking Water Guidelines* (NHMRC–NRMMC 2004) for commercial or community rainwater drinking applications
  - the *Australian Guidelines for Water Recycling: Augmentation of Drinking Water Supplies* (NRMMC–EPHC–NHMRC 2008) for drinking stormwater
- managed aquifer recharge— refer to the *Australian Guidelines for Water Recycling: Managed Aquifer Recharge* (NRMMC–EPHC–NHMRC, 2009).

Other potential uses (excluding drinking water), such as those noted in the Phase 1 guidelines (NRMMC–EPHC–NHMRC, 2006), are listed in Table A6.1.

Table A6.1 Potential uses of roofwater and stormwater (excluding drinking water)

Agricultural uses		
• horticulture	• lucerne	• vegetables
• trees or woodlots	• flowers	• viticulture
• pasture or fodder	• orchard	• hydroponics
• dairy pasture	• nursery	• turf farm
Fire-control uses		
• controlling fires • testing and maintenance of fire-control systems • training facilities for firefighting		
Municipal uses		
• roadmaking and dust control • street cleaning		
Residential and commercial property uses		
• within buildings (toilet flushing) • garden watering, car washing • water features and systems (ponds, fountains, cascades) • utility washing (paths, vehicles, fences, etc).		
Industrial and commercial uses		
• cooling water • process water • washdown water		

A6.2 Health and environmental risk assessment for alternative applications

The standard approach to stormwater reuse (Chapter 3) was based on:

- low health risk where the application has
  - less than 50 unintended personal exposure events per year, each of less than 1 mL
  - no intended direct or indirect ingestion
  - no intended direct skin contact, with unintended direct skin contact possible but likely only to be sporadic, isolated incidents
  - indirect skin contact intended due to body contact with irrigated surfaces
- low environmental risk when irrigating grass or garden beds.

The Phase 1 guidelines (NRMMC–EPHC–AHMC 2006) note a range of applications, other than irrigation, where the exposure is expected to be similar or lower than municipal irrigation (see Table 3.3 of the Phase 1 guidelines). For these applications, the standard approach to health risk management for unrestricted irrigation can be used (Table A6.2). For other applications, a health risk assessment should be undertaken due to the higher exposure, using the information from Appendix 3 and the Phase 1 guidelines.

The standard environmental risk assessment is based on irrigation of grass and watering of garden beds. The trigger values for some sensitive crops are higher than those for grass; hence, an environmental risk assessment is appropriate, using the approach outlined in Appendix 4 and the Phase 1 guidelines.

For some applications (eg dual reticulation, industrial use), the nature of the specific application will determine what risk assessment is needed.

Table A6.2 Risk assessment approaches for alternative applications

Application	Health risks	Environmental risks
Garden watering	Standard approach	Standard approach
Toilet flushing, washing machine use	Additional assessment	Not applicable
Car washing[a]	Standard approach	Standard approach
Roadmaking and dust control[a]	Standard approach	Standard approach
Street cleaning[a]	Standard approach	Standard approach
Firefighting	Additional assessment	Standard approach
Water features and ponds	Additional assessment	Not applicable
Food crop consumption — home grown	Additional assessment	Additional assessment
Food crop consumption — commercial	Additional assessment	Additional assessment
Agricultural uses (other than food crops)	Standard approach	Additional assessment
Dual reticulation	Additional assessment	Standard approach
Industrial uses	Additional assessment	Not applicable

a No exposure data available from the Phase 1 guidelines — exposure assumed to be equivalent to garden irrigation, based on similar treatment criteria (Table 3.8 of the Phase 1 guidelines).

Glossary

aquifer storage and recovery	The recharge of an aquifer via a well for subsequent recovery from the same well.
baseflow	Portion of stream flow that comes from groundwater and not runoff.
biochemical oxygen demand	Decrease in oxygen content in a sample of water caused by the bacterial breakdown of organic matter.
bioretention system	Stormwater treatment measure similar to a sand filter, in which vegetation is planted on the top of a soil filter medium; also known as a biofiltration system.
Campylobacter	A genus of bacteria that is a major cause of diarrhoeal illness.
chemical oxygen demand	Measure of the amount of organic compounds in water.
coliform bacteria	A group of bacteria whose presence in drinking water and wastewater can be used as an indicator for operational monitoring.
corrective actions	Procedures to be followed when monitoring results indicate that a deviation occurs from acceptable criteria.
critical control point	A step or procedure at which controls can be applied and a hazard can be prevented, eliminated or reduced to acceptable (critical) levels.
Cryptosporidium	Microorganism that is highly resistant to disinfection; commonly found in lakes and rivers. *Cryptosporidium* has caused several large outbreaks of gastrointestinal illness with symptoms such as diarrhoea, nausea and stomach cramps. People with severely weakened immune systems are likely to have more severe and more persistent symptoms than healthy individuals (adapted from United States Environmental Protection Agency).

disability adjusted life year (DALY)	DALYs are used to set health-based targets and assess risks for human health in relation to pathogens. The Phase 1 guidelines (NRMMC–EPHC–AHMC 2006) set the tolerable risk at 10^{-6} DALYs per person per year. DALYs are used to convert the likelihood of infection or illness into burdens of disease; one DALY represents the loss of one year of equivalent full health.
disinfection	The process designed to kill most microorganisms, including essentially all pathogenic bacteria. There are several ways to disinfect; chlorine is most frequently used in water treatment.
dispersive soil	Clay soil that behaves as a single-grain soil and is highly likely to erode when subjected to water forces.
E. coli	*Escherichia coli;* bacterium found in the gut. Used as an indicator of faecal contamination of water.
conductivity or electrical conductivity (EC)	A measure of the conduction of electricity through water; can be used to determine the total dissolved soluble salts content. EC is measured in µS/cm.
eutrophication	Degradation of water quality due to enrichment by nutrients such as nitrogen and phosphorus, resulting in excessive algal and plant growth and decay, and often low dissolved oxygen in the water.
evapotranspiration	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.
first flush	Situation where the concentrations of pollutants in roofwater or stormwater are relatively high at the start of the storm event.
flocculation	Process in which small particles are agglomerated into larger particles (which can settle more easily) through gentle stirring, by hydraulic or mechanical means.
grey water	Wastewater from the hand basin, shower, bath, spa bath, washing machine, laundry tub, kitchen sink and dishwasher.

gross pollutants	Litter and debris transported by urban runoff.
gross pollutant trap	Stormwater treatment measure that traps gross pollutants using a screen or trash rack.
hydraulic conductivity	Soil property that describes the ease with which water can move through pore spaces or fractures.
indicator organisms or indicator bacteria	Microorganisms whose presence is indicative of pollution or of more harmful microorganisms (eg *E. coli* indicates the presence of pathogenic bacteria).
log reduction or removal	Logarithmic (base 10) concentration reductions, effectively reduction by a factor of 10. Used in reference to the physical–chemical treatment of water to remove, kill, or inactivate microorganisms such as bacteria, protozoa and viruses. • 0.5 log reduction = 68% reduction • 1 log reduction = 90% reduction • 1.5 log reduction = 97% reduction • 2 log reduction = 99% reduction • 2.5 log reduction = 99.7% reduction • 3 log reduction = 99.9% reduction.
mainswater	Potable water from a reticulated water supply (eg town water supply).
managed aquifer recharge	The intentional recharge of water to aquifers for subsequent recovery or environmental benefit.
nutrient	Substance that provides nourishment for an organism — the key nutrients in stormwater runoff are nitrogen and phosphorus.
pathogen	A disease-causing organism (eg bacteria, viruses, protozoa).
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	Alternative term for drinking water.
preventive measures	Any planned action, activity or process that is used to prevent hazards from occurring, or reduce them to acceptable levels of risk.
probability density function	Function that represents a probability distribution in terms of integrals.
rainwater	Precipitation that has not reached a roof or other surface.
reuse	Using water that would otherwise be discharged to wastewater or stormwater systems, for domestic, commercial, agricultural or industrial purposes.
roofwater	Water collected from the roofs of buildings.
sewage or wastewater	Material collected from internal household and other building drains. Includes faecal waste and urine from toilets, shower and bath water, laundry water and kitchen water.
shandying	Addition of one water source to another (eg effluent and stormwater) to modify the quality of the water.
soil horizon	Specific layer in the soil parallel to the soil surface that possesses physical characteristics that differ from the layers above and beneath.
somatic coliphage	A type of virus that infects *E. coli.*
storage	A natural or artificial impoundment used to hold water before its treatment or distribution (eg dam, reservoir, aquifer).
stormwater	Rainwater that runs off all urban surfaces such as roofs, pavements, car parks, roads, gardens and vegetated open spaces.
strainer polishing filtration	Water treatment process which involves passing water through a strainer followed by a filter for final or 'polishing' treatment

suspended solids	Solids in suspension in water that can be removed by laboratory filtering, usually by a filter of nominal pore size of about 1.2 µm.
swale	Shallow and wide grass-lined channel.
thermotolerant coliforms	Coliform bacteria that originate from the gut of warm-blooded animals and whose presence in drinking water can be used as an indicator for operational monitoring.
tolerable risk	Level of risk deemed to be acceptable. These guidelines use disability adjusted life years (DALYs) to convert the likelihood of infection or illness into burdens of disease, and set a tolerable risk at 10^{-6} DALYs per person per year.
total dissolved salts	A measurement of the total dissolved salts in a solution. Major salts in recycled water typically include: sodium, magnesium, calcium, carbonate, bicarbonate, potassium, sulfate and chloride. Used as a measure of water or soil-water salinity with the units of mg/L.
turkey's nest dam	Dam constructed on a valley slope or plain rather than a watercourse, usually with no catchment.
vascular plant	A plant that possesses a well-developed system of conducting tissue to transport water, mineral salts and sugars, for example, ferns and seed-bearing plants.
zoonotic	Pertaining to diseases in animals that can be transmitted to humans.

Tables, figures and boxes

Tables

Figures

Boxes

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