NATIONAL WATER QUALITY MANAGEMENT STRATEGY

AUSTRALIAN GUIDELINES FOR WATER RECYCLING: MANAGING HEALTH AND ENVIRONMENTAL RISKS (PHASE 1)

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National Guidelines for Water Recycling:
Managing Health and Environmental Risks

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Abbreviations and acronyms

AATSE	Australian Academy of Technological Sciences and Engineering
ABS	Australian Bureau of Statistics
ADWG	*Australian Drinking Water Guidelines* (NHMRC–NRMMC 2004)
AES	alkane ethoxy sulfonate
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agricultural and Resource Management Council of Australia and New Zealand (Note: in 2001, the functions of ARMCANZ and ANZECC were taken up by the Environment Protection and Heritage Council and the Natural Resource Management Ministerial Council)
ASR	aquifer storage and recovery
BNR	biological nutrient reduction
BOD	biochemical oxygen demand
BOD_5	biochemical oxygen demand over 5 days
CCL	cumulative contaminant loading limit
cfu	colony-forming unit
CP	control point
CRC	cooperative research centre
CRCWQT	Cooperative Research Centre for Water Quality and Treatment
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Ct	term used in disinfection to describe the product of disinfectant concentration (C, in mg/L) and contact time (t, in minutes)
DAFF	dissolved air flotation and filtration
DALY	disability adjusted life year
DALYd	doses equivalent to 10^{-6} DALY
EC	electrical conductivity (deci-Siemens/metre, dS/m)
ECe	electrical conductivity of a soil paste extract
ECi	electrical conductivity of irrigation water

EDC	endocrine disrupting chemical
EIL	ecological investigation level
EPA	Environment or Environmental Protection Agency or Authority
ESP	exchangeable sodium percentage
FSANZ	Food Standards Australia New Zealand
HACCP	hazard analysis and critical control point
HD	health department
HIL	health-based investigation level
LAS	linear alkylbenzene sulfonate
LC_{50}	lethal concentration of a substance that kills 50% of test animals in a given time
NATA	National Association of Testing Authorities
NDMA	nitrosodimethylamine
NHMRC	National Health and Medical Research Council
NOEC	no observed effect concentration
NRMMC	Natural Resource Management Ministerial Council
NTU	nephelometric turbidity unit
NWQMS	National Water Quality Management Strategy
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
P_{inf}	probability of infection
QA	quality assurance
QC	quality control
RO	reverse osmosis
RSC	residual sodium carbonate
RSCL	receiving soil contaminant limit
SAR	sodium adsorption ratio
SS	suspended solids

TDS	total dissolved salts
THM	trihalomethane
USEPA	United States Environmental Protection Agency
UV	ultraviolet
VCH	volatile chlorinated hydrocarbons
WHO	World Health Organization

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Joint Steering Committee

Chair	
Mr Peter Sutherland	New South Wales Department of Natural Resources
Members	
Ms Jo Beatty	Department of Sustainability & Environment, Victoria
Mr Chris Bell	Environment Protection Authority (EPA), Victoria
Ms Jan Bowman	Department of Human Services, Victoria
Prof Don Bursill	Cooperative Research Centre (CRC) for Water Quality & Treatment
Ms Christine Cowie	National Health and Medical Research Council
Dr David Cunliffe	Department of Health, South Australia
Dr David Dettrick	Department of Infrastructure, Planning & Environment, Northern Territory
Mr John Doherty	Department of Transport & Regional Services
Mr Leon English	Department of Water, Western Australia
Dr Helen Foard	National Water Commission
Mr Rob Hogan	Department of Environment & Conservation, New South Wales
Mr Theo Hooy	Australian Government Department of the Environment and Heritage (DEH)
Dr Greg Jackson	Environmental Protection Agency, Queensland
Dr Karin Leder	National Health and Medical Research Council
Mr Peter Marczan	Department of Environment & Conservation, New South Wales
Dr Kaye Power	Department of Health, New South Wales
Mr Neil Power	Department of Water, Land and Biodiversity Conservation, South Australia
Ms Nina Rogers	Australia Local Government Association
Ms Chris Schweizer	DEH
Mr Ian Smith	Department of Infrastructure, Planning & Environment, Northern Territory
Mr Ross Young	Water Services Association of Australia

Risk Management Framework and Integration Working Group

Chair	
Prof Don Bursill	CRC for Water Quality & Treatment
Members	
Dr David Cunliffe	Department of Health, South Australia
Dr Daniel Deere	CRC for Water Quality & Treatment
Mr Peter Donlon	Water Services Association of Australia
Mr Theo Hooy	DEH
Mr Alec Percival	Consumer Health Forum
Prof Brian Priestley	Monash University
Ms Chris Schweizer	DEH
Mr Peter Scott	Melbourne Water
Dr Martha Sinclair	Monash University

Health Risk Working Group

Chair

Dr David Cunliffe	Department of Health, South Australia
Members	
Prof Nick Ashbolt	University of New South Wales
Mr Peter Donlon	Water Services Association of Australia
Dr Jim Fitzgerald	Department of Human Services, South Australia
Ms Amelia Savage	Department of Human Services, Victoria
Dr Melita Stevens	Melbourne Water
Dr Simon Toze	Commonwealth Scientific and Industrial Research Organisation (CSIRO) Land & Water

Environmental Risk Working Group

Chair

Mr Theo Hooy and Ms Chris Schweizer	DEH
Members	
Dr Heather Chapman	CRC for Water Quality & Treatment
Ms Nerida Davies	DEH
Dr Ana Deletic	Monash University
Dr Peter Dillon	CSIRO Land & Water
Mr Ted Gardner	Department of Natural Resources, Queensland
Mr George Gates	Department of Infrastructure, Planning & Natural Resources, New South Wales
Dr Ben Gawne	Murray-Darling Freshwater Research Centre
Ms Kaia Hodge	Sydney Water
Ms Annie Josline	DEH
Dr Stuart Khan	Centre for Water & Waste Technology, University of New South Wales
Dr Rai Kookana	CSIRO Land & Water
Dr Anu Kumar	CSIRO Land & Water
Prof Sam Lake	Monash University
Mr Charles Lewis	DEH
Ms Therese Manning	Department of Environment & Conservation, New South Wales
Mr Russel Martin	Department of Water, Land & Biodiversity, South Australia
Dr Mike McLaughlin	CSIRO Land & Water
Dr Grace Mitchell	CSIRO Manufacturing & Infrastructure Technology
Ms Louise Oliver	DEH
Dr Hamish Reid	EPA Victoria/South East Water
Dr Stephanie Rinck-Pfeiffer	United Water International
Ms Suzie Sarkis	EPA Victoria
Dr Daryl Stevens	Arris Pty Ltd
Dr John Whittington	Department of Primary Industries, Water & Environment, Tasmania

Project Coordination and Scientific Services for the Environmental Risk Component of the National Guidelines on Water Recycling

Dr Daryl Stevens	Arris Pty Ltd

Chapter on consultation and communication

Ms Lis Gerrard	Bluebird Communication
Dr Stuart Khan	Centre for Water & Waste Technology, University of New South Wales

Public comments

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Executive summary

This document — the National Water Quality Management Strategy (NWQMS) *National Guidelines for Water Recycling: Managing Health and Environmental Risks* — is an authoritative reference for the supply, use and regulation of recycled water schemes.

Through recycling, various water sources that have traditionally been wasted, such as stormwater, sewage effluent and greywater can become a valuable resource. This document provides guidance on how such recycling can be safely and sustainably achieved. It focuses on uses such as agriculture, fire control, municipal, residential and commercial property, and industry.

Publication of these guidelines is timely, because pressure on freshwater supplies is increasing in many cities and regional areas of Australia, due to widespread drought and movement of population to large centres near capital cities. In recent years, several reports have suggested that we need to use water more efficiently; for example, by reusing water that has traditionally been seen as wastewater (SECITA 2002, Rathjen et al 2003, AATSE 2004). In response to this situation, the Environment Protection and Heritage Council and the Natural Resource Management Ministerial Council developed these national guidelines on water recycling, under the auspices of the NWQMS.

These guidelines overcome some of the deficiencies of related publications. For example, they are more comprehensive than the *NWQMS Guidelines for Sewerage Systems, Use of Reclaimed Water* (NHMRC and ARMCANZ 2000) and provide a consistent approach, whereas the guidelines developed by individual state and territory governments vary in their approach. An important feature of these guidelines is that they use a risk management framework, rather than simply relying on post-treatment testing as the basis for managing recycled water schemes.

When recycling water, it is essential to protect the health of both the public and the environment, and a risk management approach is the best way to achieve this. This type of approach been used in the food industry for many years, through application of the hazard analysis and critical control point (HACCP) system. More recently it has been adopted in the water industry; for example in the latest edition of the *Australian Drinking Water Guidelines* (NHMRC-NRMMC 2004) and of the World Health Organization's *Guidelines for Drinking-water Quality* (WHO 2004).

The risk management framework used in these guidelines is based on the framework detailed in the *Australian Drinking Water Guidelines* (NHMRC-NRMMC 2004). As the framework is generic it can be applied to any system that is recycling water. The framework involves identifying and managing risks in a proactive way, rather than simply reacting when problems arise.

The first step is to look at hazards in the recycled water that could potentially affect human or environmental health (ie 'What might happen and how it might occur?'). The next step is to estimate the risk from each hazard by assessing the likelihood that the event will happen and the consequences if it did (ie 'How likely is it that it will happen, and how serious will it be if it does?'). After characterising the risks, preventive measures to control hazards are then identified (ie 'What can we do about it?'). The approach also includes monitoring to ensure that the preventive measures operate effectively, and verification to ensure that the management system consistently provides recycled water of a quality that is fit for its intended use.

The risk management framework (detailed in Chapter 2) comprises 12 elements that fall into four main categories:

- commitment to responsible use and management of recycled water
- system analysis and management
- supporting requirements (eg employee training, community involvement, research and development, validation, and documentation and reporting systems)
- review (eg evaluation and audit processes).

The 12 elements are related, and all need to be implemented for the risk management approach to be successful. An important feature of the approach is that multiple barriers are used to control hazards, meaning that if one measure fails, other measures continue to provide control. For example, in a scheme to irrigate commercial crops with recycled water from a major metropolitan sewage treatment plant, preventive measures designed to protect human health might include restrictions on the type of waste entering the plant, a range of treatment processes, cross-connection control at all irrigation sites and an education program on irrigation practices for those using the water or working on the scheme (case studies are given in Appendix 1). Also essential to the approach are critical control points; that is, activities, procedures or processes where control can be applied, and that are essential for either preventing or reducing to acceptable levels those hazards that represent high risks.

These guidelines should always be implemented in collaboration with relevant authorities such as those for protection of health and the environment.

The guidelines consider management of risks to human health and environmental health (Chapters 3 and 4, respectively), and focus on two specific situations — water recycled from a centralised sewage treatment plant and from greywater. The approach is to identify major health risks and the preventive measures needed to reduce those risks to an acceptably low level. Sources of recycled water such as sewage and greywater can contain a wide range of agents that pose risks to human health, including pathogenic (disease-causing) microorganisms and chemicals. Microbial hazards include bacteria, viruses, protozoa and, to a lesser extent, helminths. Chemical hazards include inorganic and organic chemicals, pesticides, potential endocrine disruptors, pharmaceuticals and disinfection byproducts.

For human health, the main focus is on microbial hazards, although chemicals must also be considered, with some emerging areas of concern with long-term exposure to low levels of chemicals. For the environment, chemical hazards pose a greater risk than microbial hazards, although there are emerging areas of concern with respect to microbial hazards, such as transfer of antibiotic-resistant bacteria through waste going into the environment.

In managing risks to human health (covered in Chapter 3) it is necessary to determine acceptable or tolerable risk, set health-based targets and assess risks. 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 as 10^{-6} DALYs per person per year. The tolerable risk is then used to set health-based targets that, if met, will ensure that the risk remains below 10^{-6} DALYs per person per year.

In identifying hazards, it is impractical to set human health-based targets for all microorganisms that might be present in a source of recycled water; therefore, the guidelines specify the use of reference pathogens instead — *Campylobacter* for bacteria, rotavirus and adenovirus for viruses, and C*ryptosporidium parvum* for protozoa and helminths. Dose–response information obtained from investigations of outbreaks or experimental human-feeding studies can be used to determine how exposure to a particular dose of a hazard relates to incidence or likelihood of illness.

In considering exposure, both intended and unintended uses need to be considered. Unintended uses can be deliberate (eg filling a swimming pool with recycled water) or accidental (eg mistakenly cross-connecting water supplies). Similarly, in characterising risk, both maximum risk (ie risk in the absence of preventive measures) and residual risk (ie risk that remains after consideration of existing preventive measures) need to be taken into account.

In managing risks to the environment from recycled water (Chapter 4), the aims are to safeguard the welfare of future generations, provide for equity within and between generations, protect biological diversity and maintain essential ecological processes and life-support systems. In place of DALYS and health-based targets, environmental guideline values are used; these are guideline values related to impacts on specific endpoints or receptors within the environment. Examples of endpoints include specific grasses, native tree species or soil types in the area where the recycled water is to be used.

The process used to assess environmental risks is to first identify water sources, uses, users and routes of exposure. Following this, the recycled water system and water quality data are assessed; and finally, hazards are identified and the overall risk assessed.

As with health risks, assessing risks to the environment involves consideration of both maximum and residual risk. However, in the case of the environment, there is also an initial screening-level risk assessment, which might involve, for example, comparing hazard concentrations in the recycled water with known guideline values for hazards in the recycled water.

In developing these guidelines, nine environmental hazards were identified that should be priorities for assessing the environmental risk associated with specific uses of recycled water (eg including agricultural, municipal, residential and fire control). The nine hazards are boron, cadmium, chlorine disinfection residuals, hydraulic loading (water), nitrogen, phosphorus, salinity, chloride and sodium. A screening-level risk assessment identified a further nine hazards associated with use of recycled water for environmental allocation for water bodies — ammonia, aluminium, arsenic, copper, lead, mercury, nickel, surfactants (ie linear alkylbenzene sulfonates and alcohol ethoxylated surfactants) and zinc.

Preventive measures to protect human and environmental health include preventing hazards from entering recycled water, removing them using treatment processes, and reducing exposure, either by using preventive measures at the site of use or by restricting uses of the recycled water. For example, treatment processes used before recycling can reduce the concentration of both microbial and chemical contaminants.

Monitoring (covered in Chapter 5) is essential to determine baseline data (ie ‘Where are we now?’), to validate systems (ie ‘Will it work?’), for operational purposes (ie ‘Is it working now?’) and to verify that the processes used in recycling are effective (ie ‘Did it work?’). All types of monitoring should be used in relation to both human and environmental health risks.

For human health risks, validation monitoring is essential because of the magnitude of potential health risks from use of recycled water. This means that log reductions assured by designers and manufacturers of treatment systems, or by user group representatives, cannot be assumed to be valid — some objective empirical evidence of the log reductions is required. The precise nature of the evidence depends on the nature of the barriers.

For environmental health risks, two major factors influence monitoring requirements — the size of the recycled water scheme and the level of risk being managed. Generally, the larger the recycled water system, the more endpoints are potentially affected, and the greater the extent of monitoring needed. However, monitoring will also be influenced by the level of risk, which depends on the specific recycled water, and the preventive measures used to minimise the risks associated with that system.

Consultation and communication (covered in Chapter 6) form part of the risk management framework. These aspects are particularly important in water recycling, where a number of proposed schemes in Australia and overseas have failed or been drastically altered because of a lack of stakeholder support. Many different factors affect acceptance of water recycling, ranging from disgust and cost to sociodemographic factors. However, there are also many factors that may make the community more likely to accept a water recycling scheme, such as minimal human contact, clear protection of public health and the environment, and confidence in local management of public utilities and technologies. Research has also identified features needed for a successful communication strategy, a range of possible methods for engaging stakeholders at the planning and operation stages of a water recycling scheme, and ideas for managing communication in a crisis.

These guidelines represent a first stage in developing information for water recycling in Australia. They do not deal specifically with recycling of water from industrial and commercial sources because such waters can have very specific characteristics relating to quality, variability and quantity. However, the generic approach described here can be applied to these sources. Other aspects not covered by this document are the use of recycling to reduce the amount of wastewater and stormwater discharged into environments such as oceans and rivers, and the subject of water allocations (including environmental flows).

1 Introduction

> Recycled water is 'a valuable resource that should not be wasted and which can be used in a safe and sustainable manner to reduce pressures on limited drinking water resources' (Rathjen et al 2003)

These national guidelines have been developed under the auspices of the *National Water Quality Management Strategy* (NWQMS), to provide guidance on best practices for water recycling. They are not prescriptive and do not represent mandatory standards, but are designed to provide an authoritative reference that can be used to support beneficial and sustainable recycling. The guidelines are intended to be used by anyone involved in the supply, use and regulation of recycled water schemes, including government and local government agencies, regulatory agencies, health and environment agencies, operators of water and wastewater schemes, water suppliers, consultants, industry, private developers, body corporates and property managers.

This chapter contains the following sections:

- *Overview* (Section 1.1), which outlines the purpose of these guidelines, and discusses the principles behind the sustainable use of recycled water
- *Scope of the guidelines* (Section 1.2), which describes the sources of water used for recycling, introduces the generic risk management approach on which these guidelines are based, and identifies the uses for which specific guidance is provided
- *How to use the guidelines* (Section 1.3), which outlines the structure of this document and explains how it is intended to be used.

1.1 Overview

Increased recycling of waters that have traditionally been wasted can have two distinct advantages. The first advantage — and the focus of these guidelines — is that recycling can provide additional sources of water for various purposes, including many that are currently supplied by Australia's limited freshwater resources (eg provision of drinking water supplies from surface and groundwater sources).

The second advantage of recycling is that it can reduce discharge of wastewater and stormwater — which is often nutrient rich and physically poor — into receiving environments (including oceans and rivers). This aspect is an important driver for water recycling, and is often referenced in planning and development of recycled water schemes; however, it is outside the scope of these guidelines, and is not considered further here.

1.1.1 Safe and sustainable use of recycled water

The provision of safe water and sanitation has been more effective than any other intervention in reducing infectious disease and increasing public health. The public expects to have safe water and sanitation; therefore, when recycling water, it is essential to protect public health and the environment. There are also broader ramifications to consider, such as public and institutional confidence, which can be fragile and, once lost, are difficult to regain. For example, in the Netherlands in 2001, an outbreak of illness caused by mismanagement of a dual-water scheme, in which lower quality river water was supplied for non-drinking residential purposes, led to the abandonment of future water recycling schemes of this type.

Box 1.1 lists the main principles of sustainable use of recycled water, and the requirements for adherence to these principles.

Box 1.1 Principles of sustainable use of recycled water

Sustainable use of recycled water is based on three main principles:

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

Adherence to these principles requires:

- an awareness and understanding of how recycled water quality management can affect public health and the environment
- maintenance of recycled water schemes and reinforcement of the importance of ongoing management (by senior managers, to employees, stakeholders and end users)
- an organisational philosophy that supports continuous improvement and cultivates employee responsibility and motivation
- ongoing communication between regulators, owners, operators, plumbers and other stakeholders as well as end users, supported by audit and inspections.

1.1.2 The need for water recycling

In Australia, the beginning of the 21st century has been characterised by widespread drought and population movement to large centres near capital cities. Together, these changes have increased pressure on fresh water supplies in most large cities and in many regional areas.

A Federal Parliament Senate Committee established to look into Australia's management of urban water found that Australia could greatly improve on its performance with regard to water reuse. The committee observed that 'efficient water use is still perceived as an emergency measure to be adopted during drought condition … in a country of such limited water resources, this behaviour [efficient water use] must be the norm, not the exception' (SECITA 2002).

In 2003, a report prepared for the Prime Minister's Science, Engineering and Innovation Council identified possible mechanisms by which Australian cities could make better use of available water resources, including stormwater, greywater and treated sewage (Rathjen et al 2003). The report noted that essential criteria for all initiatives would include maintenance of public health, economic viability, environmental sustainability and social acceptance. It also supported the development of new national guidelines dealing with health and environmental aspects of water recycling.

In 2004, the Australian Academy of Technological Sciences and Engineering (AATSE) published a report titled *Water Recycling in Australia* (AATSE 2004). The report suggested that water traditionally seen as wastewater, such as sewage effluent and stormwater, should be considered as a water resource, and should be used more widely, particularly in situations where water is not required to be of drinking water quality. The report also noted that existing guidelines relating to water recycling had limitations and required revision, and recommended that new national guidelines should be progressed as rapidly as possible.

In response to this situation, the Environment Protection and Heritage Council and the Natural Resource Management Ministerial Council have developed these national guidelines on water recycling, as part of the NWQMS. The guidelines will expand on and replace the *NWQMS Guidelines for Sewerage Systems, Use of Reclaimed Water* (NHMRC and ARMCANZ 2000).

The National Water Initiative, signed by the Australian Government and most state and territory governments in June 2004, has now been signed by all state and territory governments.[1] The development of national guidelines on water recycling is an identified action (92 (i)) under that initiative.

1.1.3 The need for national guidelines

National guidelines on water recycling are needed for a number of reasons:

- the national guidelines for water reuse in Australia — the *NWQMS Guidelines for Sewerage Systems, Use of Reclaimed Water* (NHMRC and ARMCANZ 2000) — are not sufficiently detailed to provide a nationally consistent approach to treatment and recycling of treated sewage, and they are not directly applicable to greywater or stormwater
- state and territory governments have developed their own guidelines, a situation that has led to some inconsistencies (in part due to limitations of the national water reuse guidelines) and a lack of uniformity for recycling
- defined criteria for system management are lacking
- there is a tendency to rely on after-treatment testing as the basis for managing recycled water schemes.

At the end of the 1990s, similar difficulties were identified for drinking water supplies, and were addressed when developing the *Australian Drinking Water Guidelines* (NHMRC–NRMMC 2004). National guidelines for recycled water are therefore required that will promote a risk management approach, based on quality assurance of water before use. This document is designed to meet this need.

Box 1.2, below, shows how these national guidelines relate to state and territory guidelines.

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[1] Available online at http://www.coag.gov.au/meetings/250604/iga_national_water_initiative.pdf

Box 1.2 Relationship between the national guidelines and state and territory guidelines

A nationally consistent approach to the management of health and environmental risks from water recycling requires high-level national guidance on risk assessment and management. Such guidance is provided here in the form of a risk management framework for beneficial and sustainable management of water recycling systems.

Although these guidelines are not mandatory and have no formal legal status, their adoption provides a shared national objective, and at the same time allows flexibility of response to different circumstances at regional and local levels. All states and territories are therefore encouraged to adopt the framework in this document. However, application of the framework may vary across jurisdictions, depending on the arrangements for water and wastewater management.

The water recycling systems addressed in this document are regulated by states and territories. State or local jurisdictions may use their own legislative and regulatory tools to refine the information given here into their own guidelines. Where there are relevant state and territory regulations, standards or guidelines, these should be consulted to ensure that any local requirements are met. Where state and territory guidelines differ from this document, either those state and territory guidelines should be followed, or the local regulatory agency should be consulted to clarify requirements.

1.2 Scope of the guidelines

1.2.1 Sources of water

These guidelines deal with recycling of stormwater, greywater and treated sewage. Water for recycling can come from centralised schemes or from smaller on-site systems involving, for example, treated sewage or greywater. On-site systems are generally privately owned, and many are installed on domestic blocks. Box 1.3 describes the different types of water sources for recycling.

Box 1.3 Sources of recycled water

Greywater

Greywater refers to water sourced from kitchen, laundry and bathroom drains, but not from toilets (note: some guidelines exclude water from the kitchen because it can contain high levels of food scraps and other undesirable particles and wastes). Greywater may contain urine and faeces from nappy washing and showering, as well as kitchen scraps, soil, hair, detergents, cleaning products, personal-care products, sunscreens, fats and oils. Cleaning products discharged in greywater can contain boron and phosphates, and the water is often alkaline and saline — all of which pose potential risks to the receiving environment. Greywater quality can be affected by inappropriate disposal of domestic wastes.

Box 1.3 (continued)

Sewage

Sewage refers to material collected from all internal household drains; it contains all the contaminants of greywater and urine, in addition to high concentrations of faecal material from toilets. Sewage can therefore contain a range of human infectious enteric pathogens, plus wastes from industrial and commercial premises. Discharge of trade wastes to sewer can introduce a range of contaminants, particularly chemicals. Sewage also contains high levels of nutrients, particularly phosphorus and nitrogen, which have been identified as key environmental hazards. Groundwater infiltrating into sewers can cause substantial increases in chloride, salinity and sodicity (high sodium concentrations relative to calcium and magnesium), which have also been identified as key environmental hazards.

Stormwater

Stormwater refers to the water resulting from rain draining into the stormwater system from roofs (rainwater), roads, footpaths and other ground surfaces. It is usually channelled into local waterways. Stormwater carries rubbish, animal faeces, human faecal waste (in some areas), motor oil, petrol, tyre rubber, soil and debris. Initial runoff associated with storms can contain very high concentrations of enteric pathogens (disease-causing organisms) and contaminants (both chemical and physical).

These guidelines do not deal specifically with recycling of water from industrial and commercial sources; such waters can have very specific characteristics relating to quality, variability and quantity. However, the generic approach described here can be applied to these sources.

1.2.2 Risk management framework

A central feature of these guidelines is a generic risk management framework that can be applied to any system recycling water from treated sewage, greywater and stormwater.

Risk management systems (summarised in Box 1.4) are seen as the most effective way to assure the appropriate quality of drinking water or recycled water. Risk management has been adopted by the food industry for many years, through application of the hazard analysis and critical control point (HACCP) system, which is seen internationally as best practice for ensuring food safety (CAC 1997). The development of risk management systems for water quality is covered in various guidelines. For example, the 2004 *Australian Drinking Water Guidelines* (NHMRC–NRMMC 2004) provides a ‘framework for management of drinking water quality’, and the latest edition of the World Health Organization (WHO) *Guidelines for Drinking-water Quality* (WHO 2004) describes ‘water safety plans’. Both these approaches incorporate HACCP principles and are consistent with other established systems such as ISO 9001 (AS/NZS 2000) and AS/NZS 4360 (AS/NZS 2004ab).

The principles used to assure drinking water safety can also be applied to recycled water, and the WHO suggests that a common risk management approach should be applied to drinking water, recycled water and recreational water (WHO 2001).

The risk management framework is used to develop a management plan that describes the nature of a recycled water system and how it should be operated and managed. The plan is referred to as a ‘risk management plan’.

Box 1.4 Risk management approach to water quality and use

A risk management approach involves identifying and managing risks in a proactive way, rather than simply reacting when problems arise. In applying this approach to water recycling, the first step is to look systematically at all the hazards in the recycled water that could potentially affect human or environmental health (ie what might happen and how). Once the hazards are identified, the risk from each hazard is assessed by estimating the likelihood that the event will happen and the consequences if it did. That is, the risk assessment asks 'How likely is it that something will happen?' and 'How serious will it be if it does happen?', and thus provides a means to identify those hazards that represent significant risks for the proposed end use. The next step is to identify preventive measures to control such hazards, and to establish monitoring programs, to ensure that the preventive measures operate effectively. The final step is to verify that the management system consistently provides recycled water of a quality that is fit for the intended use (ie 'fit for purpose').

Adapted from: *Water Made Clear: A Consumer Guide to Accompany the Australian Drinking Water Guidelines,* NHMRC 2004

1.2.3 Aim of the framework for management of recycled water quality and use

The framework for management of recycled water quality and use given in this document is based on, and follows the same principles as, the model used in the 2004 *Australian Drinking Water Guidelines* (NHMRC–NRMMC 2004). The framework, which is given in detail in Chapter 2, describes a generic process for developing and implementing preventive risk management systems for recycled water use. Such systems can be applied to all combinations of water source and end use, including applications not specifically addressed in this document, such as stormwater recycling and use of recycled water to augment drinking water sources. The aim is to provide a measurable and ongoing assurance that performance requirements are met and that, as far as possible, faults are detected before recycled water is supplied, discharged or applied, so that corrective actions can be implemented.

The risk management approach outlined here incorporates the concept of identifying and producing recycled water of a quality that is 'fit-for-purpose'. To be consistent with this approach, these guidelines do not include a classification system for recycled water. A principal reason for this decision is that classification systems can limit flexibility. For example, uses such as dual reticulation, municipal irrigation with unrestricted access and irrigation of salad crops are often grouped together under a heading of (relatively) high exposure uses. However, using a risk assessment approach as shown in Chapter 3, the pathogen removal requirements are different for each of these three end uses. Including them under a single classification (eg Class A) could be misleading.

1.2.4 Flexibility and application of the framework

The risk management framework given here is sufficiently detailed and flexible to apply to all types of recycled water scheme, irrespective of size and complexity. It applies equally to on-site systems serving single dwellings and to large, centralised treatment plants in capital cities, with their varying institutional arrangements. The flexibility of application of the framework is illustrated by the case studies provided in Appendix 1.

The central principle of the guidelines is that all recycled water schemes require a risk management plan to assure safety and sustainability. Although all risk management plans should be consistent with the principles described in the framework, the level of detail and breadth of an individual plan will reflect the complexity and potential level of risk associated with the recycled water scheme in question. Hence, a risk management plan for an on-site system serving a single dwelling will be much simpler than one for a small system involving drip irrigation of a woodlot. In turn, the woodlot plan will be much simpler than one for a dual-reticulation system where recycled water is to be used for garden watering and toilet flushing in multiple buildings, for residential and commercial property.

The responsibility for developing, operating and overseeing risk management plans using the framework outlined here will generally depend on the size and complexity of the system. Different agencies are likely to be involved, depending on the size of the system. For example, plans for a large centralised system are likely to be developed on a case-by-case basis by a wide range of stakeholders (typically led by operators working with regulators), but are likely to be implemented by specialist operators. In contrast, management plans for medium-sized systems may be developed by specialist operators, developers or local government (which may also be the regulator). These systems may be operated by a specialist operator, developer or local government.

Management of on-site recycled water systems is a particular challenge. Such systems could incorporate collection and treatment of sewage or greywater from single domestic dwellings or from complexes such as apartment buildings. They are often operated by homeowners, body corporates, property managers or other private companies, placing a greater onus on regulators to assist in developing management plans and ensuring compliance with operational and maintenance requirements. One approach to this situation could be for regulators to develop generic plans that apply to particular types of on-site system. Such plans need to be robust and should include communication and inspection, to ensure that design, installation and operation are adequate and that performance is maintained. Centralised oversight and support is an essential requirement for decentralised on-site systems. There may also be a need for plans that can be applied to small-scale systems in specific regions. These plans may need to include cautionary notes that make clear the specific regions or situations where recycling may be problematic (eg where there are skeletal soils, shallow groundwater or salinity problems).

Effective management systems must be capable of accommodating change, such as developments in the catchment that may affect source water quality, emerging issues, advances in technology or new institutional arrangements. Development of risk management plans should be an ongoing and iterative process, whereby performance is continually evaluated and reviewed.

1.2.5 Elements of the framework

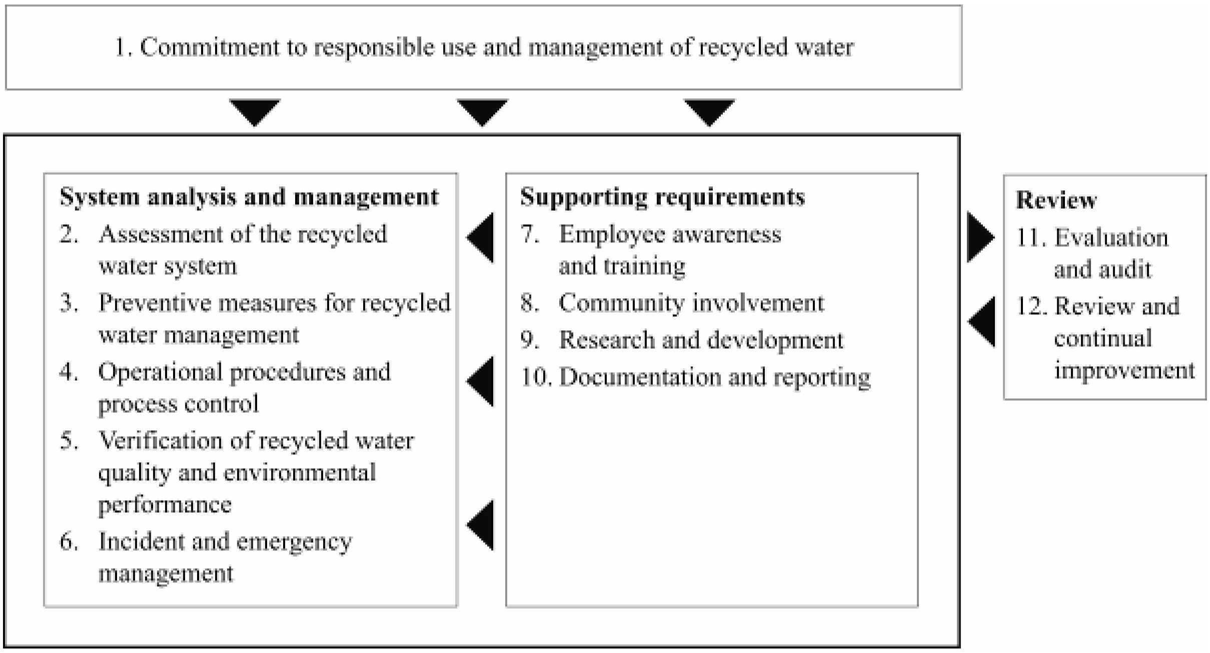
The framework for management of recycled water quality incorporates 12 elements, each of which is described in detail in Chapter 2. Although listed as discrete components in Chapter 2, these elements are interrelated, and each supports the effectiveness of the others. Because most problems associated with recycled water schemes are attributable to a combination of factors, the 12 elements need to be addressed together to assure a safe and sustainable recycled water supply.

The 12 elements are organised within four general areas, as illustrated in Figure 1.1, and listed below:

- *Commitment to responsible use and management of recycled water*. This requires the development of a commitment to responsible use of recycled water and to application of a preventive risk management approach to support this use. The commitment requires active participation of senior managers, and a supportive organisational philosophy within agencies responsible for operating and managing recycled water schemes.

- *System analysis and management*. This requires an understanding of the entire recycled water system, the hazards and events that can compromise recycled water quality, and the preventive measures and operational control necessary for assuring safe and reliable use of recycled water.
- *Supporting requirements*. These include basic elements of good practice, such as employee training, community involvement, research and development, validation of process efficacy, and systems for documentation and reporting.
- *Review*. This includes evaluation and audit processes to ensure that the management system is functioning satisfactorily. It also provides a basis for review and continuous improvement.

Figure 1.1 Elements of the framework for management of recycled water quality and use



1.2.6 Specific uses

Specific guidance is needed for certain uses of recycled water — such guidance is being developed in two phases. The first phase, described in this document, deals with large-scale treated sewage and greywater to be used for:

- residential garden watering, car washing, toilet flushing and clothes washing
- irrigation for urban recreational and open space; agriculture and horticulture
- fire protection and fire fighting systems

- industrial uses, including cooling water (from a human health perspective)
- greywater treated on-site for use for residential garden watering, car washing, toilet flushing and clothes washing.

The second phase, not covered here, will provide specific guidance for:

- use of stormwater and treated sewage to augment drinking water supplies
- stormwater recycling for residential uses, urban irrigation, agricultural and industrial purposes, as well as fire fighting
- managed aquifer recharge, as a component of recycled water schemes.

The second phase will also consider the use of recycled water to enhance environmental flows.

1.2.7 Existing uses

The viability of water recycling has been demonstrated across Australia, and there are many situations where the specific uses considered in these guidelines are already being implemented (Table 1.1). The aim of these guidelines is to increase these and other uses of recycled water.

In addition to the uses described in Table 1.1, there are proposals to use recycled water to augment drinking water supplies.

Table 1.1 Examples of recycled water uses currently undertaken and considered in these guidelines

Agricultural uses

Agricultural uses for recycled water are diverse, and there are now at least 270 agricultural schemes operating across Australia (Radcliffe 2004). The framework used to develop these guidelines should allow the environmental risk associated with any form of agricultural use of recycled water to be assessed. Some current agricultural uses include:

• horticulture	• cotton	• viticulture
• trees/woodlots	• flowers	• hydroponics
• pasture/fodder	• orchard	• turf farm
• dairy pasture	• nursery	• cane fields
• lucerne	• vegetables	• grain cropping

Fire control uses

Recycled water can be used for:

- controlling fires
- testing and maintenance of fire control systems
- training facilities for fire fighting

Managed aquifer recharge

In a number of schemes, stormwater is collected, stored in aquifers and then extracted for use for municipal irrigation. Aquifers could also be used to store treated sewage as part of recycling schemes.

Municipal uses

Municipal uses for recycled water are diverse, and there are currently at least 230 schemes where municipal use is practiced across Australia. The municipal uses covered by these guidelines include:

- irrigation of public parks and gardens, roadsides, sporting facilities (including golf courses)
- road making and dust control
- street cleaning

Table 1.1 (continued)

Residential and commercial property uses
A number of dual-reticulation schemes supply water for residential and commercial property uses, including: • in-building (toilet flushing) • garden watering, car washing • water features and systems (ponds, fountains, cascades) • utility washing (paths, vehicles, fences etc)
Industrial and commercial uses
Industrial uses include: • cooling water • process water • washdown water
Environmental uses
Environmental uses include: • streams and creeks • rivers • lakes and dams

Note: These guidelines assess the risk from a water quality perspective only. Another guideline or process should be used to determine water resource allocations, including those to the environment.

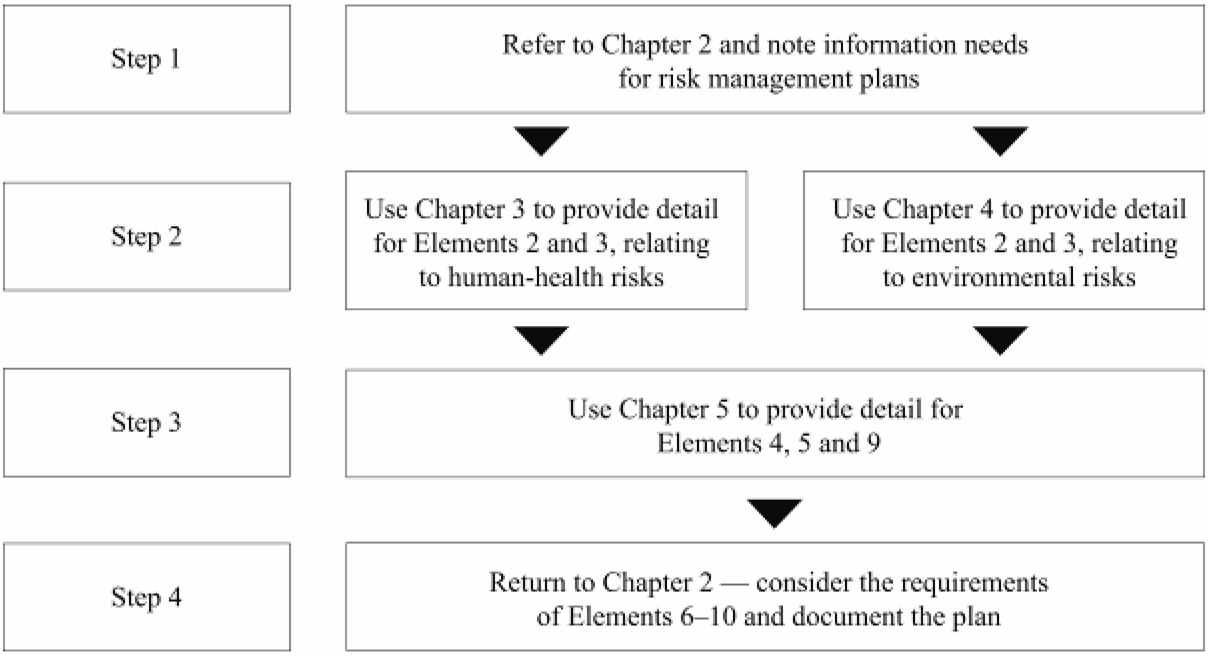
1.3 How to use the guidelines

These guidelines deal with the theory and practice of water recycling. They include chapters on:

- the risk management framework (Chapter 2)
- managing health risks (Chapter 3)
- managing environmental risks (Chapter 4)
- monitoring (Chapter 5)
- consultation and communication (Chapter 6).

Figure 1.2 shows how the guidelines are intended to be used to design risk management plans for recycled water schemes.

Figure 1.2 How to use the guidelines



1.3.1 Step 1 — Risk management framework and plan

Those considering the introduction of a recycled water scheme should first consider the risk management framework. In combination, the 12 elements of the framework provide a system for designing and managing recycled water schemes. The framework provides:

- a mechanism for identifying the major hazards, risks and appropriate preventive measures (treatment and on-site controls) (supplementary information on this topic is given in Chapters 3 and 4)
- an operational monitoring approach designed to detect faults before use of recycled water (supplementary information on this topic is given in Chapter 5)
- the use of verification (compliance) monitoring to ensure that management systems function effectively (supplementary information on this topic is given in Chapter 5)
- establishment of incident protocols
- implementation of supporting requirements including training, community involvement (supplementary information on this topic is given in Chapter 6), documentation and reporting.

The outcome of using the framework is a risk management plan that describes the nature of a recycled water system and how it should be operated and managed. The plan is necessary for operators — it provides a 'living' document that can be reviewed and audited, both internally and externally. As discussed above, a risk management plan should be prepared for every recycled water system.

Although the framework appears to be relatively detailed, it is not particularly difficult to apply, nor is it completely new. Well-designed schemes already employ many elements of the framework. Appendix 1 provides overviews of five typical schemes, illustrating how the framework is applied. The level of detail provided for each example is proportional to the complexity of the scheme.

1.3.2 Step 2 — Human and environmental health risks

Once general principles and information requirements have been identified, Chapters 3 and 4 can then be used to help identify major risks to human and environmental health, and preventive measures that can be used to reduce risks to acceptable levels. These chapters provide detailed information that can be used to complete Elements 2 and 3 of the framework.

Managing health risks

Chapter 3 discusses microbial and chemical hazards; it identifies harmful microorganisms as the major risks associated with the specific uses of treated sewage and greywater discussed in this document. This chapter:

- defines 'tolerable risk'
- sets targets for pathogenic bacteria, protozoa and viruses for a range of specific uses of recycled water
- describes how these targets can be achieved using combinations of treatment (to reduce pathogen concentrations) and on-site controls (to reduce exposure).

Proponents can choose to determine health targets from first principles using scheme-specific data and formulae described in Chapter 3 and Appendix 2, or they can use summary tables to identify typical preventive measures, as described in Table 3.8.

Managing environmental risks

The major environmental risks from recycled water are caused by chemical hazards. Chapter 4 describes how to identify hazards and assess risks from treated sewage and greywater, taking into account the uses of the recycled water and receiving environments (soil, biota, plant, groundwater and surface water). This chapter identifies:

- a broad range of hazards found in treated sewage and greywater
- a shorter list of key hazards (boron, cadmium, chloride, sodium, chlorine, hydraulic loading salinity, nitrogen and phosphorus)
- potential impacts
- preventive measures.

Chapter 4 also describes how to undertake screening assessments to determine whether environmental risks are acceptably low, and whether additional preventive measures are required. Appendix 4 provides more detailed information for key hazards, and Appendix 5 contains tables of guideline values.

1.3.3 Step 3 — Monitoring

Once the characteristics of the recycled water system (including the source of water, end uses, health and environment risks, and preventive measures) have been identified, monitoring characteristics need to be established to fulfil the requirements for Elements 4, 5 and 9 (in part) of the framework. Chapter 5 provides guidance on types of monitoring, parameters and suggested frequencies. The types of monitoring discussed are:

- validation — used to determine whether risk management systems will work
- operational monitoring — used to assesses whether preventive measures are working
- verification monitoring — used to determine whether management systems have worked and have successfully achieved safe and sustainable recycling; this type of monitoring also assesses whether the recycled water scheme has achieved and maintained a quality that is fit-for-purpose.

1.3.4 Step 4 — Completion of the management plan

After completing steps 1–4, proponents should return to Chapter 2 and consider the remaining elements of the framework; that is, elements 6–12. To complete the management plan, all components of the recycled water system should be documented.

1.3.5 Consultation and communication

The importance of consultation and communication should not be underestimated (see Chapter 6). Consultation and communication is not shown as a separate step because it should start at the planning phase and continue through the development of the scheme. Community support and understanding are crucial to the successful implementation of water recycling schemes.

1.3.6 State and territory contacts

The appropriate contact for water recycling issues in each state and territory will vary according to administrative arrangements and the nature of the enquiry. In most cases, it will be necessary to contact the environment, natural resources or health agency in the particular jurisdiction. A list of all departments in each state and territory is available online.[2]

[2] http://www.australia.gov.au/states-territories

2 Framework for management of recycled water quality and use

This chapter describes the 12 elements of the framework for recycled water quality management and use. It outlines the components of each element, together with background information on their purpose and the actions needed to achieve them. Appendix 1 contains five case studies, each of which illustrates how the 12 elements of the framework were implemented.

For each recycled water scheme, the actions taken to implement the elements of the framework should be assembled into a single cohesive and structured document. This document represents the risk management plan for the scheme.

2.1 Commitment to responsible use and management of recycled water quality (Element 1)

Components:	Responsible use of recycled water (Section 2.1.1)
	Regulatory and formal requirements (Section 2.1.2)
	Partnerships and engagement of stakeholders (including the public) (Section 2.1.3)
	Recycled water policy (Section 2.1.4)

This section explains why a commitment to responsible use and management of recycled water quality is needed, and how it can be achieved. It introduces the issue of community consultation and communication, which is discussed in more detail in Chapter 6.

2.1.1 Responsible use of recycled water

Summary of actions

- Involve agencies (ie stakeholders) with responsibilities and expertise in protection of public and environmental health.
- Ensure that design, management and regulation of recycled water schemes is undertaken by agencies and operators with sufficient expertise.

Involve relevant agencies

Assessment of the viability and potential risks associated with recycled water schemes should always involve people with appropriate expertise in public and environmental health. This usually means involving agencies with responsibilities in these areas; for example, health and environment protection authorities.

Ensure that agencies have sufficient expertise

Centralised treatment plants for recycled water should only be operated by agencies or operators with sufficient qualifications and expertise. On-site systems are often operated by householders or private companies with variable levels of expertise. Therefore, such systems generally require a surveillance system overseen by a regulatory agency, to ensure that they are appropriately managed and maintained, and that the recycled water is used responsibly.

2.1.2 Regulatory and formal requirements

Summary of actions

- Identify and document all relevant regulatory and formal requirements.
- Identify governance of recycled water schemes for individual agencies, designers, installers, operators, maintainers, owners and users of recycled water.
- Ensure that responsibilities are understood and communicated to designers, installers, maintainers, operations employees, contractors and end users.
- Review requirements periodically, to reflect any changes.

Identify and document all regulatory and formal requirements

Regulatory and formal requirements for a recycled water scheme need to be identified and documented. Requirements that may govern the design, installation, maintenance, use and management of recycled water include:

- federal, state and territory, and local government legislation and regulations
- operating licences and agreements
- recycled water use agreements and contracts
- agreed levels of service
- memoranda of understanding
- industry standards and codes of practice.

These requirements can also apply to water resource ownership and access rights.

There may also be legal and other requirements relating to the individual responsibilities of participants in recycling schemes (such as suppliers and users).

Identify governance for individual agencies, operators, owners and users of recycled water

Governance for a recycled water scheme needs to be clearly identified and understood. Governance issues include responsibilities and duties of individual agencies, designers, installers, operators, maintainers, owners and users of recycled water.

Ensure responsibilities are understood and communicated

For centralised water recycling systems, primary responsibility for operation and management generally rests with water suppliers, local government or private industry, in conjunction with regulatory agencies. For on-site systems, primary responsibility generally rests with approving or regulatory authorities, such as health departments, environment protection authorities or local governments, working in conjunction with householders and other owners and operators.

Whatever the size of the water recycling system, responsibilities and accountabilities for all relevant agencies need to be understood, documented and communicated. In some cases, this may require reuse agreements or memoranda of understanding to be included in the management plan.

Employees, contractors and other stakeholders should be aware of their responsibilities and duties.

Review requirements

A registry of relevant regulations and other requirements should be readily accessible. The registry should be regularly reviewed and updated. Responsibilities for this must be identified and communicated.

2.1.3 Partnerships and engagement of stakeholders (including the public)

Summary of actions

- Identify all agencies with responsibilities for water resources and use of recycled water; regularly update the list of relevant agencies.
- Establish partnerships with agencies or organisations as necessary or where this will support the effective management of recycled water schemes.
- Identify all stakeholders (including the public) affecting, or affected by, decisions or activities related to the use of recycled water.
- Engage users of recycled water; ensure responsibilities are identified and understood.
- Develop appropriate mechanisms and documentation for stakeholder commitment and involvement.

Identify agencies with responsibilities and regularly update list

Integrated management, with collaboration from all relevant agencies, is essential for effective recycled water management; therefore, it is important to identify such agencies. Different combinations of agencies will be involved in developing, operating and maintaining recycled water systems, depending on the size and complexity of the scheme, and the source of water. Agencies may include those with regulatory and formal requirements, those responsible for collecting recycled water sources, and those responsible for the treatment, quality, use and discharge of recycled water. Box 2.1 lists some of the many agencies that may be involved in water recycling.

The range of agencies involved in an individual recycled water supply system will depend on local organisational and institutional arrangements. Once a list of relevant agencies has been established, it should be updated regularly.

Box 2.1 Examples of agencies that may be involved in water recycling

Some of the agencies that may be involved in water recycling include:

- health and environment protection authorities
- catchment and water resource management agencies
- primary industry agencies
- local government and planning authorities
- nongovernment organisations
- community based groups
- industry associations
- construction industry representatives.

Consultation with regulatory agencies is particularly important for many elements of recycled water management, such as use restrictions, monitoring and reporting requirements, emergency response plans and communication strategies.

Establish partnerships

Effective use of recycled water requires cooperative partnerships between different agencies, with the relationship between partners and the specific responsibilities of each partner clearly defined. Partnerships may be established between any of the agencies listed above (Box 2.1), and with private organisations or companies, such as:

- operators of recycled water treatment and distribution systems
- owners or managers of apartment buildings
- maintenance contractors who service recycled water treatment systems, including on-site systems
- end users of recycled water (eg residents, farmers and councils).

Identify stakeholders

The success of water recycling schemes will depend on early and ongoing engagement and consultation with the community and potential users of the recycled water. All stakeholders must be committed to using and managing recycled water responsibly. Therefore, it is important to identify all major stakeholders that could either affect recycled water schemes (eg regulators and catchment boards) or be affected by them (eg water users, farmers, industry and plumbers). The list of stakeholders should be updated regularly.

Engage users and develop mechanisms for involvement

Consultation with potential users of recycled water and the public is a vital element in developing recycled water systems — success is more likely if public support is established and maintained. Thus, efforts to gain public support should be initiated as early as possible, and should involve all the agencies and partners involved in the recycled water project. Opposition or objections to recycled water are more likely where consultation is inadequate, or where the community considers that they lack input into decision-making processes. Chapter 6 describes the elements required for successful engagement of users of recycled water.

Once schemes are established, users of recycled water are a particularly important group of stakeholders. Depending on the size and complexity of the scheme, regular meetings with users of the recycled water may be useful. Other mechanisms for involving stakeholders include establishing working groups, committees or task forces with appropriate representatives; and developing partnership agreements, including signed memoranda of understanding.

2.1.4 Recycled water policy

Summary of actions

- Develop a recycled water policy, endorsed by senior managers, to be implemented within an organisation or by participating agencies.
- Ensure that the policy is visible and is communicated, understood and implemented by employees and contractors.

Develop a recycled water policy

A recycled water policy is important in formalising the commitment to responsible, safe and sustainable use of recycled water. The policy should provide a basis for developing more detailed guiding principles and implementation strategies. As such, it should be clear and succinct, and should address broad issues and requirements, such as:

- commitment to responsible use of recycled water, and the application of a risk management approach
- recognition and compliance with relevant regulations and other requirements
- communication and partnership arrangements with agencies with relevant expertise, and with users of recycled water
- communication and engagement with employees, contractors, stakeholders and the public
- intention to adopt best-practice management and a multiple-barrier approach
- continuous improvement in managing the treatment and use of recycled water
- the opinions and requirements of all partnership agencies, employees, users of recycled water, other stakeholders and the wider community.

Box 2.2 provides an example of a generic policy for a recycled water supplier. Other agencies (eg regulators) should also develop policies relating to their responsibilities. This is particularly important for management of on-site systems.

Ensure compliance with the policy

The policy needs to be highly visible, continually communicated, understood and implemented. All partners, contractors and partnership agencies should be made aware of the policy.

Box 2.2 Example of a policy for a recycled water supplier

The organisation or partnership supports and promotes the responsible use of recycled water and the application of a management approach that consistently meets the *National Guidelines on Water Recycling*, as well as recycled water user and regulatory requirements.

To achieve this we will:

- ensure that protection of public and environmental health is recognised as being of paramount importance
- maintain communication and partnerships with all relevant agencies involved in management of water resources, including waters that can be recycled
- engage appropriate scientific expertise in developing recycled water schemes
- recognise the importance of community participation in decision-making processes and the need to ensure that community expectations are met
- manage recycled water quality at all points along the delivery chain from source to the recycled water user
- use a risk-based approach in which potential threats to water quality are identified and controlled
- integrate the needs and expectations of our users of recycled water, communities and other stakeholders, regulators and employees into planning processes
- establish regular monitoring of control measures and recycled water quality and establish effective reporting mechanisms to provide relevant and timely information, and promote confidence in the recycled water supply and its management
- develop appropriate contingency planning and incident-response capability
- participate in and support appropriate research and development activities to ensure continuous improvement and continued understanding of recycled water issues and performance
- contribute to the development of industry regulations and guidelines, and other standards relevant to public health and the water cycle
- continually improve our practices by assessing performance against corporate commitments and stakeholder expectations.

The organisation or partnership will implement and maintain recycled water management systems consistent with the *National Guidelines on Water Recycling* to effectively manage the risks to public and environmental health.

All managers and employees involved in the supply of recycled water are responsible for understanding, implementing, maintaining and continuously improving the recycled water management system. Membership and participation in professional associations dealing with management and use of recycled water is encouraged.

Signed by responsible officer(s) Dated

2.2 Assessment of the recycled water system (Element 2)

Components:	Intended uses and source of recycled water (Section 2.2.1)
	Recycled water system analysis (Section 2.2.2)
	Assessment of water quality data (Section 2.2.3)
	Hazard identification and risk assessment (Section 2.2.4)

This section looks at assessment of a recycled water system, which must be carried out before strategies to prevent and control hazards are planned and implemented. The aim of the assessment is to provide a detailed understanding of:

- the entire recycled water supply system, from source to end use or receiving environment
- the hazards, sources and events (including treatment failure) that can compromise recycled water quality
- the preventive measures needed to effectively control hazards and prevent adverse impacts on humans and the environment.

2.2.1 Source of recycled water, intended uses, receiving environments and routes of exposure

Summary of actions

- Identify source of water.
- Identify intended uses, routes of exposure, receiving environments, endpoints and effects.
- Consider inadvertent or unauthorised uses.

Identify source of water

Potential sources of recycled water considered in these guidelines include sewage, greywater and stormwater (defined in the Glossary). It is important to identify the source, because this will influence the type and amount of hazard found.

Identify intended uses, routes of exposure, receiving environments, endpoints and effects

The intended uses of each specific recycled water scheme must be defined, to determine the water quality required and the management measures that need to be implemented to achieve the required quality.

People may be exposed to contaminants in recycled water via ingestion, inhalation or contact with skin. Ingestion generally represents the greatest risk for both microbial pathogens and chemical contaminants.

Environmental exposure to recycled water and potential environmental effects is generally something that is site specific. Factors to consider could include:

- characteristics and proximity of receiving waters (surface water and groundwater)

- characteristics of soils at the point of application (ie receiving environments)
- site hydrology (groundwater, soil permeability, drainage)
- the type of crops or plants to be irrigated (ie endpoints)
- application rates
- on-site storages
- climatic conditions and evapotranspiration rates
- characteristics and proximity of sensitive or protected ecosystems
- quantities required, time of application, spatial variability of application across a district or catchment.

Further information on potential health and environmental impacts associated with specific uses of recycled water are discussed in Chapters 3 and 4, respectively. Receiving environments and endpoints are explained in detail in Chapter 4.

Consider inadvertent or unauthorised use

Although these guidelines focus on intended uses, it is important to consider inadvertent or unauthorised use of the water, because this may result in higher than intended exposure to humans and the receiving environment (see Box 2.3). For example, in schemes that supply recycled water for non-drinking purposes, such as irrigation of parks and gardens, people may occasionally drink from a recycled water tap by accident. Similarly, in dual-reticulation systems, a cross-connection may result in recycled water being supplied to taps used to supply water for drinking, or recycled water may be used to fill a domestic swimming pool. Some householders may deliberately and knowingly use recycled water for an unauthorised purpose, despite advice to the contrary. This is more likely to occur where there is a large price difference between drinking and recycled supplies. In addition, over application of recycled water in domestic gardens or public parks may result in runoff or seepage to adjacent ecosystems (eg bushlands, wetlands).

Box 2.3 Cross-connections and misuse of recycled water

The Rouse Hill residential development in the northwest of Sydney has a dual-reticulation system that supplies recycled water from sewage and drinking water to individual households. Many companies were involved in subcontracting plumbing work for the initial development of 12 500 homes. Drinking-quality water was supplied through both reticulation systems while development occurred.

Household plumbing was audited before recycled water was supplied to homes, revealing households with direct cross-connections and a range of significant plumbing faults. All these defects were corrected before the introduction of recycled water.

Since the recycled water was supplied in September 2001, there have been four separate incidents of cross-connections of the recycled water supply to drinking water mains due to defective household plumbing. In one case, 80 households were reported to have been affected.

There have also been anecdotal reports of some householders deliberately using recycled water to fill swimming pools, despite advisory notices including warnings against this type of use. Although these reports could not be substantiated, a possible motivation for this misuse could be the lower cost of the recycled water and the belief that substantial savings are being achieved (even though the cost of filling a pool with drinking water is only about $25–30).

2.2.2 Recycled water system analysis

Summary of actions

- Assemble pertinent information and document key characteristics of the recycled water system to be considered.
- Assemble a team with appropriate knowledge and expertise.
- Construct a flow diagram of the recycled water system from the source to the application or receiving environments.
- Periodically review the recycled water system analysis.

Assemble pertinent information and document key characteristics of the recycled water system

Effective management requires an understanding of the recycled water system from the source to the end user. Each part of the recycled water system should be characterised with respect to water quality, the factors that affect it, and the integrity of the supply system (particularly in terms of maintaining effective segregation from drinking water). Such characterisation promotes understanding of the recycled water system; it is also useful in identifying hazards and assessing risks to public and environmental health, including those due to inadvertent or unauthorised use. These principles apply to both centralised treatment systems and domestic on-site systems; however, the level of detail required will depend on the complexity of the system.

Assemble a team with appropriate knowledge and expertise

The analysis requires a team with appropriate knowledge and expertise. For centralised systems, the team should include:

- management and operations staff from the recycled water supplier
- health, environment and other regulatory agencies
- local government and primary industry agencies (depending on the nature of the scheme)
- prospective users (where appropriate).

Construct a flow diagram of the recycled water system

The next step is to construct a generalised flow diagram, describing the recycled water system from source to application site or receiving environment. The diagram should:

- outline all steps and processes, whether or not they are under control of the recycled water supplier
- summarise the basic characteristics of each component and level of variability (see Section 2.2.4 for a discussion of variability)
- make explicit any characteristics that are unique to the system
- be verified by field audits and checked by those with specific knowledge of the system
- identify permitted uses and on-site restrictions at application areas
- identify physical and chemical characteristics of application areas and receiving environments
- identify any sensitive ecological systems or threatened species in the vicinity of the site of application or a system element such as recycled water storages.

An example of a flow diagram is shown in Figure 2.1, below. The characterisation will be specific for each system, but examples of characteristics to consider are listed in Table 2.1.

Figure 2.1 Potential systems for use of recycled water from treated sewage or greywater

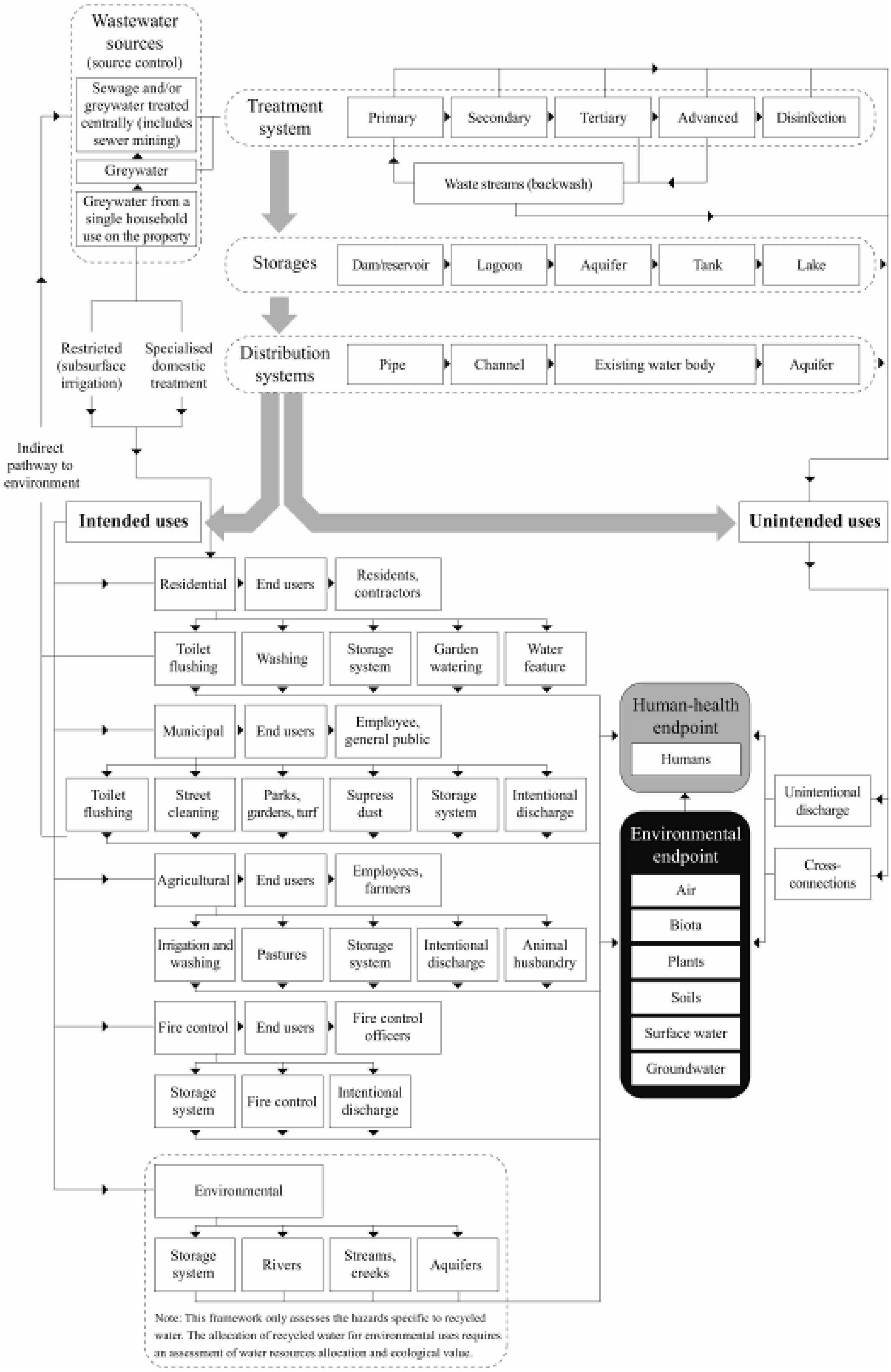


Table 2.1 Characteristics of recycled water systems

Recycled water sources (catchment and collection systems)	

• Development and planning restrictions
• Future planning activities
• Industrial developments
• Input controls, such as:
  o household chemical regulation, labelling and education
  o livestock yards and abattoirs
  o trade waste programs (for sewerage systems)
	o management of contaminated sites (for stormwater systems)
	o regulation of household plumbing configuration (for greywater systems)
	• Meteorology and weather patterns (climatic and seasonal variations)
	• Residential developments
	• Topography and drainage patterns (hydrology)

Source water characteristics	

• Flow and reliability of source water
• General and unique constituents (physical, chemical, microbial):
  o bacteria, viruses, protozoa and helminths
  o detergents (greywater)
  o industrial chemicals
  o major ions, salinity, hardness and pH
  o metals and radionuclides
	o nutrients (nitrogen and phosphorus)
	o organic chemicals
	o disinfection byproducts
	o biologically active compounds including endocrine disruptors, pharmaceuticals
	• Seasonal and event changes (including infrequent events such as droughts or floods)
	• Spatial variations

Treatment systems	

• Disinfection residual and contact period
• Equipment design:
  o size
  o materials
  o peak flow rates
  o process change control
  o backup systems
  o bypass provisions
• Monitoring equipment and automation
	• Nature of treatment processes including primary, secondary and tertiary treatment, on-site treatment, nutrient reduction, disinfection, etc
	• Recycled water treatment chemicals used:
	  o coagulant
	  o filtration aids
	  o disinfectant
	• Stability and reliability of processes
	• Treatment configuration and efficiencies

Storages (including lagoons and wetlands)	

• Algae, macrophytes, zooplankton–plant dynamics
• Aquatic community characteristics and any protection status
• Detention times
• Protection (eg covers, enclosures, access)
• Recreational or human activity
• Seasonal variations:
  o stratification
  o algal blooms
	• Storage design:
	  o depth
	  o materials
	  o size
	  o storage capacity
	• Intake location and operation
	• Treatment efficiencies (microbial removal)
	• Use of the site by birds

Distribution systems, application and receiving environments	
• Access controls (eg fencing) • Application controls including methods (eg spray, drip, subsurface irrigation), design of irrigation system and scheduling (eg night-time only) • Application rates • Conservation status/protected areas • Cross-connection controls and audit systems • Groundwater characteristics including nature of existing aquifers, current uses, depth and quality	• Local vegetation (on-site and off-site) • Physical barriers (eg buffer zones, trees and shrubs) • Plumbing standards and requirements (eg location of piping, colour coding, labelling) • Permitted uses • Receiving water characteristics including their nature (marine or freshwater, flows, volume, tidal movement, current uses and environmental values) • Soil characteristics

Table 2.1 (continued)

Uses of recycled water	
• Residential and commercial use of water for toilet flushing, car washing, garden watering, clothes washing • Environmental flow (intentional discharge) • Fire control	• Water features (eg ponds and fountains) • Agriculture and horticulture • Industrial uses • Irrigation of urban recreational areas, open spaces, parks and gardens
End users of recycled water	
• Communities in vicinity of application sites (permanent or visitors) • Communities that may use products or facilities irrigated with recycled water or that receive recycled water • Agricultural, horticultural, commercial and industrial users of recycled water	• Employees of organisations using recycled water (eg fire control officers, road workers, irrigation officers, farmers) • Local plumbers who may gain access to distribution systems
Receiving environments and endpoints	
• Air • Biota • Groundwater • Humans	• Infrastructure • Plants • Soils • Surface water
Other	
• Extreme and infrequent events (eg droughts or floods)	• Seasonal characteristics

Much of the necessary information may be available in existing documentation from previous studies or from external agencies. Examples of sources of useful information are listed in Box 2.4. Geographic information systems (GIS) can provide a useful means of displaying, cataloguing and interpreting data.

Box 2.4 Examples of useful sources of information for assessing systems

Useful sources of information for system assessment include:

- employee knowledge
- existing approvals or licences recording recycled water compliance data and permitted uses of recycled water
- experts in specific fields
- hydrological records and stormwater flows
- inspections and field audits
- land-use surveys and catchment maps (stormwater)
- maps (of sewerage system, stormwater system)
- records from local authorities (eg locations of on-site systems, animal feedlots, sewage treatment plants), and records of trade waste programs (sewage)
- research and investigative monitoring
- resource maps and reports from natural resource management agencies (eg for soils, vegetation, geology, groundwater)
- sanitary surveys (stormwater) and surveys of industrial inputs into sewerage systems.

Periodically review the recycled water scheme analysis

The recycled water scheme analysis should be reviewed periodically to incorporate any changes that occur, for example in industrial activity, treatment processes, end uses or the characteristics of the end user populations. Normally, management plans will require notification of substantive changes implemented by any party associated with a recycled water scheme.

2.2.3 Assessment of water quality data

Summary of actions

- Assemble historical data about sewage, greywater or stormwater quality, as well as data from treatment plants and of recycled water supplied to users; identify gaps and assess reliability of data.
- Assess data (using tools such as control charts and trends analysis), to identify trends and potential problems.

Assemble historical data, identify gaps and assess reliability

In many cases, recycled water schemes are developed from existing or standard sources of water. A review of historical water quality data can help in understanding source water characteristics and system performance; it can also help in identifying hazards and aspects of the system that require improvement. Parameters that can provide useful information include:

- suspended solids or turbidity
- biochemical oxygen demand
- microbial quality, including faecal pathogens and indicators
- chemical quality, including salinity — for example, total dissolved salts (TDS) or electrical conductivity (EC), sodium adsorption ratio (SAR), nutrients (macro and micro), heavy metals and metalloids, pesticides and other organics
- algal counts
- organic matter
- colour
- pH
- disinfectant residuals and byproducts.

Data should be reviewed over time and after specific events, such as heavy rainfall, which can lead to poor water quality in stormwater systems.

Although historical data can be useful, there may be substantial gaps that should be identified; therefore, such data should only be used as one component of the assessment. Generic data (eg about sewage or greywater quality) can sometimes be useful, but such data should be used with care. Variability should also be considered, particularly for smaller systems.

Available water quality data, obtained from monitoring source waters, the operation and stability of treatment processes, and recycled water as supplied to users should be assessed. The reliability of the available data should be taken into account in the assessment.

Assess data

Tools that may be useful in assessing data include control charts and temporal analysis of water quality records. Records should be analysed for short-term or seasonal spikes (eg caused by trade-waste discharges, seasonal occurrence of illnesses, or storm events if considering stormwater). Sometimes it may be difficult to be aware of potential problems or hazards, because events occur gradually or result from cumulative effects. Trends analysis can be a valuable tool for recognising such effects.

2.2.4 Hazard identification and risk assessment

Summary of actions

- Define the approach to hazard identification and risk assessment, considering both public and ecological health.
- Periodically review and update the hazard identification and risk assessment to incorporate any changes.
- Identify and document hazards and hazardous events for each component of the recycled water system.
- Estimate the level of risk for each identified hazard or hazardous event.
- Consider inadvertent and unauthorised use or discharge.
- Determine significant risks and document priorities for risk management.
- Evaluate the major sources of uncertainty associated with each hazard and hazardous event and consider actions to reduce uncertainty.

Define approach to hazard identification and risk assessment

Effective risk management involves identifying all potential hazards and hazardous events, and assessing the level of risk they present to human and environmental health. The distinction between hazard and risk needs to be understood, so that attention and resources can be directed to actions based primarily on the level of risk rather than just the existence of a hazard. In this context:

- a *hazard* is a biological, chemical, physical or radiological agent that has the potential to cause harm to people, animals, crops or plants, other terrestrial biota, aquatic biota, soils or the general environment; for example:
  - the protozoan parasite *Cryptosporidium parvum* is a hazard to human health
  - salinity is a hazard to soils
- a *hazardous event* is an incident or situation that can lead to the presence of a hazard — that is, what can happen and how; for example:
  - failure at a recycled water treatment plant leading to *C. parvum* passing into the distribution system of a dual-reticulation system is a hazardous event
  - bursting of a pipeline reticulating recycled water high in phosphorus is a hazardous event
- *risk* is the likelihood of identified hazards causing harm in exposed populations or receiving environments in a specified timeframe, including the severity of the consequence (risk = likelihood × impact); for example:

- the likelihood of *C. parvum* being present in source water and passing through the treatment plant in sufficient numbers to cause illness in users of recycled water is a risk
- the likelihood of phosphorus concentrations in the source water remaining sufficiently high to cause eutrophication (degradation of water quality due to enrichment by nutrients) in a waterway near an irrigation site is a risk.

Some of the information required before assessing risk is listed in Box 2.5.

Box 2.5 Examples of information needed for assessing risks for recycled water systems

Information needed in assessing risks might include:

- the source of recycled water
- information on hazards and the quality of the source water
- preventive measures, including treatment processes already in place
- quality of treated water
- intended uses
- preventive measures to be applied at the site of use or discharge of the recycled water
- the potential impacts being assessed (eg impacts on human health or receiving environments).

It is also important to determine what might happen and how it might happen; for example, by determining hazardous events and their possible causes (eg contamination of stormwater by human and livestock waste; unintended cross-connection in a recycled water distribution system; and over irrigation).

There is no single correct way to perform these activities; however, a consistent methodology should be established for both identifying hazards and assessing potential impacts and risks (Chapters 3 and 4 provide processes for assessing health and environmental risks, respectively). The methodology needs to be transparent and fully understood by everyone involved in the process. Staff should be aware of the outcomes of the hazard identification and risk assessment processes. There needs to be confidence that the process will identify all significant risks.

Periodically review and update hazard identification and risk assessment

The hazard identification and risk assessment should be reviewed and updated periodically, because changing conditions may introduce important new hazards or modify risks associated with identified hazards.

Identify and document hazards and hazardous events, and estimate risk

All potential hazards and hazardous events should be included in the assessment for each component of the recycled water system, regardless of whether or not the component is under the direct control of the recycled water supplier. The assessment should include:

- point sources of hazards (eg industrial waste discharge)
- diffuse sources of hazards (eg those arising from agricultural and animal husbandry activities)

- continuous, intermittent or seasonal pollution patterns
- extreme and infrequent events (eg floods and accidental or illegal industrial waste discharges).

Hazards include microbial, chemical, physical and radiological agents. Sources of water used for recycling may contain a large array of hazards (eg sewage will always contain large numbers of microbial hazards or nutrients). In addition, hazards may be introduced through discharges into catchment and collection systems, during treatment and distribution. Chemical contaminants can be introduced through preventable discharges into sewage, and chemicals and microbes can be introduced by discharges into greywater and stormwater. The potential for trade-waste discharges can be assessed by considering the range of industries in a catchment or collection system and information held by the agency responsible for trade-waste control.

Human health

The most significant human health hazards in recycled water are microorganisms capable of causing enteric illness. Such microorganisms can be found at high concentrations in stormwater and greywater, as well as in sewage, although the concentration of pathogens is more variable in stormwater and greywater than in sewage. Numbers of individual pathogens will vary depending on rates of illness in the humans and animals contributing faecal waste. Chemical hazards also need to be considered, particularly for uses of recycled water involving potential for direct contact or ingestion. Chapter 3 provides detailed information on human health hazards that may be found in recycled water.

Environmental health

In terms of environmental health, the most significant hazards in recycled water are generally chemical and physical, and the variable sources of recycled water can potentially expose the environment to many different hazards. Although chemical and physical hazards normally pose a greater potential threat to the environment than to humans, incidents such as major spills or unauthorised chemical discharges can be hazardous to both environmental and human health. The most significant environmental hazards (key hazards) in recycled water have been identified as boron, cadmium, chlorine disinfection residuals, hydraulic load (water), nitrogen, phosphorus, salinity, chloride and sodium (the process by which these hazards were identified is discussed in Chapter 4).

Examples of hazards and hazardous events

Table 2.2 lists the potential hazards found in sewage, with hazards classified as ‘conventional’ or ‘emerging’. In most cases potential human health impacts of waterborne exposure to the emerging hazards has not been established, however, there is evidence that some of the emerging hazards may have environmental impacts (eg see WHO 2002). Table 2.3 provides examples of potential sources of hazards for stormwater, sewage and greywater, and Table 2.4 provides examples of potential hazardous events.

Table 2.2 Potential hazards found in sewage

Classification	Examples of constituents
Conventional	• Suspended solids • Biochemical oxygen demand • Total organic carbon • Ammonia, nitrate, nitrite, total nitrogen • Phosphorus • Metals • Surfactants • Organic chemicals • Pesticides • Total dissolved solids/salinity • Bacteria • Helminths • Protozoa • Viruses
Emerging	• Prescription and non-prescription drugs — antipyretic, antibiotics, antacids, anti-inflammatory, etc • Home care products • Veterinary and human antibiotics • Industrial and household products • Sex and steroidal hormones • Other endocrine disrupters (hormonally active agents) • Water disinfection byproducts — N-nitrosodimethylamine (NDMA)

Source: Adapted from Tchobanoglous et al (2003)

Table 2.3 Examples of sources and potential hazards

Sources	Potential hazards
Stormwater	
Animal husbandry	Pathogens, pharmaceuticals, nutrients, ammonia, turbidity
Forestry	Pesticides, turbidity
Horticulture	Pesticides, fertiliser nutrients, ammonia, turbidity
Industry	Heavy metals, organic chemicals including halogenated organics; specific industries can be associated with specific types of contaminants (eg arsenic and copper associated with wood preserving, cadmium and chromium with electroplating and chromium with leather tanning), turbidity
Illegal sewerage connections	Hazards as for sewage
Mining	Acid mine wastes from pyrites tailings can release and transport metals such as aluminium, iron and manganese; other naturally occurring metals such as cadmium and copper can also be leached; arsenic can be associated with old goldfield areas
Septic tanks	Pathogens, nitrates/nitrites, phosphorus, ammonia
Sewage overflows	Pathogens, nutrients, ammonia, turbidity
Urban areas	Lead and zinc from roads, turbidity, petrol/oil products, microorganisms from pets (lower range of pathogens than from humans or livestock waste)
Sewage	
Domestic/household waste	Food wastes, nutrients, ammonia, detergents, heavy metals (eg copper from domestic pipes), domestic chemicals (eg inappropriate disposal of garden chemicals, paint, solvents, petrochemicals)
Industry	Heavy metals, organic chemicals, specific industries can be associated with specific types of contaminants (eg arsenic and copper associated with wood preserving, cadmium and chromium with electroplating and chromium with leather tanning)
Abattoirs	Pathogens, pharmaceuticals, nutrients, ammonia
Groundwater infiltration	Salinity
Human waste	Pathogens, nutrients, ammonia, pharmaceuticals, personal care products
Greywater	
Domestic/household chemicals	Detergents (including boron, phosphates), personal care products, sunscreens, domestic chemicals (eg inappropriate disposal of garden chemicals, paint, solvents, petrochemicals)
Kitchen waste	Food scraps, nutrients, oils, detergents, cleaning products
Laundry waste	Pathogens and nutrients (from soiled clothing, nappies, etc), detergents, salts

Table 2.4 Examples of potential hazardous events

Stormwater catchments

- Chemical use in catchment areas (eg use of fertilisers and agricultural pesticides)
- Climatic and seasonal variations (eg heavy rainfalls, droughts)
- Flushing of pipes and intentional discharge
- Inadequate buffer zones
- Industrial discharges
- Leaching from existing or historical waste-disposal or mining sites, or contaminated sites and hazardous wastes
- Major fires (firefighting chemicals), natural disasters, sabotage
- Major spills and accidental spillage or discharge
- Poorly vegetated riparian zones, failure of sediment traps and soil erosion
- Road washing
- Sewage overflows and septic system discharges
- Unrestricted livestock

Table 2.4 (continued)

Sewerage systems

- Discharges of domestic/household chemicals
- Discharges of toxic material
- Infiltration of stormwater
- Infiltration of saline groundwater to sewer
- Trade-waste discharges

Treatment systems

- Chemical dosing failures
- Disinfection malfunctions
- Equipment malfunctions
- Failure of alarms and monitoring equipment
- Formation of disinfection byproducts
- Inadequate backup for key processes
- Inadequate equipment or unit processes
- Inadequate filter operation and backwash recycling
- Inadequate mixing of treatment chemicals/coagulants
- Poor reliability of processes
- Power failures
- Sabotage and natural disasters
- Significant flow variations through water treatment system
- Use of unapproved or contaminated water treatment chemicals and materials

Storages, including wetlands and lagoons

- Birds and vermin
- Bushfires and natural disasters
- Climatic and seasonal variations (eg heavy rainfalls, droughts)
- Cyanobacterial blooms
- Leakage from storage to groundwater
- Livestock access
- Inadequate buffer zones and vegetation
- Inadequate storage (eg during winter or other times of low recycled water usage)
- Public roads and accidental spillage
- Sabotage
- Short-circuiting of lagoon or wetland

Distribution systems, application and receiving environments

- Biofilms, sloughing and resuspension, regrowth
- Buildup of sediments and slimes (eg following periods of low use)
- Change in biodiversity from increased nutrients applied in recycled water
- Deliberate or inadvertent misuse of recycled water
- Eutrophication of receiving waters
- Failure to identify recycled water systems (below- and above-ground components)
- Failure to maintain buffer zones and other access controls (eg fencing and signage)
- Flow variability, inadequate pressures
- Formation of disinfection byproducts
- Groundwater intrusion (salinity)
- Human or livestock access, absence of exclusion areas
- Inadequate repair and maintenance, inadequate system flushing and reservoir cleaning
- Lack of separation between recycled water and drinking water systems
- Inappropriate materials and coatings or material failure
- Pipe bursts or leaks
- Poor cross-connection control and backflow protection of higher quality water sources (eg drinking water)
- Poor cross-connection control and backflow protection of recycled water from lower quality water sources
- Raised watertables, salinisation, soil structure decline
- Sabotage and natural disasters
- Soil, groundwater or surface water contamination by recycled water
- Toxicity to plants, terrestrial or aquatic biota
- Waterlogging of plants

Users of recycled water

- Cross-connections to, and lack of backflow protection from, higher quality water sources (e.g drinking water)
- Inadequate education and information about permitted uses
- Leaching of metals from piping and fittings
- Overwatering
- Potential for unauthorised use
- Use of inappropriate plumbing and construction materials

Estimate level of risk

Once potential hazards, hazardous events and their sources have been identified, the level of risk associated with each should be estimated, so that priorities for risk management can be established and documented. Not all hazards will require the same degree of attention; risk estimation helps to direct attention and resources to those hazards that are most threatening.

Screening-level risk assessment

An initial, screening-level risk assessment may be useful to identify broad issues and show where to focus efforts for a more detailed assessment. The aim should be to distinguish between very high and low risks. The trap to avoid is becoming lost in minor detail.

Qualitative and quantitative risk estimation

The level of risk for each hazard or hazardous event can be estimated by identifying the likelihood that it will happen and the severity of the consequences if it does, as shown in Tables 2.5 and 2.6, below.[3] Guidelines and criteria developed for specific combinations of source water and end use should be referred to when estimating risk (further information on risk estimation is provided in the chapters on health and environmental risks (Chapters 3 and 4, respectively).

The likelihood and consequences can then be combined to provide a qualitative estimation of risk, as shown in Table 2.7, below. The aim should be to reduce all risks to low, starting with the high and very-high risks. Risks that are very high will generally be the focus of critical control points (see Section 2.3.2).

For some contaminants, it may be possible to carry out a quantitative risk assessment, to provide a numerical estimate of risks (eg the annual impact of illness caused by a specific pathogen under a particular exposure scenario). Typically, quantitative risk assessment uses a four-step process that includes hazard identification, dose response, exposure assessment and risk assessment. This approach is described in Chapter 3, for assessing risks from hazards to public health.

Limitations

Realistic expectations for hazard identification and risk assessment are important. For example, for any recycled water scheme, a detailed quantitative risk assessment will be possible only for a limited range of contaminants. Hazard identification and risk assessment are predictive activities that will often include subjective judgment, and they will inevitably involve uncertainty. These inherent limitations must be recognised to ensure that effective responses are provided when events differ from predictions. Staff need to have a realistic perception of the limitations of these predictions and need to convey this to the public. A possible outcome of risk assessment is the identification of specific areas where further information and research is required to fill knowledge gaps.

[3] Tables 2.5–2.7 illustrate one approach to estimating the level of risk. These tables can be modified to meet the needs of an organisation.

Table 2.5 Qualitative measures of likelihood

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

Table 2.6 Qualitative measures of consequence or impact

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

Table 2.7 Qualitative risk estimation

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

Note: Level of environmental risk is specific to definitions of likelihood and consequence defined in Tables 2.5 and 2.6

Consider inadvertent and unauthorised use or discharge

It is important to consider inadvertent or unauthorised uses because, as discussed in Section 2.2.1, such uses may present significant risks. In well-managed systems, problems should be uncommon, but this makes them challenging to anticipate and possibly to counter. Experiences from Australia and overseas have shown that hazardous events can include inadvertent cross-connections with drinking water systems, other types of misuse leading to higher than expected or inappropriate exposures, and breakdown of processes and equipment.

Determine significant risks and document risk management priorities

The risk assessment provides a basis for managing risks and applying preventive measures (discussed in Section 2.3). Risk should be assessed at two levels:

- *maximum (unmitigated) risk*, which is risk in the absence of preventive measures — assessment of maximum risk is useful for identifying high-priority risks, determining where attention should be focused and preparing for emergencies
- *residual risk*, which is risk after consideration of existing and proposed preventive measures — assessment of residual risk provides an indication of the safety and sustainability of the recycled water scheme or the need for additional preventive measures.

Evaluate the main sources of uncertainty for each hazard and hazardous event

Evaluating the major sources and types of uncertainty associated with hazards can assist in understanding the limitations of the hazard identification and risk assessment; it can also illustrate how these limitations can be reduced. Hazard identification and risk assessment need to consider explicitly the sources and types of uncertainty. Uncertainty can be broadly classified into two types: variability and knowledge uncertainty, described below.

Variability

Variability represents the true differences that can occur in the specific values of parameters that contribute to a risk. An example of variability would be changes in contaminant concentrations over time and space, flows and number of people exposed. Variability contributes to uncertainty because it usually cannot be described completely (due to monitoring data being incomplete or insufficient), and no single correct answer will cover all circumstances. For example, the mean temperature over a defined period will not represent the high and low extremes, which may be more important than the means, depending on the information being sought. Because there is variability in temperature, a decision will need to be made on which value or values to use from the available data, and this choice will carry with it some uncertainty.

Variability cannot be reduced by more accurate measurement. Instead, it is reduced by characterising the risk more fully, because this allows the nature of a hazard (and thereby the dimensions of the risk) to be better understood. An example of an action to reduce the variability of a system might be increasing reservoir storage times to minimise fluctuations in water quality.

Knowledge uncertainty

Knowledge uncertainty represents an inadequate state of knowledge about the values of parameters measured. It may lead to a lack of assurance that methods are accurately measuring what is intended or that there is a good understanding of how a process works. For example, in using methods to count *Cryptosporidium* oocysts, there may be some uncertainty that the particles being counted are truly *Cryptosporidium* oocysts. Alternatively, there may be confidence that the method for counting oocysts is accurate, but uncertainty about whether oocysts are viable and, if viable, whether they are infective, which in turn leads to uncertainty about what the measurement means.

In contrast to variability, knowledge uncertainty can be reduced by better measurement and research. The increased understanding from reducing knowledge uncertainty can provide greater assurance that the preventive measures being considered will achieve their intended purpose. This requirement supports the need for a research capability within the water industry.

2.3 Preventive measures for recycled water management (Element 3)

Components:	Preventive measures and multiple barriers (Section 2.3.1)
	Critical control points (Section 2.3.2)

This section deals with preventive measures, which (in the context of managing recycled water schemes) are the actions, activities and processes used to prevent significant hazards from being present in recycled water or to reduce the hazards to acceptable levels. The section also considers critical control points, which are preventive measures that are amenable to operational control, and are essential for preventing or reducing hazards representing high risks to acceptable levels.

2.3.1 Preventive measures and multiple barriers

Summary of actions

- Identify existing preventive measures system-wide for each significant hazard or hazardous event, and estimate the residual risk.
- Identify alternative or additional preventive measures that are required to ensure risks are reduced to acceptable levels.
- Document the preventive measures and strategies, addressing each significant risk.

Identify existing preventive measures and estimate residual risk

The identification and planning of preventive measures should always be based on system-specific hazard identification and risk assessment, to ensure that the level of protection to control a hazard is proportional to the associated risk. When identifying existing preventive measures, or developing new measures, the following aspects must be considered:

- the entire recycled water system, including the water source, its characteristics and proposed end uses
- existing preventive measures, from source(s) to the user of recycled water, for each significant hazard or hazardous event
- increased risk due to inadvertent or unauthorised actions
- spatial aspects (these need to be considered when identifying preventive measures for environmental risks, because the sensitivity of receiving environments can vary over space)
- areas where the use or discharge of recycled water is not appropriate due to, for example, environmental sensitivity or soil type topography.

Box 2.6 lists examples of preventive measures for recycled water systems. Additional information on these measures is given in Appendix 3.

Box 2.6 Examples of preventive measures for recycled water systems

Water source protection

Examples of water source protection include preventing or managing industrial discharges, protecting stormwater from animal and human waste, and controlling the type of water discharged into greywater systems.

Water treatment

Treatment processes used to remove or reduce hazards (discussed in detail in Appendix 3) include:

- primary treatment — such as physical treatment process, with or without chemical assistance; some heavy metals removed
- secondary treatment — typically a process that removes dissolved and suspended organic material by biological treatment and sedimentation; biodegradable organics, volatile organics, some nitrogen and phosphorus removed
- tertiary treatment — such as filtration, membrane filtration, and detention in polishing lagoons or wetlands; usually combined with coagulation, sedimentation (or flotation), filtration and disinfection; more removal of nitrogen and phosphorus, dissolved solids and heavy metals; if lagoons are used, salts can be concentrated through evaporation
- on-site advanced aerated systems with disinfection.

Storage/treatment

Storage methods used to remove hazards include:

- lagoons, constructed or natural wetlands and subsurface wetlands
- infiltration (soil aquifer treatment) and direct injection (aquifer treatment).

Protection and maintenance

Protection and maintenance of distribution systems and storages can act as preventive measures. Examples include:

- buffer zones
- minimising light to restrict algal growth (eg by covering storages)
- maintaining drainage and sites (eg ground cover, nutrient balancing)
- backflow prevention and cross-connection control.

Restrictions on distribution system and application site

Preventive measures that involve restricting the distribution and use of recycled water include:

- adoption of recycled water plumbing codes of practice (eg colour coding)
- application of soil ameliorants (eg gypsum to counter a sodium imbalance causing sodicity)
- anemometer controls
- buffer zones, tree and shrub screens, fencing
- control of access; application methods, rates and times; crops or plants grown; odour; plumbing and distribution systems
- control of method and time of application (eg spray, microspray, drip or subsurface irrigation; night-time only)

Box 2.6 (continued)

- control of rate of application (eg moisture sensors, determination of water and nutrient balances, leach requirements)
- diverter switches to allow householders to chose the volumes and types of greywater directed to gardens
- harvesting controls (eg no dropped fruit, withholding periods)
- hydraulic loading and interception drains
- management plan
- prohibition of recycled water use in specific areas
- residential and commercial property non-drinking use only (eg toilet flushing, garden irrigation, car washing)
- restrictions on types of crop to be irrigated (eg food crops, salt sensitive, phosphorus sensitive)
- 'shandying' recycled water with fresh or desalinated water
- signage (eg 'recycled water — do not drink')
- site selection.

Users of recycled water

Various education programs can act as preventive measures; for example, programs relating to:

- backflow prevention and cross-connection controls
- correct installation of plumbing and appliances
- permitted uses and use restrictions.

Education and training can assist preventive measures; for example, initiatives relating to best-practice management of irrigation relating to water and nutrient balances, salinity and sodicity control, etc.

Unlike the other barriers listed in Box 2.6, end-use controls do not prevent entry or remove hazards physically; instead, they reduce risk by controlling exposure. For example, high-quality recycled water might be used for residential and commercial property non-drinking use (where the level of human exposure is potentially high), whereas a lower quality recycled water might be restricted to drip irrigation of fruit trees. Although hazards may be present in higher concentrations in the lower quality water, the application of end-use controls ensures that both types of use have a similar level of risk. If water applied through overhead sprinklers was found to be toxic to foliage due to a high level of chloride, then drip irrigation could be used as an end-use restriction to manage this hazard.

End-use restriction relies on user compliance. Experience indicates that monitoring is required to ensure that compliance with restrictions is maintained, and this should be considered when implementing such measures. Regulatory surveillance may also be required to ensure user compliance (see Section 2.11).

Preventive measures should be applied as close as possible to the source of the hazard, and the focus should be on prevention rather than a sole reliance on downstream treatment or control.

Multiple barriers

The multiple-barrier approach, used in the management of drinking water quality, should also be adopted in the management of recycled water schemes. In this approach, multiple preventive measures or barriers are used to manage hazards, meaning that reduced performance of one barrier does not result in total loss of management. Importantly, it may be possible to temporarily increase the performance of the remaining barriers while remedial action is taken to restore function of the faulty barrier. In addition, as a combination, multiple barriers produce less variability in performance than single barriers (NRC 1998). Examples of the multiple-barrier approach are provided in Box 2.7.

Box 2.7 Examples of multiple barriers to microbial pathogens

Sewage

Large-scale treatment plants generally include a number of processes that reduce pathogen numbers, such as primary, secondary and tertiary treatment, disinfection and lagoon storage. In addition, on-site and end-use controls provide barriers against exposure to harmful levels of pathogens. No single process provides a complete barrier to the risk presented by microbial pathogens, but combinations of barriers can be effective. For example, the Virginia Pipeline Scheme described in Appendix 1 incorporates:

- primary treatment
- secondary treatment (activated sludge)
- lagoon detention
- coagulation, dissolved air flotation and filtration
- disinfection
- on-site controls
- user education.

On-site systems

On-site systems, designed to collect recycled water from single domestic dwellings, should include a number of treatment barriers, but have a greater emphasis on use restrictions. Treatment barriers include primary and secondary treatment, followed by disinfection. Use restrictions limit the method of application to drip or subsurface irrigation of ornamental or landscape plants.

Greywater

The quality of greywater depends on inputs. The first barrier is to minimise inputs of faecal material from nappies and other soiled clothing and inputs of automotive products, garden chemicals, solvents, etc. In addition, the nature of detergents, shampoos, soaps and household cleaners will influence quality and these agents should be selected carefully. A greater emphasis is generally placed on use restrictions such as drip or subsurface irrigation, but treatment barriers can include filtration, biological treatment and disinfection.

Stormwater

In contrast to sewage, the concentration of pathogens in stormwater can be influenced by catchment-management programs. Protection of stormwater from human and livestock waste can prevent the entry of human infectious viruses and greatly reduce the presence of human infectious protozoa. This type of early prevention can greatly reduce the need for downstream treatment (eg detention in lagoon or wetland systems).

Assessing residual risk

As explained above, residual risk is the risk that remains in the presence of preventive measures. Once existing preventive measures have been identified, the risk assessment process outlined above can be used to estimate the residual risk, which will indicate whether alternative or additional preventive measures are needed to reduce risks to an acceptable level.

Identify alternative or additional preventive measures

If the assessment of residual risk indicates that existing measures do not reduce risk to an appropriate level, then alternative or additional preventive measures should be identified. The types and range of preventive measures employed will depend on the quality of the source water and the proposed end use. The process of selecting these measures will be informed by the hazard identification and risk assessment outlined above.

Document the preventive measures and strategies, addressing each significant risk

It is important to document the preventive measures and strategies addressing each risk identified as significant. The documentation process is discussed in Element 10, below.

2.3.2 Critical control points

Summary of actions

- Assess preventive measures throughout the recycled water system to identify critical control points.
- Establish mechanisms for operational control.
- Document the critical control points, critical limits and target criteria.

Assess preventive measures and identify critical control points

A critical control point is defined as an activity, procedure or process where control can be applied, and that is essential for preventing hazards that represent high risks or reducing them to acceptable levels. Critical control points are particularly important for assuring water quality in centralised schemes.

Identification of critical control points is system specific, being based on knowledge of potential hazards and associated risks, and preventive measures. Where possible, each identified hazard should have a critical control point. More than one critical control point may be associated with a single hazard, and a single critical control point may prevent or reduce more than one hazard. Critical control points should be selected appropriately, because they will be the focus of operational control. Too many critical control points can make the system unwieldy, whereas too few can fail to provide adequate assurance of recycled water quality.

Critical control points require:

- operational parameters that can be measured, and for which critical limits can be set to define effectiveness (eg chlorine residuals for disinfection)
- operational parameters that can be monitored sufficiently frequently to reveal any failures in a timely manner (eg online and continuous monitoring of key treatment processes) — in some cases ‘timely’ may mean monitoring regularly rather than frequently (eg backflow prevention audits)
- procedures for corrective action that can be implemented in response to deviation from critical limits.

The decision tree shown in Figure 2.2 (below) can be used to identify critical control points.

Establish mechanisms for operational control

Critical limits

For preventive measures identified as critical control points, critical limits (which can be quantitative or qualitative) must also be defined and validated. A critical limit is a prescribed tolerance that distinguishes acceptable from unacceptable performance. When a process that represents a critical control point is operating within critical limits, performance in terms of hazard removal is regarded as being acceptable. However, deviation from a critical limit represents loss of control of a process and indicates that there may be an unacceptable health or environmental risk. Corrective actions should be instituted immediately to resume control of the process, and the health or environmental regulator may need to be notified.

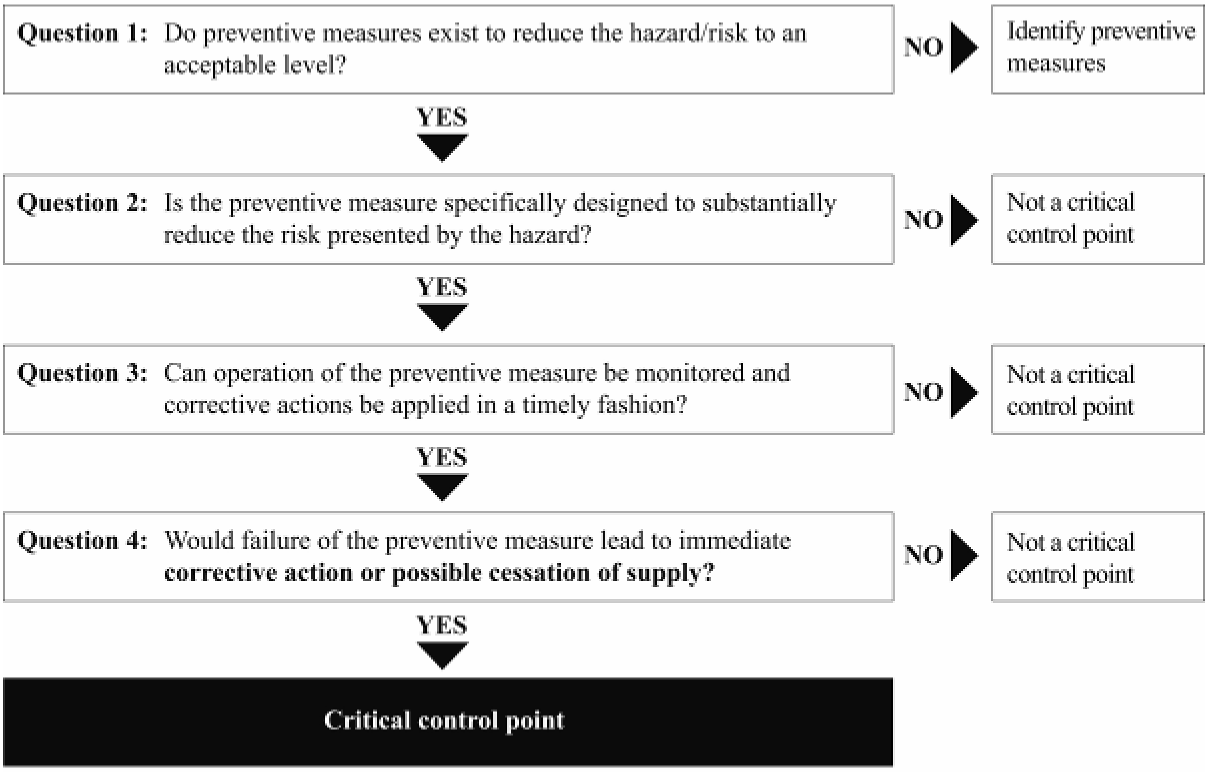
Target criteria

Operators may establish target criteria (performance goals) to provide early warning that a critical limit is being approached. Target criteria should be more stringent than critical limits, so that corrective actions can be instituted before an unacceptable health or environmental risk occurs. For example, where filtration is used, the critical limit might be set at 2 nephelometric turbidity units (NTU) and the target criterion at 1.5 NTU. Similarly, in setting a minimum lagoon detention time to achieve pathogen or nutrient reduction, a critical limit might be 50 days and a target criterion might be 55 days.

Any deviation from established targets should be regarded as a trend towards loss of control of the process, and should result in appropriate actions being taken, as shown in Table 2.8, which summarises examples of possible critical control points and operational criteria. These examples are illustrative and are not intended to be definitive. The identification of critical control points and criteria for individual schemes will depend on a risk assessment and on consideration of specific targets associated with required end uses.

Figure 2.2 Critical control point decision tree

Questions to be asked for each hazard identified in Element 2 as representing a moderate to very high risk and requiring removal or reduced exposure to assure supply of safe recycled water.



Note: Preventive measures should be applied from the point of input of water to sources, to application or receiving environments in accordance with the multiple-barrier approach. Overall, when considered together, these preventive measures should prevent the specific hazard or reduce it to an acceptable level.

Table 2.8 Examples of potential critical control points and operational criteria

		Operational criteria		
Potential critical control point	**Hazard(s)**	**Potential critical limits**	**Monitoring**	**Corrective action**
Filtration of recycled water	Enteric bacteria, viruses, protozoa and helminths	Filtered water turbidity ≤2 NTU 95% of the time; maximum turbidity 5 NTU (target criterion 1.5 NTU)	Continuous online monitoring	Identify problem and take action (eg repair faulty operation, increase coagulant dose, filter backwash, stop supply)
Lagoon detention of recycled water	Enteric bacteria, viruses and protozoa	Minimum detention time 50 days (target criterion 45 days)	Continuous flow monitoring	Identify cause of problem (eg stormwater intakes), decrease filtered water turbidity, increase chlorine dose, stop supply
Lagoon detention of recycled water	Helminths	Minimum detention 25 days (target criterion 30 days)	Continuous flow monitoring	Identify cause of problem (eg stormwater intakes), stop use of treated recycled water for livestock pasture irrigation
Primary disinfection and storage	Enteric bacteria, viruses and *Giardia*	Total chlorine residual >2 mg/L; detention >x minutes (to set minimum Ct)	Continuous online monitoring and alarms with automatic feedback to chlorine dosing; flow not to exceed x mL/h	Disable illegal connection
Cross-connection control and backflow prevention (residential and commercial property use)	Enteric bacteria, viruses, protozoa and helminths, and chemical contaminants	Zero cross-connections and backflow prevention provided at property boundaries	Rolling 6-monthly audits with all houses inspected every 5 years	
Stormwater detention in lagoons	Turbidity	Maximum turbidity limit	Weekly monitoring for turbidity	Increase detention times, stop transfer of stormwater for aquifer, storage and recovery
Desalination	Chloride and sodium phytotoxicity	175 mg/L Cl and 115 mg/L Na for protection of sensitive plant species where recycled water is overhead sprinkler irrigated (eg foliar contact with recycled water)	Continuously measuring electrical conductivity as a surrogate for Cl and Na	Divert recycled water to untreated water and identify cause of exceeding critical limit

NTU = nephelometric turbidity unit; Ct = disinfectant concentration × time
Note: Critical control points must be validated on an individual basis

Document critical control points, critical limits and target criteria

Critical control points, critical limits and target criteria should be documented, as discussed in Element 10, below.

2.4 Operational procedures and process control (Element 4)

Components:	Operational procedures (Section 2.4.1)
	Operational monitoring (Section 2.4.2)
	Operational corrections (Section 2.4.3)
	Equipment capability and maintenance (Section 2.4.4)
	Materials and chemicals (Section 2.4.5)

This section covers the operational procedures and processes that formalise activities essential for ensuring that recycled water of an acceptable quality is consistently provided.

2.4.1 Operational procedures

Summary of actions

- Identify procedures required for all processes and activities applied within the whole recycled water system (source to use).
- Document all procedures and compile into an operations manual.

Identify procedures for processes and activities

Even short periods of sudden change and suboptimal performance in a recycled water supply system can represent a serious risk to public health or the environment. Therefore, it is vital to ensure that all operations are optimised and continuously controlled, and that preventive measures are functional at all times.

Process-control programs detail specific operational factors that ensure all processes and activities are carried out effectively and efficiently. Detailed procedures are required for the operation of all processes and activities (both ongoing and periodic) from sewer or stormwater source and trade-waste customer, through to the user of recycled water. Examples of process-control programs are given in Box 2.8.

Box 2.8 Examples of process-control programs

Examples of process-control programs include:

- descriptions of all preventive measures and their functions
- documentation of effective operational procedures, including identification of responsibilities and authorities
- establishment of a monitoring protocol for operational performance, including selection of operational parameters, such as target criterion and critical limits, and the routine review of data
- establishment of corrective actions to control excursions in operational parameters
- development of requirements for use and maintenance of suitable equipment
- development of requirements for use of approved materials and chemicals in contact with recycled water
- establishment of procedures for restricted end uses
- establishment of procedures for activities undertaken by users of recycled water at application sites (particularly when end use preventive measures are relied on to minimise the risk to acceptable levels).

Effective implementation of process-control programs relies on the skills and training of operations staff and, in some cases, end users. Operators should be proficient, able to interpret the significance of changes in recycled water quality and treatment, and able to respond appropriately in accordance with established procedures (see Section 2.7 — Training and awareness).

Procedures are most effective when operations staff and end users are involved in their development, documentation and verification. Participation helps to ensure that all relevant activities are included, improves operator and end-user training and awareness, and fosters commitment to operational and process control.

Document procedures

Process control programs should be documented in operations manuals, with controlled copies readily accessible to all appropriate personnel. For large or complex systems, one option is to organise manuals into sections dealing with individual components of the recycled water system. Documentation is covered in detail in Section 2.10.

2.4.2 Operational monitoring

Summary of actions

- Develop monitoring protocols for operational performance of the recycled water supply system, including the selection of operational parameters and criteria, and the routine analysis of results.
- Document monitoring protocols into an operational monitoring plan.

Develop monitoring protocols for operational performance

Chapter 5 discusses all types of monitoring, including operational monitoring.

Operational monitoring should assess and confirm the performance of preventive measures through a planned sequence of observations and measurements. Key elements of operational monitoring include:

- development of operational monitoring plans from source to point of use and beyond, detailing strategies and procedures
- identification of the parameters and criteria to be used to measure operational effectiveness and, where necessary, trigger corrective actions
- ongoing review and interpretation of results to confirm operational performance.

Observation and measurement

Observational monitoring could include, for example:

- regular inspections of industrial waste facilities, sewer integrity and plant equipment
- monitoring of application methods, timing of irrigation, access controls and signage.

Because the use of recycled water is often subject to on-site controls and limitations on the range of permitted uses, operational monitoring needs to include observational monitoring or auditing to ensure that these controls and limitations are being maintained. Observational monitoring programs are often part of an environmental improvement plan or customer site-management plan with which the users of the recycled water must comply, and are particularly appropriate for on-site systems.

Measurement of operational parameters is used to indicate whether processes are functioning effectively.

Aim of operational monitoring

The general intent of operational monitoring is different from that of recycled water quality monitoring (see Section 2.5.1 — Recycled water quality monitoring). Operational monitoring is used to confirm that preventive measures implemented to control hazards are functioning properly and effectively. Data from operational monitoring can be used as triggers for immediate short-term corrective actions to protect recycled water quality or to prevent increased risk to human or environmental health.

Selection of operational parameters

Operational parameters should reflect the effectiveness of each process or activity, and provide an immediate indication of performance. Typically, parameters should be readily measured and able to be responded to appropriately. For example, where detention is used to remove pathogens, flow measurement can be used to determine that minimum requirements are being met; similarly, where disinfection processes are used, online measurement of residuals can be used to determine that requirements are being met.

Surrogates are often used as operational parameters in place of direct measurement of hazards. For example, turbidity is used as an indicator of filtration plant performance and can be a surrogate for removal of *Cryptosporidium*, *Giardia* and viruses.

Operational parameters should be monitored with sufficient frequency to reveal, in a timely fashion, any violation of operating targets or critical values. Online and continuous monitoring should be used wherever possible, particularly for treatment processes deemed to be critical control points.

Analyse results

Results must be reviewed frequently to confirm that records are complete and accurate, and to identify any deviations from critical limits or target criteria. Those responsible for interpreting and recording operational results should understand how the results should be assessed.

A system should be established for regular reporting of operational monitoring results to relevant staff, sections and organisations, using methods such as graphs or trend charts to facilitate interpretation.

Document monitoring protocols

Monitoring protocols should be documented, and should form part of an operational monitoring plan, as discussed in Element 10.

2.4.3 Operational corrections

Summary of actions

- Establish and document procedures for corrective action where operational parameters are not met.
- Establish rapid communication systems to deal with unexpected events.

Establish and document procedures for corrective action

Procedures should be developed to re-establish process control immediately in situations where target criteria or critical limits are not met. The procedures should include instructions on required adjustments, process-control changes and additional monitoring. Box 2.9 lists possible corrective actions. Responsibilities and authorities, including communication and notification requirements, should be clearly defined.

It is important to verify whether a corrective action has been effective — a process that usually requires additional monitoring. Other factors that should be considered are secondary impacts of the corrective action, and whether adjustments or action may be needed further along in the supply system.

Where possible, the underlying cause of the problem should be determined and measures implemented to prevent future occurrences. Analysis of the causes may help to identify possible solutions, such as modifying an operating procedure or improving training. Details of all incidents should be recorded and reported.

Box 2.9 Possible corrective actions

Examples of possible corrective actions include:

- identifying sources of chemical contaminants and reinforcing trade waste controls
- altering the plant flow rate (eg reducing loading)
- optimising coagulant control
- altering the mixing intensity
- changing treatment chemicals
- using auxiliary chemicals such as coagulant aids, flocculant aids, filtration aids
- adjusting pH
- varying chemical feed rates and feed points
- adjusting filtration loading rate or operation
- increasing disinfectant dose
- flushing and cleaning of the supply system
- temporarily shutting down the plant and bypassing inadequately treated recycled water
- remediating cross-connection control and further auditing
- reinforcing or modifying on-site controls, including limitations on application methods, rates and scheduling
- repairing irrigation systems, and repairing or replacing signage
- applying soil ameliorants to correct soil chemistry imbalances
- modifying buffer distances
- recalculation of nutrient balances using data obtained from monitoring program
- installation of interception drains or artificial drainage on-site
- changing the plant species or variety grown.

Establish rapid communication systems to deal with unexpected events

Because it is not always possible to anticipate every type of event, rapid communication systems should be established to deal with any unanticipated events. In some recycled water systems, responses must be prepared for times when normal corrective actions cannot re-establish operational performance sufficiently quickly to prevent recycled water of unacceptable quality from reaching users. In potential high-exposure schemes (eg growing of crops eaten raw), preventive measures and multiple barriers adopted to manage this risk should make this event ‘very’ rare.

2.4.4 Equipment capability and maintenance

Summary of actions

- Ensure that equipment performs adequately and provides sufficient flexibility and process control.
- Establish a program for regular inspection and maintenance of all equipment, including monitoring equipment.

Ensure that equipment is adequate and suitable

Equipment and infrastructure in a recycled water supply system need to be adequately designed and of sufficient capacity (in terms of size, volume and detention times) to handle all flow rates (peak and otherwise), without limiting performance. Hydraulic overload of processes may compromise performance. Variations will typically be greater in small systems, including on-site recycled water treatment systems. Rapid changes in hydraulic loading (such as those expected in stormwater systems) must be considered in the design phase.

Design features that can improve performance and process control include:

- online measuring devices that monitor operational parameters continuously
- automated responses to changes in water quality
- 24-hour monitored alarm systems that indicate operational failure
- backup equipment, including power generators
- variable control of flow rates and chemical dosing
- effective mixing facilities.

Design of new equipment and processes should be validated through appropriate research and development (see Section 2.9.2 — Design of equipment). Equipment used to monitor process performance should be selected carefully. Monitoring equipment needs to be sufficiently accurate and sensitive to perform at the levels required. Where possible, monitoring of key treatment processes (eg filtration and disinfection) should be online and continuous, with alarm systems to indicate when operational target criteria have been exceeded. Monitoring failures should not compromise the system and, in some cases, particularly at critical control points, backup equipment should be installed.

Establish a program for inspecting and maintaining equipment

Operators also need to understand the operation of monitoring equipment, so that causes of spurious results can be recognised and rectified. Regular inspection and maintenance of all equipment, from source to point of use, ensures continuing process capability. A maintenance program should be established and documented; the program should detail:

- operational procedures and records for the maintenance of equipment, including the calibration of monitoring equipment
- schedules and timelines
- responsibilities
- resource requirements.

2.4.5 Materials and chemicals

Summary of actions

- Ensure that only approved materials and chemicals are used.
- Establish documented procedures for evaluating chemicals, materials and suppliers.

Ensure only approved materials and chemicals are used

Materials and chemicals used in recycled water systems have the potential to adversely affect recycled water quality or the environment to which they are applied. Chemicals added to recycled water include disinfectants, oxidants, coagulants, flocculants, antioxidants and chemicals for softening, pH adjustment and scale prevention. Chemicals and products added to the soil environment include inorganic and organic fertilisers, manures, gypsum, lime and other soil conditioners.

All chemicals should be evaluated for potential contamination, chemical and physical properties, maximum dosages, behaviour in water, migration and concentration build-up. In addition, the potential impact of such chemicals on materials used in treatment plants or on the environment should be considered. For example, ferric chloride, which is used as a coagulant, can severely corrode commonly used grades of stainless steel, and calcium nitrate amendments, used as a conditioner, can add excessive nitrate to the soil. Chemicals used in treatment processes must be securely stored to avoid spills or leakage.

Establish documented procedures for evaluating products, materials and chemicals

Chemical suppliers should be evaluated and selected on their ability to supply product in accordance with required specifications. Documented procedures for the control of chemicals, including purchasing, verification, handling, storage and maintenance should be established to assure their quality at the point of application. Responsibilities for testing and quality assurance of chemicals (supplier, purchaser or both) should be clearly defined in purchase contracts.

Contaminants may be introduced when recycled water comes into contact with materials such as filter media, protective coatings, linings and liners, jointing and sealing products, pipes and fittings, valves, meters and other components. Products and materials used in recycled water infrastructure and plumbing systems should be authorised or approved to ensure compliance with:

- Australian and New Zealand Standard AS/NZS 3500 (*Plumbing and Drainage*) (Standards Australia/Standards New Zealand 2003)
- AS/NZS 4020 (*Testing of Products for Use in Contact with Drinking Water*) (Standards Australia/Standards New Zealand 2005)
- WSAA *Sewerage Code Version 2.1* (WSAA 2002a)
- WSAA *Water Supply Code* (*Dual Water Supply Supplement Version 1.1*) (WSAA 2002b).

2.5 Verification of recycled water quality and environmental performance (Element 5)

Components:	Recycled water quality monitoring (Section 2.5.1)
	Application site and receiving environment monitoring (Section 2.5.2)
	Documentation and reliability (Section 2.5.3)
	Satisfaction of users of recycled water (Section 2.5.4)
	Short-term evaluation of results (Section 2.5.5)
	Corrective responses (Section 2.5.6)

This section discusses verification of recycled water and environmental performance. Verification of recycled water quality assesses the overall performance of the treatment system, the ultimate quality of recycled water being supplied or discharged, and the quality of the receiving environment. It provides:

- confidence for all stakeholders of recycled water, including users and regulators, in the quality of the water supplied and the functionality of the system as a whole
- confidence that environmental targets are being achieved
- an indication of problems and a trigger for any immediate short-term corrective actions, or incident and emergency responses.

Verification monitoring is often combined with a degree of validation (see Section 2.9 — Validation, research and development) during the initial operation of recycled water schemes. At this stage, verification assesses whether a scheme *is* performing and validation assesses whether a scheme *will* perform. Verification monitoring is conducted more frequently during the first weeks and months of operation to demonstrate that water quality and receiving environment targets are being achieved, and to provide confidence that the target criteria for water quality will be reliably achieved in the future. For many environmental target criteria, the ultimate verification of a sustainable system may require years of annual monitoring data.

Verification should be regarded as the final overall check that preventive measures are working effectively and that the target criteria or critical limits set from relevant guidelines are appropriate. As such, the purpose of verification is different from that of operational monitoring, and the two types of monitoring also differ in what, where and how often water quality characteristics are measured.

Chapter 5 discusses all types of monitoring, including operational monitoring.

2.5.1 Recycled water quality monitoring

Summary of actions
• Determine the characteristics to be monitored.
• Determine the points at which monitoring will be undertaken.
• Determine the frequency of monitoring.

Determine characteristics to be monitored

As it is neither physically nor economically feasible to test for all parameters equally, monitoring effort and resources should be carefully planned, and directed at key characteristics and hazards identified for the recycled water system.

Key characteristics that should be considered for verification include:

- microbial indicator organisms
- salinity, sodicity, sodium, chloride, boron, chlorine disinfection residuals, nitrogen and phosphorus
- any health or environment-related characteristic that can be reasonably expected to exceed relevant guideline values, even if occasionally
- any characteristic of relevance to end use or discharge of the recycled water, which can be reasonably expected to exceed the guideline value, even if occasionally.

Determine points at which monitoring will be undertaken

Verification includes regular sampling and testing to assess whether recycled water quality and receiving environments (eg soil, groundwater, surface water) are meeting guideline values, regulatory requirements or agreed levels of service. Assessment of public health requirements is generally undertaken at the point of entry to distribution systems. However, in the case of recycled water supplied for domestic non-drinking uses, some monitoring at point of supply to consumers may be required, particularly for indicators of microbiological quality.

Determine frequency of monitoring

Frequency of testing for individual characteristics will depend on variability. Sampling should be sufficiently frequent to obtain meaningful information and statistical validity. From a public health perspective, sampling and analysis are required most frequently for microbial constituents, and less often for organic and inorganic compounds. Exposure to microbial pathogens can lead to immediate illness, whereas episodes of chemical contamination leading to acute health concerns are rare, except in the case of a specific event, such as chemical overdosing at a treatment plant. Guideline values for most health chemical parameters are based on impacts of chronic exposure.

From an environmental perspective, the focus is on chemical rather than microbial testing. This is because chemical properties of recycled water are a much great risk than pathogens and because human-health requirements far exceed environmental requirements in relation to pathogens. Some environmental risks are immediate. In these cases, there are usually established target criteria or critical limit values for common species (plants, terrestrial or aquatic biota), particularly if they have agronomic importance, and sampling can be less frequent. However, if species do not have known target criteria or critical limit values, more frequent sampling is required. Many environmental impacts from chemical hazards are based on chronic exposure. To reflect this, sample frequency is often monthly or yearly, rather than continuously or daily. Sampling frequency will also depend on the level of risk and confidence in preventive measures in place (see Section 5.4)

Routine verification monitoring is a general requirement for centralised systems, but is less common for on-site systems. Monitoring of on-site systems tends to be focused on observational monitoring (ie that irrigation systems are operational and that surface pooling is not occurring) supported by surveillance undertaken by regulatory agencies.

2.5.2 Application site and receiving environment monitoring

Summary of actions

- Determine the characteristics to be monitored and the points at which monitoring will be undertaken.

Determine characteristics to be monitored and monitoring points

Recycled water is commonly applied to the land, so there is potential for inadvertent (and sometimes intentional) discharge to groundwaters and surface waters. The range of monitoring parameters selected will depend on the impacts, prevention measures and the related target criteria or critical limits determined when assessing the impacts of specific hazards with specific environmental endpoints (eg see Section 4.2.1). Areas requiring monitoring could include:

- soil chemistry and physical properties (eg salinisation, dispersion, structural stability)
- plants, terrestrial and aquatic biota
- groundwater and surface water quality and quantity (levels)
- infrastructure
- air.

Environmental monitoring can include testing for macroinvertebrates and examination of vegetation characteristics, as well as analyses for physical and chemical parameters.

All sites that could be affected by the use or discharge of recycled water may need to be monitored. Regular verification monitoring can, in some cases, be as simple as visual assessment (eg for yellowing or browning of leaves, or ponding), with follow-up action if there are concerns. Such visual inspection may be a very important part of verification for small scale or on-site systems.

2.5.3 Documentation and reliability

Summary of actions

- Establish and document a sampling plan for each characteristic, including the location and frequency of sampling, ensuring that monitoring data is representative and reliable.

Establish a sampling plan and ensure monitoring is reliable

Once parameters and sampling locations have been identified, these should be documented in a consolidated monitoring plan. Monitoring data should be representative, reliable and fully validated (see Box 2.10). Procedures for sampling and testing should also be documented.

Box 2.10 Reliability of data

Monitoring is only as good as the data collected, so every effort should be made to ensure that the data are representative, reliable and fully validated. Important considerations are listed below.

For a *sampling plan*, consider:

- parameters measured, sampling locations, sampling frequency
- qualifications and training of personnel
- approved sampling methods and techniques
- quality assurance and validation procedures for sampling
- assessment of data (eg requirements associated with assessing compliance with means, medians or 95th percentiles)

For *analytical testing*, consider:

- qualifications and training of personnel
- suitability of equipment
- approved test methods and laboratories
- sensitivity of testing and properties measured (eg whether microbial methods measure viability or infectivity)
- quality assurance and validation procedures (eg positive and negative control samples, interlaboratory comparisons)
- accreditation with an external agency such as the National Association of Testing Authorities.

For *monitoring equipment,* consider:

- calibration and inspection procedures to ensure control of monitoring equipment.

2.5.4 Satisfaction of users of recycled water

Summary of actions

- Establish an inquiry and and response program for users of recycled water, including appropriate training of people responsible for the program.

Establish a user complaint and response program

Comments and complaints from users of recycled water can provide valuable information on problems that may not have been identified by performance monitoring of the water supply system. Complaints are more likely to be received from schemes involving close public contact, such as domestic non-drinking water systems. User satisfaction with recycled water may be based on perceptions of water quality and aesthetic issues, rather than evidence of noncompliance with guideline values.

A complaint and response program should be established, operated by appropriately trained personnel. Dissatisfaction with recycled water schemes, if not dealt with appropriately, may lead to negative perceptions that have a potential to escalate. User satisfaction is a major component of the success of recycled water schemes. In the long term, complaints and responses should be evaluated according to type, pattern and change in the number of complaints received.

2.5.5 Short-term evaluation of results

Summary of actions

- Establish procedures for the short-term review of monitoring data and satisfaction of users of recycled water.
- Develop reporting mechanisms internally and externally, where required.

Establish procedures for short-term review

Short-term performance evaluation involves reviewing monitoring data and satisfaction of users of recycled water to verify that:

- the quality of water supplied to application or receiving environments conforms to established targets and meets user expectations
- the quality of receiving environments complies with approval conditions.

In cases of nonconformance, immediate corrective actions or incident and emergency responses should be implemented.

Those responsible for interpreting and recording results should understand clearly how to assess results and, where necessary, communicate them. Results should be reviewed within appropriate timeframes, and should be compared with previous results, established guideline values, and any regulatory requirements or agreed levels of service. Procedures for performance evaluation and recording of results should be established and documented.

Develop reporting mechanisms

Mechanisms and responsibilities should be identified for the reporting of results, both internally (to operators and managers) and externally, where required (to stakeholders such as regulators and users of recycled water). More detail on reporting is given in Section 2.10 — Reporting.

2.5.6 Corrective responses

Summary of actions
• Establish and document procedures for corrective responses to nonconformance or feedback from users of recycled water. • Establish rapid communication systems to deal with unexpected events.

Establish procedures for corrective responses

Where the short-term evaluation of results indicates nonconformance, an investigation should be initiated. The performance of control measures and associated operational monitoring should be reviewed and, if necessary, corrective responses should be implemented as quickly as possible. Failure to take immediate or effective action may lead to situations requiring activation of incident and emergency response protocols. Corrective responses may also be required following reports from users of recycled water.

Corrective actions should be developed in consultation with relevant regulatory authorities and other stakeholders. Examples of corrective actions are given in Section 2.4, above.

Establish rapid communication systems to deal with unexpected events

It is important to respond immediately to significant system failures that could pose a risk to public health or the environment, or adversely affect water quality for an extended period. Such failures should also be immediately reported to the relevant health or environment authority (see Section 2.6 — Management of incidents and emergencies). Corrective responses should be documented, responsibilities and authorities should be clearly defined, and staff should be trained in appropriate procedures.

2.6 Management of incidents and emergencies (Element 6)

Components:	Communication (Section 2.6.1)
	Incident and emergency response protocols (Section 2.6.2)

This section discusses management of incidents and emergencies. Considered and controlled responses to incidents or emergencies that can compromise recycled water quality are essential. Such responses protect public and environmental health; they also help to maintain user confidence in recycled water and the supplier’s reputation. Some events cannot be anticipated or controlled, or are so unlikely to occur that providing preventive measures would be too costly. For such incidents, there must be an adaptive capability to respond constructively and efficiently.

Some of the potential hazards and events that can lead to emergency situations are listed in Box 2.11.

Box 2.11 Hazards and events that may lead to emergency situations

Potential hazards and events that can lead to emergency situations include:

- nonconformance with critical limits, guideline values and other requirements
- accidents that increase levels of contaminants or cause failure of treatment systems (eg spills in catchments, illegal discharges into collection systems, incorrect dosage of chemicals)
- equipment breakdown and mechanical failure
- illegal and accidental cross-connections
- prolonged power outages
- extreme weather events (eg flash flooding, cyclones)
- natural disasters (eg fire, earthquakes, lightning damage to electrical equipment)
- human actions (eg serious error, sabotage, strikes)
- outbreaks of illness leading to increased pathogen challenges on treatment systems
- cyanobacterial blooms in storages or waterways
- kills of fish or other aquatic life
- crops destroyed by irrigation with recycled water.

2.6.1 Communication

Summary of actions

- Define communication protocols with the involvement of relevant agencies and prepare a contact list of key people, agencies and stakeholders.
- Develop a public and media communications strategy.

Define communication protocols with the involvement of relevant agencies

Effective communication is vital in managing incidents and emergencies. Clearly defined protocols for both internal and external communications should be established with the involvement of relevant agencies including health, environment and other regulatory agencies. These protocols should include a contact list of key people, agencies and businesses, detailed notification forms, procedures for internal and external notification, and definitions of responsibilities and authorities. Contact lists should be updated regularly (eg six-monthly) to ensure they are accurate.

Develop a public and media communications strategy

User confidence and trust during and after an incident or emergency are essential, and are largely affected by how incidents and emergencies are handled. A public and media communication strategy should be developed before any incident or emergency situation occurs. Draft public and media notifications should be prepared in advance of any incident, and should be designed for the target audience. An appropriately trained and authoritative contact should be designated to handle all communications in the event of an incident or emergency. All employees should be kept informed during any incident for their own needs and because they provide informal points of contact for the community.

Users of recycled water should be told when an incident has ended, and should be provided with information on the cause and actions taken to minimise future occurrences. This type of communication helps to allay community concerns and restore confidence in the water supply. Post-incident surveys of the community are valuable to establish the perceptions of users of recycled water relating to events and how they were managed.

Further information on communication and consultation is given in Chapter 6.

2.6.2 Incident and emergency response protocols

Summary of actions

- Define potential incidents and emergencies and document procedures and response plans with the involvement of relevant agencies.
- Train employees and regularly test emergency response plans.
- Investigate any incidents or emergencies and revise protocols as necessary.

Define potential incidents and emergencies, and document procedures and response plans

Incident and emergency response protocols should be a priority. Potential incidents and emergencies should be defined, and response plans developed and documented in advance of any incident. Plans and procedures should be developed in consultation with relevant regulatory authorities and other key agencies, and should be consistent with existing government emergency response arrangements. In an emergency situation, there will not be time to establish confidence and goodwill; therefore, to be effective, plans and procedures must be established during normal operation, with parties who will be partners in responding to an emergency.

Key areas to be addressed in incident and emergency response plans include clearly specified:

- response actions, including increased monitoring
- responsibilities and authorities internal and external to the organisation
- predetermined agreements on lead agencies for decisions on potential health or environmental impacts
- plans for alternative water supplies
- communication protocols and strategies, including notification procedures (internal, regulatory body, media and public)
- mechanisms for increased health or environmental surveillance.

Train employees

Employees should be trained in emergency response and incident protocols. Emergency response plans should be regularly reviewed and practised. Such activities improve preparedness and provide opportunities to improve the effectiveness of plans before an emergency occurs.

Investigate incidents and emergencies, and revise protocols

Following any incident or emergency situation, an investigation should be undertaken and all involved staff should be debriefed, to discuss performance and address any issues or concerns. The investigation should consider factors such as:

- What was the initiating cause of the problem?
- How was the problem first identified or recognised?
- What were the most critical actions required?
- What communication problems arose and how were they addressed?
- What were the immediate and longer term consequences?
- How well did the protocol function?

Appropriate documentation and reporting of the incident or emergency should also be established. The organisation should learn as much as possible from the incident to improve preparedness and planning for future incidents. Review of the incident may show how existing protocols need to be modified. Box 2.12 provides a summary of an emergency response protocol.

Box 2.12 Recycled water incident communication and notification protocol

In South Australia, a protocol has been established between:

- the Department of Health
- the South Australian Water Corporation (SA Water)
- the Environment Protection Authority (EPA)
- the Department of Water, Land and Biodiversity Conservation.

The aim of the protocol is to ensure effective communication between government agencies in the event of incidents associated with recycled water. The protocol includes notification of users of recycled water and other relevant bodies, such as catchment water management boards and local authorities.

Incidents are classified as one of the following:

- *Type 1* — potentially serious, with either human health or environmental risks
- *Type 2* — lesser incidents representing a low risk to human health, or possible low impact and localised environmental harm.

The protocol includes agreed criteria relating to treatment of recycled water. For example, depending on the scheme, the criteria include high turbidity in filtered water, chlorinator failure, detection of *Cryptosporidium* or high numbers of *Escherichia coli*, and detection of high concentrations of health-related chemicals or pesticides.

The protocol defines the role of a water incident coordinator placed in the Department of Health, and specifies the appropriate minister and agency that will take the lead in dealing with incidents and communicating them (ie incidents with health concerns will be led by the Department of Health, those with environmental concerns by the EPA, and those with operational and supply concerns by SA Water).

The protocol also defines reporting requirements for individual agencies, as well as communication requirements and protocols for the agencies, the water incident coordinator, offices of the ministers and the lead minister.

Box 2.12 (continued)

The testing agency is required to report all Type 1 incidents immediately to the water incident coordinator, and provide written confirmation within 24 hours by email or fax. The water incident coordinator ensures that all appropriate agencies have been notified, and that relevant ministers are notified by their agencies as soon as possible and in any event within 24 hours.

Type 2 incidents are normally only notified to relevant agencies and generally do not require ministerial advice.

The protocol includes a list of 24-hour contacts for all agencies. Copies of the protocol are provided to all emergency contacts and relevant officers. The protocol is updated and reissued every 9–12 months.

2.7 Operator, contractor and end user awareness and training (Element 7)

Components:	Operator, contractor and end user awareness and involvement (Section 2.7.1) Operator, contractor and end user training (Section 2.7.2)

This section discusses awareness and training for operators, contractors and end users of recycled water systems. This area is important, because the knowledge, skills, motivation and commitment of operators, contractors and end users ultimately determine:

- a recycled water supplier's ability to successfully operate a water supply system and maintain the exclusion barriers used for preventive measures
- the effectiveness of end-use restriction barriers used as preventive measures.

2.7.1 Operator, contractor and end user awareness and involvement

Summary of actions

- Develop mechanisms and communication procedures to increase operator, contractor and end user awareness of, and participation in, recycled water quality management and environmental protection.

Develop mechanisms and procedures to increase awareness and participation

Operators, contractors and end users need to be aware of the potential consequences of system failure, and of how decisions can affect public and environmental health.

Operators and contractors

In the case of water treatment and reticulation, an understanding of recycled water quality management is essential for empowering and motivating operators and associated contractors to make effective decisions. They should all be aware of:

- the organisation's recycled water quality policy
- the principles of risk management

- characteristics of the recycled water supply system and preventive strategies in place throughout the system
- regulatory and legislative requirements
- roles and responsibilities of employees and departments
- how their actions can affect water quality, and public and environmental health.

Methods to increase employee awareness can include employee education and induction programs, newsletters, guidelines, manuals, notice boards, seminars, briefings and meetings.

Operator and contractor participation and involvement in decision making is an important part of establishing the commitment needed to continually improve recycled water quality management. Operators should be encouraged to participate in decisions that affect their areas of responsibility. This provides a sense of ownership for decisions and their implications. Open and positive communication is a foundation for a participatory culture, and operators should be encouraged to discuss issues and actions with management.

End users

End users should be made aware of the importance of end use restriction barriers. As a minimum, all end users should be aware of:

- restrictions on use of recycled water
- management requirements that are essential to ensure the sustainable use of recycled water
- any practice that will threaten human or environmental health.

2.7.2 Operator, contractor and end user training

Summary of actions

- Ensure that operators, contractors and end users maintain the appropriate experience and qualifications.
- Identify training needs and ensure resources are available to support training programs.
- Document training and maintain records of all training sessions.

Ensure operators, contractors and end users maintain appropriate experience and qualifications

All personnel involved in the operation of a recycled water system need to have the appropriate skills and training to undertake their responsibilities. Operators and contractors must be appropriately skilled and trained in the management and operation of recycled water supply systems, because their actions can have a major impact on water quality, and on public and environmental health (see Box 2.6). This situation also applies to many end users where end-user restrictions apply.

Operators, contractors and end users should have a sound knowledge base from which to make effective operational decisions. This requires training in the methods and skills required to perform their tasks efficiently and competently, as well as knowledge and understanding of the impact their activities can have on water quality. For example, treatment plant operators should understand water treatment concepts, and be able to apply these concepts and adjust processes appropriately to respond to variations in water quality. Farmers should understand soils and requirements for fertilisers and soil conditioners. In the case of water treatment and reticulation, the level of skills and training should be consistent with that required for operators of drinking water systems. For end users, the training must be appropriate to ensure compliance with end-use controls and best-management practice for the agricultural industry or residential and commercial property water use. It is important to ensure that end users understand why restrictions and management requirements are necessary, and the implications to human health and the environment of not complying with them.

Identify training needs and resources

Training needs should be identified, and adequate resources made available to support appropriate programs. Examples of relevant areas to address are:

- general areas such as
  - general water quality
  - water microbiology and water chemistry
  - soil and groundwater chemistry
- specific training to optimise recycled water system performance, such as principles of
  - recycled water treatment, including primary, secondary and tertiary treatment
  - stormwater collection and treatment
  - trade-waste control
  - irrigation management (for agricultural, municipal and urban uses)
  - hydraulic, nutrient and contaminant balances at sites of use or discharge
  - application of plumbing codes relating to recycled water and dual water supply systems
  - on-site treatment of sewage and greywater
  - operation of filtration plants
  - disinfection system operation
  - distribution management
  - sampling, monitoring and analysis of recycled water, soils, groundwater and surface water
  - interpretation and recording of results
  - maintenance of equipment.

Specific areas of training for end users might include:

- appropriate use of recycled water
- storage of recycled water
- algae control and identification
- environmental risks
- nutrient and fertiliser management
- managing salinity and sodicity
- irrigation scheduling and performance
- drainage and runoff controls

- signage and pipe identification
- good practice, health and safety
- incidents
- monitoring and reporting
- new end users (capturing the change in ownership of properties and licences for recycled water use).

Operators, contractors and end users should also be trained in other aspects of recycled water quality management, including incident and emergency response, documentation, record keeping and reporting. Box 2.13 highlights some of the issues to be taken into account when using contractors.

Commonly used training techniques and methods include formal training courses accredited by a national training body, in-house training, on-the-job experience, mentor programs, workshops, demonstrations, seminars, courses and conferences. Training programs should encourage operators, contractors and end users to communicate and think critically about the operational aspects of their work. Methods to achieve awareness and understanding among end users include brochures, meetings, manuals, newsletters, induction programs, practical training sessions and demonstrations.

Document training

Training should be documented, and records of all operators, contractors and end users who have participated in training should be maintained. Mechanisms for evaluating the effectiveness of training should also be established and documented. Training is an ongoing process, and requirements should be reviewed regularly to ensure that operators, contractors and end users maintain appropriate experience and qualifications. Where activities have a significant impact on recycled water quality, periodic verification of the capability of operations staff and end users is necessary.

Where possible, accredited training programs and certification of operators should be used.

Box 2.13 Contractors

Given the considerable restructuring of the water industry in recent years, there is now a heavy reliance on contractors to undertake work for recycled water suppliers. In some cases, more than one contractor might be involved in a scheme. For example, separate contractors might be involved in construction, operation of treatment processes, operation of distribution systems, and sampling and analytical work.

Contractors need to have the same level of awareness, training and skills as the organisation’s employees in relation to the tasks being performed. Requirements for contractor acceptability should be established, and contractors should be evaluated and selected on the basis of their ability to meet the specified requirements.

A recycled water supplier should ensure that contractors are qualified and have undergone appropriate training related directly to their task or role. When contracting labour, the organisation should ensure that contractors are educated and trained as necessary on the requirements for adherence to the organisation’s policy and protocols.

Conditions under which the contractor operates should be clear, accurate and achievable, with scope for ongoing review and improvement. Partnerships will be more successful where the recycled water supplier retains sufficient knowledge and technical expertise to manage the contract efficiently.

2.8 Community involvement and awareness (Element 8)

Components:	Consultation with users of recycled water and the community (Section 2.8.1) Communication and education (Section 2.8.2)

Consultation with users of recycled water, stakeholders (eg buyers of irrigated produce) and the general community is an essential component of the development of recycled water schemes, and needs to be started as early as possible. Public and stakeholder concerns can be very powerful, and can mean the difference between acceptance and rejection of recycled water schemes. Any issues raised during the consultation process must be addressed.

Chapter 6 covers communication and consultation in detail.

2.8.1 Consultation with users of recycled water and the community

Summary of actions

- Assess requirements for effective involvement of users of recycled water and the community.
- Develop a comprehensive strategy for consultation.

Assess requirements for effective involvement of users of recycled water and the community

Decisions on recycled water quality and uses made by water suppliers (and relevant regulatory authorities) must be aligned with the needs and expectations of users, stakeholders and the community as a whole. Therefore, all stakeholders should be consulted and involved in decision-making processes. Pre-existing community attitudes will influence the degree of acceptance of recycled water schemes. As attitudes are likely to vary from one area to another, acceptance of a scheme in one area will not guarantee acceptance of a similar scheme in another area.

Stakeholder discussions should include the establishment of levels of service and performance, costs, on-site controls, restrictions, safeguards and quality assurance. Users of recycled water should also be consulted on monitoring requirements and mechanisms for reporting system performance.

Develop a comprehensive strategy for consultation

Involving stakeholders in an effective way can be a complex task, depending on the issues and the community involved. For example, the needs and expectations of the general community may differ from those of the person using the recycled water. Chapter 6 explains the issues that need to be taken into account when developing community consultation strategies.

Records of all community consultation should be kept.

2.8.2 Communication and education

Summary of actions

- Develop an active two-way communication program to inform users of recycled water and promote awareness of recycled water quality issues.
- Provide information on the impacts of unauthorised use.
- Provide information on the benefits of recycled water use.

Develop a two-way communication program

Effective communication to increase community awareness and knowledge of recycled water quality issues, and the various areas of responsibility, is essential (see example in Box 2.14). Communication can help users of recycled water to understand and contribute to decisions about services provided by a supplier of recycled water, and the agreed quality and uses of recycled water. A thorough understanding of the diversity of views held by individuals in the community is necessary to satisfy community expectations.

A community is not a single, uniform entity, but contains groups with different needs. For example, children may be associated with higher levels of risk from recycled water and may warrant targeted education. In addition, children can be extremely effective in reinforcing and modifying behaviour in individual households, and in improving compliance and changing behaviour within the community. The Rouse Hill scheme (described in Box 2.3, above) included specific education programs for children.

Where recycling is from on-site systems, communication should include education about protecting the systems from inappropriate discharges, such as household and garden chemicals.

Box 2.14 Communications and responsibilities — Tatura Recycled Water Reuse Scheme

The Tatura Wastewater Management Facility in the Goulburn Valley in Victoria receives sewage from the town's residents and industrial waste from Tatura Milk Industries, Tatura Abattoirs and Unilever. The organic load reaching the plant is equivalent to waste from 200 000 people. The acceptance of waste from these industries is controlled by individual trade-waste agreements and is subject to online monitoring.

The anaerobic treatment process is resilient to fluctuations in load and provides a consistent quality to the final treatment stage. The treatment system is managed by Goulburn Valley Water, which has partnered with six local dairy farmers to reuse all recycled water on the farmers' land and that of Goulburn Valley Water. The utility has signed agreements with each farmer, and has signed an agreed management plan with the farmers and Tatura Milk Industries. Farmers are responsible for monitoring application rates and salinity levels, limiting recycled water to intended uses and monitoring pasture production, cow health and milk production.

Goulburn Valley Water is responsible for monitoring the treatment process, effluent quality, soils and groundwaters, and for liaising with the industries in the town. Staff from Goulburn Valley Water also audit the farmers' practices annually. A separate, independent audit is also conducted annually under the Goulburn Valley Water Environmental Management System. Annual workshops are held to discuss issues with partner farmers and industries.

Provide information on the impacts of unauthorised use

User education is an essential component of programs to limit inadvertent or unauthorised uses of recycled water. Users need to be informed of the potential public health and environmental impacts associated with unauthorised use. The education program needs to be maintained through the life of the recycled water scheme and needs to deal with change of ownership.

Management of communication is particularly important in the event of an incident or emergency (see Section 2.6 — Management of incidents and emergencies).

Chapter 6 outlines the elements that should be included in a coordinated information program for users of recycled water; it also discusses methods for disseminating information.

Provide information on benefits of recycled water use

Providing information on the benefits of recycled water use can be important in gaining community acceptance of a project. Again, this area is covered in detail in Chapter 6.

2.9 Validation, research and development (Element 9)

Components:	Validation of processes (Section 2.9.1)
	Design of equipment (Section 2.9.2)
	Investigative studies and research monitoring (Section 2.9.3)

This element covers validation monitoring, research and development. It is important that corporations, regulators and resource managers are committed to research and development activities on recycled water quality issues, including investigation of innovative processes and solutions, and validation of outcomes. Possible areas for applied research and development are listed in Box 2.15.

Box 2.15 Possible areas for applied research and development

Applied research and development could focus on areas such as:

- increasing understanding of sources and potential hazards
- investigating improvements, new processes, emerging water quality issues and new analytical methods
- validation of operational effectiveness of new products and processes
- increasing understanding of the relationship between public health and environmental outcomes and recycled water quality
- assessing quality of products grown using recycled water, in comparison with similar products grown using alternative sources of water
- improving measurements of potential exposures to recycled water (eg through aerosols, consumption of irrigated crops and irrigation of household gardens)
- improving assessments of potential impacts of recycled water on soils and other receiving environments

Box 2.15 (continued)

- assessing epidemiological effects of recycled water schemes
- community attitudes, behaviours and effectiveness of education programs on recycled water.

Local research on site-specific characteristics

Local research increases site-specific understanding of water supply systems. Such research could include:

- detailed analysis of temporal and spatial variations in source water quality parameters, and their relationship to soil and groundwater changes at receiving sites
- growth and quality characteristics of crops irrigated with recycled and non-recycled water
- mechanisms to improve and optimise plant performance, and evaluate treatment processes (including the validation of critical limits and target criteria) and the design of new equipment.

These activities should be carried out under controlled conditions by qualified staff, and all protocols and results should be documented.

Collaborations for a broader understanding of recycled water issues

Partnerships and industry-wide cooperation in research and development can be a cost-effective way to address broader issues associated with recycled water quality and treatment, including the development and evaluation of new technologies. Opportunities for such collaboration should be identified with partnership organisations, including health, environment and natural resource management agencies, industry associations, other recycled water suppliers, university departments, cooperative research centres and community groups.

2.9.1 Validation of processes

Summary of actions

- Validate processes and procedures to ensure they control hazards effectively.
- Revalidate processes when variations in conditions occur.

Validate processes and procedures to ensure they control hazards effectively

Validation involves evaluating available scientific and technical information (including historical data and operational experience) and, where necessary, undertaking investigations to validate system-specific operational procedures, critical limits and target criteria. The aim of process validation is to ensure effective operation and control of the recycled water system. Validation is particularly important for innovative hazard-control processes and for schemes involving relatively high exposures (eg residential use). In these cases, validation may be divided into stages, starting with evaluation of existing information, followed by pilot trials and precommissioning testing of full-scale plants. Pilot trials and precommissioning normally incorporate water quality monitoring. In some cases, validation may include evaluation of specific end-use restrictions for human health or environmental protection. Seasonal variations should be considered in designing validation programs.

As discussed in Section 2.5, validation monitoring can also be combined with verification monitoring in initial periods of post-commissioning testing of new recycled water schemes.

Revalidation of processes

Processes should be revalidated when variations occur that may affect performance of processes (eg impacts of changes to primary or secondary treatment processes on downstream filtration or disinfection). Any new processes should be tested using bench-top, pilot-scale or full-scale experimental studies to confirm that the required results are produced under conditions specific to the individual water supply system.

2.9.2 Design of equipment

Summary of actions

- Validate the design of new equipment and infrastructure to ensure continuing reliability.

Validate design of new equipment and infrastructure

Research and development should be undertaken when designing new equipment and infrastructure, or when implementing design changes to improve plant performance and control systems. New technologies require pilot-scale research and evaluation before full-scale implementation. Design specifications should be established to ensure that new equipment is able to meet the intended requirements and provide necessary process flexibility and controllability.

Other considerations for ensuring the reliability of water treatment systems include designing equipment and facilities to withstand natural disasters (eg earthquakes and flooding), and providing backup systems for emergency use (eg alternative power generation). Appropriate consideration of these factors during the design phase will reduce the risk that equipment failures will cause major disruptions in service, or pose risks to the health of humans or the environment.

2.9.3 Investigation of studies and research monitoring

Summary of actions

- Establish programs to increase understanding of the recycled water supply system, and use this information to improve management of the recycled water supply system.

Establish programs to increase understanding, and use this information to improve management

Investigative studies and research monitoring include strategic programs designed to increase understanding of a water supply system, to identify and characterise potential hazards, and to fill gaps in knowledge. For example, the quality of greywater and stormwater can vary over a wide range, so improved understanding of factors that affect water quality can lead to a better understanding of control measures required to improve management of recycled water systems.

In the case of stormwater, improved understanding could enable operators and suppliers to anticipate periods of poor source water quality and develop responses. Other examples include:

- baseline monitoring of parameters or contaminants, or testing of potential new water sources to identify water quality problems
- source water monitoring to understand the temporal and spatial variability of water quality parameters
- developing early-warning systems to improve the management of poor water quality
- event-based monitoring to determine the magnitude of impacts (duration and maximum concentrations)
- examining chemical quality of sewage to identify potential sources of industrial discharges
- assessing trade-waste agreements to identify chemical contaminants that may be discharged into source waters
- studying the movement of water within storages, including lagoons and wetlands, to determine real detention times and to identify short-circuiting effects
- examining seasonal or outbreak impacts on microbiological quality of sewage and treated recycled water.

In addition, monitoring could provide input into predictive modelling of source water quality and assist in the selection of management and treatment approaches.

Careful consideration should be given to selection of water quality characteristics to be analysed, use of statistical techniques, collection of samples (frequency and location), use of appropriate sampling and testing procedures, and evaluation and management of results.

2.10 Documentation and reporting (Element 10)

Components:	Management of documentation and records (Section 2.10.1)
	Reporting (Section 2.10.2)

This element of the framework for management of recycled water quality and use is part of the general area of 'supporting requirements'.

Appropriate documentation provides a foundation for establishing and maintaining effective recycled water quality management systems. Documentation should:

- demonstrate that a systematic approach is established and is implemented effectively
- develop and protect the organisation's knowledge base
- provide an accountability mechanism and tool
- satisfy regulatory requirements
- facilitate reviews and audits by providing written evidence of the system
- establish due diligence and credibility.

Documentation provides a basis for effective communication within the organisation, as well as with the community and various stakeholders. A system of regular reporting, both internal and external, is important for ensuring that the relevant people receive the information needed to make informed decisions about the management or regulation of recycled water quality and the system (from source to end user).

Documentation should include descriptions of:

- preventive measures and their purpose
- operational procedures for relevant activities
- operational monitoring protocols, including parameters and criteria
- schedules and timelines
- data and records management requirements
- corrective actions to be implemented when required
- maintenance procedures
- responsibilities and authorities
- internal and external communication and reporting requirements
- incident reporting requirements.

2.10.1 Management of documentation and records

Summary of actions
• Document information pertinent to all aspects of recycled water quality management, and develop a document-control system to ensure current versions are in use.
• Establish a records-management system and ensure that employees are trained to complete records.
• Periodically review documentation and revise as necessary.

Document information on water quality management and develop a document control system

Documentation pertinent to all aspects of managing recycled water quality should describe activities and explain procedures, including detailed information on:

- preventive measures, including target criteria and related critical limits
- critical control points, including specific operational procedures and criteria, monitoring and corrective actions
- incident and emergency response plans
- training programs
- procedures for evaluating results and reporting
- communication protocols.

A document-control system should be developed to ensure that only the most recent version of an appropriately approved document is in use.

Establish a records-management system and ensure that operators and end users complete records

Documentation should be visible and readily available to operators and end users, where required. Mechanisms should be established to ensure that operators and end users read, understand and adhere to the appropriate documents.

Operation of systems and processes generates large amounts of data that need to be recorded. Efficient record keeping can indicate and forewarn of potential problems, and provide evidence that the system is operating effectively. Activities that generate records include:

- operational and recycled water quality monitoring
- soil, plant, groundwater and surface water monitoring at application and receiving environments
- corrective actions
- incident and emergency responses
- training
- research and development, validation and verification
- assessment of the water supply system (flow diagrams, potential hazards, etc)
- community consultation
- performance evaluations, audits and reviews.

Documentation and records systems should be kept as simple and focused as possible. There should be sufficient detail to provide assurance of operational control, when coupled with a suitably qualified and competent operator or end user. Retention of corporate memory should also be considered in documentation of procedures.

Periodically review documentation and revise as necessary

Documents should be periodically reviewed and revised to reflect changing circumstances. Also, they should be assembled in a manner that will enable any necessary modifications to be made easily.

Records of all activities should be easily accessible, but should be stored in a way that protects them against damage, deterioration or loss. A system should be in place to ensure that operators and end users (where required) are properly trained to fill out records, and that records are regularly reviewed by the appropriate authority, signed and dated.

Documents and records can be stored as written documents, electronic files and databases, video and audiotapes, and visual specifications (flow charts, posters, etc). Computer-based documentation is preferable, as it provides faster and easier access, distribution and updating. Electronic documentation should be backed up regularly.

2.10.2 Reporting

Summary of actions

- Establish procedures for effective internal and external reporting.
- Produce an annual report aimed at users of recycled water, regulatory authorities and stakeholders.

Establish procedures for effective reporting

Reporting includes the internal and external reporting of activities relating to recycled water quality management.

Internal reporting supports effective decision making at the various levels of the organisation, including operations staff and management, senior executive and boards of directors. It also provides a way to communicate decisions to employees throughout the organisation.

Internal reporting requirements should be defined and a system developed for communication between the various levels of the organisation. Documented procedures (including definition of responsibilities and authorities) should be established for regular reporting (daily, weekly, monthly, etc). These reports should include summaries of monitoring data, performance evaluation and significant operational problems that occurred during the reporting period. Results from audit and management reviews should also be communicated to those within the organisation responsible for performance.

External reporting ensures that recycled water quality management is open and transparent. It includes reporting to regulatory bodies, users of recycled water and other stakeholders in accordance with requirements. External reporting requirements should be established in consultation with users of recycled water and the relevant regulatory authorities; procedures for information dissemination should also be developed.

Details should be sought from health, environment and other relevant regulators on requirements for:

- regular reports summarising performance and monitoring data
- event reports on significant system failures that may pose a public health or environmental risk or adversely affect water quality for an extended period (see Section 2.6.2 — Incident and emergency response protocols).

Reports should be provided to regulatory authorities on incidents defined in agreed incident and emergency response protocols. If necessary, the health authority can then ensure that public health concerns are reported to the community.

Produce an annual report

An annual report should be produced and made available to users of recycled water, regulatory authorities and stakeholders. The annual report should:

- summarise recycled water quality performance over the preceding year against numerical guideline values, regulatory requirements or agreed levels of service, and identify water quality trends and problems

- summarise soil, groundwater and surface water monitoring at application and receiving environments over the preceding year against numerical guideline values, regulatory requirements or agreed levels of service, and identify water quality trends and problems
- summarise any system failures and the action taken to resolve them
- specify to whom the recycled water supplier is accountable, statutory or legislative requirements, and minimum reporting requirements
- indicate whether monitoring was carried out in accordance with the principles of risk management set out in these *National Guidelines for Water Recycling*, standards set by regulators and any requirements contained in agreed levels of service.

Annual reports should contain sufficient information to enable individuals or groups to make informed judgments about the quality of recycled water and provide a basis for discussions about the priorities that will be given to improving recycled water quality. The annual report represents an opportunity to canvass feedback, and it should therefore encourage users of recycled water and stakeholders to provide comment.

2.11 Evaluation and audit (Element 11)

Components:	Long-term evaluation of results (Section 2.11.1)
	Audit of recycled water quality management (Section 2.11.2)

Long-term evaluation of recycled water quality results and audit of recycled water quality management are required to determine whether preventive strategies are effective and whether they are being implemented appropriately. This long-term evaluation allows performance to be measured against objectives and helps to identify opportunities for improvement.

Auditing could involve active participation by users of recycled water, particularly in relation to the application of on-site control measures and in assessment of on-site impacts.

2.11.1 Long-term evaluation of results

Summary of actions

- Collect and evaluate long-term data to assess performance and identify problems.
- Document and report results.

Collect and evaluate long-term data to assess performance and identify problems

A systematic review of monitoring results over an extended period (typically the preceding 12 months or longer) is required to:

- assess overall performance against numerical guideline values, regulatory requirements or agreed levels of service
- identify emerging problems and trends
- assist in determining priorities for improving recycled water quality management.

There will inevitably be instances when the system does not comply with operational criteria or numerical guideline values. Each event will need to be assessed and appropriate responses determined.

Document and report results

Mechanisms for evaluation of results should be documented with responsibilities, accountabilities and reporting requirements defined. Useful tools to interpret datasets include statistical evaluation of results and graphs or trend charts.

Evaluation should be reported internally to senior managers and externally to users of recycled water, stakeholders and regulatory authorities, in accordance with established requirements, as discussed in Section 2.10. Confidence of users of recycled water will be improved if users are given assurance that data are reviewed regularly and that improvements are made in response to identified problems.

2.11.2 Audit of recycled water quality management

Summary of actions

- Establish processes for internal and external audits.
- Document and communicate audit results.

Establish processes for internal and external audits

Auditing is the systematic evaluation of activities and processes to confirm that objectives are being met, including assessment of the implementation and capability of management systems. It provides valuable information on those aspects of the system that are effective, and identifies opportunities for improving poor operational practices. Periodic auditing of all aspects of the recycled water quality management system is needed to confirm that activities are being carried out according to defined requirements and are producing the required outcomes. This should include auditing of the actions of all stakeholders including operators, managers, users of recycled water and, where appropriate, plumbers and installers of extensions to systems; and of implementation and adherence to on-site controls and use restrictions.

The frequency and schedule of audits, as well as the responsibilities, requirements, procedures and reporting mechanisms, should be defined. The extent of auditing will generally be proportional to the potential for health and environmental impacts, taking into account the source and volume of water and the types of uses. Auditing requirements will be greater for a dual-reticulation system supplying recycled water for domestic use than for a system involving drip irrigation of, for example, wine grapes. The audit process can take place over several weeks and should be comprehensive.

Internal audits will involve trained staff, and should include review of the management system and associated operational procedures and monitoring programs. Audits should also cover the records generated to ensure that the system is being implemented correctly and is effective.

Recycled water agencies should consider external auditing, which can be useful in establishing credibility and maintaining confidence among users of recycled water. External auditing could be achieved by peer review or undertaken by an independent third party. Affiliation and qualifications of external auditors should be recorded. External audits should focus on confirming implementation and results of internal audits.

External audits could be conducted on:

- the management system
- operational activities
- recycled water quality performance
- application of on-site controls and adherence to use restrictions
- the effectiveness of incident and emergency response or other specific aspects of recycled water quality management
- environmental indicators and performance.

Document and communicate audit results

Audit results should be appropriately documented and communicated to management and personnel responsible. Results of audits should also be considered as part of the review by senior executive.

2.12 Review and continuous improvement (Element 12)

Components:	Review by senior managers (Section 2.12.1)
	Recycled water quality management improvement plan (Section 2.12.2)

Senior management support, commitment and ongoing involvement are essential to the continuous improvement of the organisation's activities. Senior managers should regularly review their approach to recycled water quality management, develop action plans and commit the resources necessary to improve operational processes and overall recycled water quality.

2.12.1 Review by senior managers

Summary of actions

- Senior managers review the effectiveness of the management system and evaluate the need for change.

Review the effectiveness of the management system and evaluate the need for change

In order to ensure continuous improvement, the highest levels of the organisation(s) should review the effectiveness of the recycled water quality management system and evaluate the need for change, by:

- reviewing reports from audits, recycled water quality performance, environmental performance and previous management reviews
- considering concerns of users of recycled water, regulators and other stakeholders
- evaluating the suitability of the recycled water quality policy, objectives and preventive strategies in relation to changing internal and external conditions such as
  - changes to legislation, expectations and requirements

- changes in the activities of the organisation
- advances in science and technology
- outcomes of recycled water quality incidents and emergencies
- reporting and communication.

The review by senior managers should be documented.

2.12.2 Recycled water quality management improvement plan

Summary of actions

- Develop a recycled water quality management improvement plan.
- Ensure that the plan is communicated and implemented, and that improvements are monitored for effectiveness.

Develop a recycled water quality management improvement plan

An improvement plan should be developed to address identified needs; the plan should be endorsed by senior executive. Improvement plans may encompass:

- capital works
- training
- enhanced operational procedures
- consultation programs
- research and development
- incident protocols
- communication and reporting.

Improvement plans can be short term (eg one year) or long term. Short-term improvements might include actions such as improving on-site audit programs, increasing staffing and developing community awareness programs. Long-term capital works projects could include increasing storage capacity, extending distribution systems, or improving coagulation and filtration processes.

Improvement plans should include objectives, actions to be taken, accountability, timelines and reporting. They should be communicated throughout the organisation and to the community, regulators and other agencies.

Ensure the plan is communicated and implemented, and improvements are monitored

Making improvements will often have significant budgetary implications and therefore may require detailed cost–benefit analysis and careful prioritisation with reference to the outcomes of risk assessment (see Section 2.2.4 — Hazard identification and risk assessment). Implementation of plans should be monitored to confirm that improvements have been made and are effective.

3 Managing health risks in recycled water

This chapter describes the assessment and management of health risks from recycled water. Although the approach outlined here can be applied to any type of recycled water, this chapter focuses on the use of treated sewage and greywater for the purposes identified during the first phase of guideline development (see Section 1.2.6). Other forms of recycling, including augmentation of drinking water supplies, will be considered in the second phase of development of guidance for water recycling.

The chapter covers:

- the general principles involved in safe reuse of water (Section 3.1)
- risk assessment (Section 3.2)
- calculation of health-based performance targets (Section 3.3)
- preventive measures to achieve performance targets (Section 3.4)
- managing risks in recycling from treated sewage (Section 3.5 and 3.6) and greywater (Section 3.7)
- monitoring recycled water treatment and use (Section 3.8).

3.1 General principles

Sources of recycled water, such as sewage and greywater, can contain a wide range of agents that pose risks to human health, including chemicals and pathogenic (disease-causing) microorganisms.

Safe use of recycled water requires potential health risks to be reduced to acceptable levels. Hence, the first step is to define acceptable or tolerable risk, and then to use this to set health-based targets for individual hazards.

3.1.1 Tolerable risk

The traditional approach to identifying tolerable risk has been to define maximum levels of infection or disease, such as one infection per 10 000 people per year (Macler and Regli 1993). However, this approach fails to consider the varying severity of outcomes associated with different hazards; for example, the differences between mild diarrhoea, typhoid, haemolytic uraemic syndrome and cancer. This shortcoming can be overcome by measuring severity in terms of disability adjusted life years (DALYs) (see Box 3.1).

DALYs have been used extensively by agencies such as the World Health Organization (WHO) to assess disease burdens and to identify intervention priorities associated with a broad range of environmental hazards (WHO 2004).

Box 3.1 Disability adjusted life years (DALYs)

The various hazards that can be found in sources of recycled water can have very different health outcomes. Some outcomes are mild (eg diarrhoea) while others can be severe (eg haemolytic uraemic syndrome associated with *Escherichia coli* O157:H7 or cancer). Assessment of these outcomes and allocation of resources based on severity of impact requires a mechanism for quantifying impacts. Disability adjusted life years (DALYs) provide this mechanism for both microbial and chemical parameters. Standard risk assessments determine the likelihood of infection or illness. DALYs convert these likelihoods into burdens of disease.

The basic principle of the DALY is to weight each health impact in terms of severity within the range of zero for good health to one for death. The weighting is then multiplied by duration of the effect and the number of people affected by the effect. In the case of death, duration is regarded as the years lost in relation to normal life expectancy.

Hence, DALYs = YLL (years of life lost) + YLD (years lived with a disability or illness).

In this context, disability refers to conditions that detract from good health. In these guidelines it generally relates to illness, but in other arenas it can relate to physical or mental impairment.

Using this approach, a mild diarrhoea with a severity weighting of 0.1 and lasting for 7 days results in a DALY of 0.002, whereas death of a 1-year old resulting in a loss of 80 years of life equates to a DALY of 80.

Using an Australian example, infection with rotavirus causes:

- mild diarrhoea (severity rating of 0.1) lasting 3 days in 97.5% of cases
- severe diarrhoea (severity rating of 0.23) lasting 7 days in 2.5% of cases
- rare deaths of very young children in 0.015% of cases

The DALY per case = (0.1 x 3/365 x 0.975) + (0.23 x 7/365 x 0.025) + (1 x 80 x 0.00015)
= 0.0008 + 0.0001 + 0.012
= 0.013

Infection with *Cryptosporidium* can cause watery diarrhoea (severity weighting of 0.067) lasting for 7 days with extremely rare deaths in 0.0001% of cases. This equates to a DALY per case of 0.0015.

Campylobacter can cause diarrhoea of varying severity, Guillain–Barré syndrome of varying severity, reactive arthritis and occasional deaths. The calculated DALY per case is 0.0046.

Based on DALYs per case, the impacts of the three pathogens is rotavirus > *Campylobacter* > *Cryptosporidium*.

DALYs per case is based on Havelaar and Melse (2003), with a modification using Australian data for rotavirus, as described in WSAA (2004).

Determining DALYs for individual hazards includes considering acute impacts (eg diarrhoeal disease or even death) and chronic impacts (eg cancer). In terms of waterborne disease, the most commonly recognised illness is gastroenteritis following ingestion of enteric pathogens, with symptoms such as diarrhoea and vomiting. However, a number of these pathogens can cause more severe and long-lasting symptoms in a small percentage of infected people, for example:

- diabetes, associated with Coxsackie B4 virus (Mena et al 2003)
- myocarditis, associated with echovirus and Coxsackievirus (Mena et al 2003)
- reactive arthritis and Guillain–Barré syndrome, associated with *Campylobacter jejuni* (Havelaar et al 2000, Nachamkin et al 2001)

- haemolytic uraemic syndrome, associated with haemorrhagic *Escherichia coli* (Teunis et al 2004)
- reactive arthritis, associated with *Salmonella* (Rudwaleit et al 2001).

DALYs provide a means of quantifying the burden of public health impacts arising from disease caused by microbiological, chemical and physical hazards. They can be used to:

- define tolerable risk in terms of public health outcomes
- compare impacts from different hazards; for example, in the normal population, *Cryptosporidium* causes a short-lived and self-limiting diarrhoeal illness with only rare severe impacts, whereas *Campylobacter* can have both acute and chronic impacts (Havelaar et al 2000, Nachamkin et al 2001)
- prioritise resources toward controlling hazards with the greatest potential impact.

The tolerable risk adopted in these guidelines is 10^{-6} DALYs per person per year, which is consistent with the latest edition of the WHO *Guidelines for Drinking-water Quality* (WHO 2004). This is approximately equivalent to a lifetime additional risk of cancer of 10^{-5} (ie 1 case per 100 000 people) or an annual diarrhoeal risk of illness of 10^{-3} (ie one illness per 1000 people). In comparison, the reported rate of diarrhoeal illness in Australia is 0.8–0.92 cases per person per year (OzFoodNet Working Group 2003, Hellard et al 2001).

3.1.2 Health-based targets

Establishing the tolerable risk allows health-based targets to be set. Health-based targets are the 'goal-posts' or 'benchmarks' that have to be met by each recycled water scheme to ensure that the risk of 10^{-6} DALYs per person per year is not exceeded. They underpin the development of risk management plans (see Chapter 1). Health-based targets can take a number of forms, the most common being guideline values for chemical hazards and performance targets for microbial hazards.

In relation to health, a chemical guideline value is the concentration or measure of a water quality characteristic that, over a lifetime of consumption, will not lead to more than 10^{-6} DALYs per person per year.

Performance targets represent required reductions in hazard concentrations provided by measures such as treatment processes (aimed at reducing hazards) and on-site controls (aimed at reducing both hazards and exposure). Removal targets depend on hazard concentrations in source water; hence, the targets for sewage will generally be greater than for stormwater or greywater. Performance targets are generally framed in terms of categories of pathogens (eg bacteria, viruses and protozoa) rather than individual organisms, due to the wide array of pathogens that may be present in source waters (see Section 3.2.1).

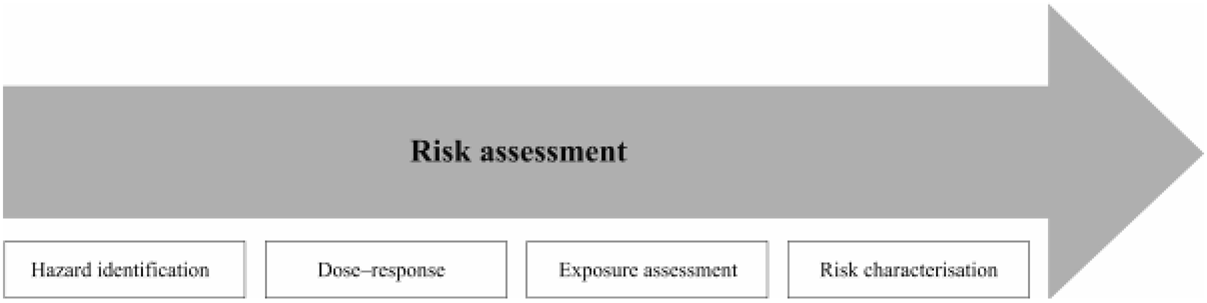
3.2 Risk assessment

DALYs are applied once hazard concentrations, dose responses and exposures are determined; that is, after completion of a risk assessment. The theory of risk assessment is covered in Chapter 2 (Section 2.2.4). Quantitative assessment of health-based risks typically incorporates the following steps:

1. Hazard identification — identification of hazards that might be present and the associated effects on human health; this step also includes consideration of variability in hazard concentrations (Section 3.2.1).
2. Dose response — establishment of the relationship between the dose of the hazard and the incidence or likelihood of illness (Section 3.2.2).
3. Exposure assessment — determination of the size and nature of the population exposed to the hazard, and the route, amount and duration of exposure (Section 3.2.3).
4. Risk characterisation — integration of data on hazard presence, dose response and exposure, obtained in the first three steps (Section 3.2.4).

These steps are illustrated in Figure 3.1.

Figure 3.1 Process of risk assessment



The remainder of Section 3.2 looks in detail at the four steps in risk assessment. It deals mainly with microbial rather than chemical hazards, because microbial hazards represent by far the greatest risk to human health. Given the uses of recycled water described in this chapter, chemical hazards will generally only occur in the event of contamination, due to accidental or inappropriate discharge into source water collection systems. Preventive measures can be expected to minimise the likelihood that such events will occur.

3.2.1 Hazard identification

This section discusses general issues associated with:

- the identification of microbial hazards and reference pathogens
- potential variability in concentration of hazards.

The sections on treated sewage (Sections 3.5 and 3.6) and greywater (Section 3.7) provide specific information on microbial hazards that may be found in these types of recycled water, they also deal with chemical hazards.

Microbial hazard identification and reference pathogens

Sewage and greywater can contain a wide array of microbial pathogens, including those shown in Table 3.1. It is impractical to identify health-based targets for all these microorganisms, particularly since this would require information on concentrations present in source waters, dose responses and disease burdens — information that is often not available. A more practical approach is to identify reference pathogens for which this type of information is available. Reference pathogens representing each of the major groups of organisms (ie bacteria, viruses, protozoa and helminths) is required, due to variations in characteristics, behaviours and susceptibilities of each group to treatment processes.

Table 3.1 Microorganisms of concern in raw sewage

Pathogen type	Examples	Illness
Bacteria	*Salmonella*	Gastroenteritis, reactive arthritis
	Campylobacter	Gastroenteritis, Guillain–Barré syndrome
	Pathogenic *Escherichia coli*	Gastroenteritis, haemolytic uraemic syndrome
	Shigella	Dysentery
	Yersinia	Gastroenteritis, septicaemia
	Vibrio cholerae	Cholera
	Atypical *Mycobacteria*	Respiratory illness (hypersensitivity pneumonitis)
	Legionella spp	Respiratory illness (pneumonia, Pontiac fever)
	Staphylococcus aureus	Skin, eye, ear infections, septicaemia
	Pseudomonas aeruginosa	Skin, eye, ear infections
	Helicobacter pylori (?)	Peptic ulcers
Viruses	Enterovirus	Gastroenteritis, respiratory illness, nervous disorders, myocarditis
	Adenovirus	Gastroenteritis, respiratory illness, eye infections
	Rotavirus	Gastroenteritis
	Norovirus	Gastroenteritis
	Hepatitis A	Infectious hepatitis
	Calicivirus	Gastroenteritis
	Astrovirus	Gastroenteritis
	Coronavirus	Gastroenteritis
Protozoa	*Cryptosporidium*	Gastroenteritis
	Giardia	Gastroenteritis
	Naegleria fowleri	Amoebic meningitis
	Entamoeba histolytica	Amoebic dysentery
Helminths	*Taenia (T. saginata)*	Tapeworm (beef measles)
	Ascaris	Roundworm
	Trichuris	Whipworm

Source: Adapted from Feacham et al (1983), Geldreich (1990), NRC (1996), Bitton (1999)

Suitable reference pathogens are those that present a worst case combination of:

- high occurrence
- high concentration in water to be recycled
- high pathogenicity
- low removal in treatment
- long survival in the environment.

Reference pathogens for viral hazards

Of the enteric viruses, there is no single virus that represents an ideal reference pathogen.

Rotaviruses are a good candidate for risk assessment because they pose a major threat of viral gastroenteritis worldwide, they have a relatively high infectivity compared with other waterborne viruses and a dose–response model has been established (Havelaar and Melse 2003). Noroviruses, though causing less severe disease, have been shown to be the most prevalent cause of viral gastroenteritis in developed regions (Lopmam et al 2003), but at present there is no published dose–response model for norovirus. However, although rotaviruses and noroviruses have the highest pathogenicity of candidate viruses and are likely to be present in high numbers in human waste, there are no suitable cell-culture methods and little data on prevalence of viable viruses in sources of recycled water.

Reoviruses, enteroviruses and adenoviruses are culturable, and there are Australian and international data for numbers of these viruses in sewage, but infection rates are lower. Of these three viruses, adenoviruses have been detected in the highest numbers, and they appear to be the most resistant to removal or disinfection (WHO 2004, Gerba et al 2002, unpublished data SA Department of Health).

Australian adenovirus data (from the Virginia Pipeline Scheme in South Australia) have been compared with published polymerase chain reaction (PCR) data for rotavirus and norovirus, adjusted to consider infectivity (Lodder and Roda-Husman 2005). The comparison indicates that prevalence of the three viruses in sewage could be similar.

In view of these considerations, the virus chosen as a reference pathogen is an amalgam of rotavirus and adenovirus, using dose–response data for rotaviruses and occurrence data for adenovirus.

Reference pathogens for protozoan hazards

Cryptosporidium parvum is a good candidate for a reference organism for protozoa, because it is reasonably infective (Teunis et al 2002), is resistant to chlorination and is one of the most important waterborne human pathogens in developed countries (NHMRC–NRMMC 2004). *Giardia lamblia* is another candidate, as it is typically present in sewage at some 10–100 times the concentration of *C. parvum* (Yates and Gerba 1998), and may be marginally more infective (Rose et al 1991); however, *Giardia lamblia* is more readily removed by treatment processes and is more sensitive to most types of disinfection than *C. parvum* (WHO 2004, NHMRC–NRMMC 2004). Therefore *C. parvum* is the preferred choice as the reference pathogen for protozoan hazards.

Reference pathogens for bacterial hazards

There are a number of candidates for bacterial reference organisms, including *E. coli* O157:H7, *Campylobacter*, *Shigella* and *Salmonella*. *E. coli* O157:H7 has the highest disease burden per case (Havelaar and Melse 2003), but *Campylobacter* is by far the most common cause of bacterial gastroenteritis in Australia (OzFoodNet Working Group 2003). Therefore, *Campylobacter* has been selected as the bacterial reference pathogen.

Reference pathogens for helminthic hazards

Helminth infections are not endemic in most parts of Australia, there is limited information on occurrence in water and there is no human dose–response model. However, for protection of human health, the protozoan reference pathogen can be used as a reference for helminths. Helminths are likely to be present in lower numbers than protozoa in sources of recycled water and, being larger than protozoa, they will be removed more readily by physical treatment processes such as lagoon detention and filtration.

Variability in hazard concentrations

Variability in hazard concentrations can be influenced by a range of factors, including source of water, the size of the scheme and impacts of seasons, events and incidents. Because of this variability, assessment of the microbial quality of source waters and recycled water should generally be based on consideration of 95^{th} percentile values of data. (The 95^{th} percentile represents the smallest remaining value after the lowest 95% of values in a dataset have been discarded).

Sewage

There can be seasonal variations in concentrations of individual pathogens (Krikelis et al 1984, Hovi et al 1996). For example, in many areas, cryptosporidiosis is more common in spring and autumn, meaning that concentrations of infectious *Cryptosporidium* in sewage will be higher in these seasons. Outbreaks of specific illnesses may also influence concentrations of pathogens in sewage.

Microbial variability is likely to be lower at major metropolitan treatment plants because the impacts of isolated outbreaks of infection will be diluted by the total volume of sewage from the large populations served by the plants. In contrast, variability may be higher at small sewage treatment plants, because outbreaks in small groups may substantially increase pathogen concentrations.

Variations in chemical quality are also likely to be greater in small sewage schemes, where low volume discharges of trade wastes may have a greater impact.

Greywater

Concentrations of microbial hazards can be extremely variable, due to the limited control over inputs. Microbial quality will depend on the amount of faecal material that enters greywater through activities such as washing of nappies or other types of soiled clothing. Concentrations of faecal indicator organisms in greywater can vary widely (Jeppesen and Solley 1994, Dixon et al 1999, Casanova et al 2001, Ottoson and Stenstrom 2003).

3.2.2 Dose response

Information on relationships between doses of organisms and incidence or likelihood of illness is generally obtained from investigations of outbreaks or from experimental human-feeding studies (Rose and Gerba 1991, Haas et al 1999, Messner et al 2001,Teunis et al 2004, WHO 2004). The doses associated with infection are typically much lower for viruses and protozoa than for bacteria. Ingestion of 1–10 pathogenic virus particles or protozoan cysts can be associated with a high likelihood of infection. In contrast, infection might require ingestion of an average of about 100 bacteria (depending on the type of bacterial pathogen). *Shigella*, typhoid salmonellae and haemorrhagic *E. coli* are notable exceptions to these figures, requiring fewer organisms to cause disease (Haas et al 1999, Teunis et al 2004, WHO 2004). For example, investigation of one outbreak found that average doses of *E. coli* O157:H7 associated with infection were 30–35 organisms (Teunis et al 2004).

Dose response can be influenced by host factors such as immune status, pre-existing health conditions and nutrition. However, the influence of these multiple factors is not well characterised and the general approach taken in developing water guidelines is to conduct risk assessments for the general population, including the very young and the elderly, through the normal course of life. Those with markedly increased vulnerability, such as people with severe immunodeficiency, generally receive specialist advice from their medical practitioners regarding additional precautions to prevent waterborne infections.

If considered appropriate, dose responses associated with vulnerable groups could be considered in performing risk assessments for specific recycled water schemes.

Dose–response models developed from human-feeding studies are common components of risk assessments (Haas et al 1999). Table 3.2 provides dose–response information and lists the models that can be used to determine probabilities of infection following exposure to the reference organisms discussed above.

Table 3.2 Dose–response relationships for reference organisms

<table>
<tr><th>Organism type</th><th>Distribution</th><th>Model</th><th>Parameters</th></tr>
<tr><td>Enteric virus (rotavirus)</td><td>Beta-Poisson</td><td rowspan="2">$P_{inf} = 1\text{-}(1+d/ß)^{-\alpha}$</td><td>$\alpha$ = 0.253
ß = 0.426</td></tr>
<tr><td>Bacterium
(Campylobacter jejuni)</td><td>Beta-Poisson</td><td>α = 0.145
ß = 7.58</td></tr>
<tr><td>Protozoan
(Cryptosporidium parvum)</td><td>Exponential</td><td>P_{inf} = 1–exp(–rd)</td><td>r = 0.059</td></tr>
</table>

α and r are parameters describing probability of infection; d = dose; ß = median infective dose (N_{50}) ÷ ($2^{1/\alpha}$–1);
P_{inf} = probability of infection
Model parameters are as described in Table 9.15 from Haas et al (1999), except for *Cryptosporidium*, where the data of Messner et al (2001) have been used.

3.2.3 Exposure assessment

Exposure assessment typically focuses on the public or consumers; for example:

- consumers of foods irrigated with recycled water
- users of, and those passing by, municipal areas irrigated with recycled water
- occupiers of homes supplied with recycled water through dual-reticulation systems.

Occupational exposure may also be determined in some cases; for example, for firefighters in areas supplied with recycled water. However, in most cases, occupational exposure can be managed by workplace procedures, as discussed in Section 3.4.4.

The main route of exposure to microbial hazards from recycled water is ingestion, including ingestion of droplets produced by sprays (although lower volumes are involved in this situation). Some microorganisms found in recycled water have the potential to cause respiratory illness (eg certain types of adenoviruses and enteroviruses) and, for these organisms, inhalation of fine aerosols (rather than droplets) may be a source of infection. There is insufficient information to characterise the risk associated with inhalation of this type of pathogen, and the general approach is to minimise risk by restricting the production and exposure to fine aerosols. Dermal exposure is also possible, but there is a lack of evidence of health impacts through this route and it is considered unlikely to cause significant levels of infection or illness in the normal population.

Assessment of exposure requires consideration of both intended and unintended uses. Unintended uses can take two forms:

- *deliberate misuse* — for example, filling a swimming pool with recycled water supplied for non-drinking residential use
- *accidental misuse* — for example, mistakenly cross-connecting water supplies.

Both deliberate and accidental misuse can be reduced by educating stakeholders (users, plumbers, etc) and by managing processes such as auditing. Nevertheless, for many recycled water systems, it is difficult to eliminate all forms of misuse. The risk assessments in these guidelines do not cover deliberate misuse by individuals, but do take into account accidental misuse, particularly that caused by third parties. The best-known example of this type of exposure is associated with cross-connections introduced into dual-reticulation schemes.

Exposure assessments have been published for intended and unintended uses (Asano et al 1992, Shuval et al 1997, FDEP 1998), but are often based on limited information. Further research is required in this area.

Examples of exposure volumes and frequencies of exposures per person are provided in Table 3.3. These values could be used as defaults where specific or local information is not available. In general, the volumes provided are considered to be conservative. Industrial use of recycled water has not been included in Table 3.3 because exposures will vary widely depending on the particular type of use. However, recycled water can be used for purposes such as cooling, process water and washdown water (one example is provided in Table 3.9). In these circumstances, potential occupational and public exposures need to be determined on a case-by-case basis.

3.2.4 Risk characterisation

The last step in risk assessment is to integrate information from hazard identification, dose response and exposure assessment, to determine the magnitude of risk. In all cases, the variables in determining the magnitude of risk for the reference pathogens are concentrations of the organisms and exposure.

As described in Chapter 2 (Section 2.2.4), the magnitude of risk should be assessed on two levels:

- *maximum risk* — risk in the absence of preventive measures
- *residual risk* — risk that remains after consideration of existing preventive measures.

Maximum risk is useful for identifying high-priority risks, identifying appropriate preventive measures, calculating performance targets and preparing for emergencies should preventive measures fail. Residual risk provides an indication of the safety and sustainability of the recycled water scheme or the need for additional preventive measures.

After consideration of preventive measures, residual risk should be less than 10^{-6} DALYs per person per year.

Table 3.3 Intended uses and associated exposures for recycled water

Activity	Route of exposure	Volume (mL)	Frequency/ person/year	Comments
Garden irrigation	Ingestion of sprays	0.1	90	Garden watering estimated to typically occur every second day during dry months (half year). Exposure to aerosols occurs during watering.
Garden irrigation	Routine ingestion	1	90	Routine exposure results from indirect ingestion via contact with plants, lawns, etc.
	Accidental ingestion	100	1	Infrequent event.
Municipal irrigation	Ingestion	1	50	Frequencies moderate as most people use municipal areas sparingly (estimate 1/2–3 weeks). People are unlikely to be directly exposed to large amounts of spray and therefore exposure is from indirect ingestion via contact with lawns, etc. Likely to be higher when used to irrigate facilities such as sports grounds and golf courses (estimate 1/week).
Food crop consumption (home grown)	Ingestion	5 (lettuce) 1 (other raw produce)	7 50	100 g of lettuce leaves hold 10.8 mL water and cucumbers 0.4 mL at worst case (immediately post watering).[a] A serve of lettuce (40 g) might hold 5 mL of recycled water and other produce might hold up to 1 mL per serve. Calculated frequencies are based on ABS data.[b]
Food crop consumption (commercial)	Ingestion	5 (lettuce) 1 (other raw produce)	70 140	100 g of lettuce leaves hold 10.8 mL water and cucumbers 0.4 mL at worst case (immediately post watering).[a] A serve of lettuce (40 g) might hold 5 mL of recycled water and other produce might hold up to 1 mL per serve. Calculated frequencies are based on ABS data.[c]
Toilet flushing	Ingestion of sprays	0.01	1100	Frequency based on three uses of home toilet per day. Aerosol volumes are less than those produced by garden irrigation.
Washing machine use	Ingestion of sprays	0.01	100	Assumes one member of household exposed. Calculated frequency based on ABS data.[d] Aerosol volumes are less than those produced by garden irrigation (machines usually closed during operation).
Fire fighting	Ingestion of water and sprays	20	50	Median ingestion for firefighters estimated at 20 mL per fire with a maximum number of fires fought within area served by recycled water of 50 per year.
Cross-connection of dual-reticulation systems with drinking water mains	Ingestion	1000/day	1/1000 houses	Total consumption is assumed to be 2 litres per day, of which 1 litre is consumed cold.[f] Affected individuals may consume water 365 days per year. A conservative estimate of 1/1000 houses has been considered.

ABS = Australian Bureau of Statistics
a Shuval et al (1997)
b ABS data show that 12% of households grow lettuce and 35% grow some type of produce (ABS 1995); they also show that Australians eat leafy vegetables 140 times per year and eat other vegetables at a similar rate (ABS 1994). Hence, it can be estimated that 'other produce', such as tomatoes, carrots, etc in combination, are eaten 280 times per year.
Watering with recycled water is used to augment rainfall. Assuming that watering occurs for six months of the year, frequency of consumption of lettuce irrigated with recycled water = 140 × 0.5 × 12%, and frequency of consumption of other raw produce = 280 × 0.5 × 35%.
c Using the same ABS data as in Note b, frequency of consumption of lettuce irrigated with recycled water = 140 × 0.5 for lettuce and frequency of consumption of other raw produce = 280 × 0.5.
d ABS data show an average of 2.6 people per household (ABS 2001). The amount of washing is estimated at five loads per week; therefore, the frequency = 5 × 52 ÷ 2.6.
e Note: fire fighting is an occupational exposure; the exposures were assessed by the Queensland Department of Emergency Services.
f WHO (2004)

3.3 Calculation of health-based performance targets

Performance targets for microbial hazards represent the reductions required to achieve a residual risk that complies with the tolerable level of 10^{-6} DALYs per person per year.

Since DALYs are determined by impacts from human exposure to hazardous microorganisms, the performance targets can be calculated (providing the initial concentration of organisms in the source water and the exposures to recycled water are known), using the formula:

$$\text{log reduction} = \log(\text{concentration in source water} \times \text{exposure} \times N \div \text{DALYd})$$

where N is the number of exposures per year and DALYd is the dose equivalent to a DALY of 10^{-6} (1.6×10^{-2} *Cryptosporidium*, 2.5 × 10–3 rotavirus, 3.7×10^{-2} *Campylobacter*). DALYd includes consideration of dose response and ratio of infection to illness.

Default exposures are provided in Table 3.3, and concentrations of reference pathogens in sewage and greywater are discussed in Sections 3.5 and 3.7 respectively.

Further details on calculation of health-based targets are provided in Appendix 2.

3.4 Preventive measures to achieve performance targets

Unrestricted exposure to hazards contained in untreated sources of recycled water (maximum risks) will inevitably represent unacceptable risks (ie DALYs above 10^{-6} per person per year). Safe use of recycled water requires strategies (ie preventive measures) to reduce exposure to hazards by:

- preventing hazards from entering recycled water (Section 3.4.1)
- removing them using treatment processes (Section 3.4.2)
- reducing exposure, either by using preventive measures at the site of use or by restricting uses (Section 3.4.3).

This section also discusses the preventive measures that can be used to protect the public as well as measures to reduce occupational exposures associated with the use of recycled water (Section 3.4.4).

3.4.1 Preventing entry of hazards into recycled water

Prevention can take a number of different forms depending on the nature of the source water, for example:

- in *sewage*, trade-waste controls can be used to minimise the presence of chemical hazards in sewage
- in *greywater*, input controls, including changing people's behaviour, can be used to limit concentrations of microbial and chemical hazards.

3.4.2 Removing hazards using treatment processes

Hazard concentrations can be reduced using various treatment processes, either singly or in combination. Table 3.4 summarises indicative removals of microbial hazards that can be achieved using identified treatment processes. The achievable ranges of pathogen reduction shown in Table 3.4 are relatively broad because effectiveness will be influenced by design features such as:

- bed depth, hydraulic flows and media characteristics for dual-media filtration
- pore size of membranes (eg microfiltration versus ultrafiltration)
- disinfectant doses and detention times (eg a minimum 1-log reduction of adenovirus can be achieved through exposure to 50 mJ/cm^2 of UV light, and a 2-log reduction can be achieved by exposure to 100 mJ/cm^2)
- detention times in lagoons and wetlands.

More specific removal rates can be identified by defining design features. For example, the *California Code of Regulations* states that filtration coupled with chlorination should provide a 5-log removal of viruses from secondary treated effluent (State of California 2001). This removal is subject to compliance with:

- specified filtration design features and chlorine Cts (Ct = chlorine residual × detention time)
- monitoring limits for turbidity, chlorine residual and coliform bacteria indicating removal of
  - viruses (turbidity and chlorine residual)
  - protozoa (turbidity)
  - bacteria (turbidity, chlorine residual and coliforms).

Whenever treatment options are selected, performance claims need validation. This can be achieved using published data or by testing for specific pathogens or suitable indicators (see Chapter 5). Standard well-established treatment processes are generally supported by published data, which reduces the requirement for specific testing. However, if new or innovative approaches are used, or if design features are changed, direct testing will often be required. In California, for example, direct testing is generally not required for treatment meeting specified design criteria, but alternative processes can be used only if testing shows that they achieve a 5-log virus reduction (State of California 2001).

Table 3.4 Indicative log removals of enteric pathogens and indicator organisms

Treatment	Indicative log reductions[a]							
	Escherichia coli	Bacterial pathogens (including *Campylobacter*)	Viruses (including adenoviruses, rotaviruses and enteroviruses)	Phage	*Giardia*	*Cryptosporidium*	*Clostridium perfringens*	Helminths
Primary treatment	0–0.5	0–0.5	0–0.1	N/A	0.5–1.0	0–0.5	0–0.5	0–2.0
Secondary treatment	1.0–3.0	1.0–3.0	0.5–2.0	0.5–2.5	0.5–1.5	0.5–1.0	0.5–1.0	0–2.0
Dual media filtration with coagulation	0–1.0	0–1.0	0.5–3.0	1.0–4.0	1.0–3.0	1.5–2.5	0–1.0	2.0–3.0
Membrane filtration	3.5–>6.0	3.5–>6.0	2.5–>6.0	3–>6.0	>6.0	>6.0	>6.0	>6.0
Reverse osmosis	>6.0	>6.0	>6.0	>6.0	>6.0	>6.0	>6.0	>6.0
Lagoon storage	1.0–5.0	1.0–5.0	1.0–4.0	1.0–4.0	3.0–4.0	1.0–3.5	N/A	1.5–>3.0
Chlorination	2.0–6.0	2.0–6.0	1.0–3.0	0–2.5	0.5–1.5	0–0.5	1.0–2.0	0–1.0
Ozonation	2.0–6.0	2.0–6.0	3.0–6.0	2.0–6.0	N/A	N/A	0–0.5	N/A
UV light	2.0–>4.0	2.0–>4.0	>1.0 adenovirus >3.0 enterovirus, hepatitis A	3.0–6.0	>3.0	>3.0	N/A	N/A
Wetlands — surface flow	1.5–2.5	1.0	N/A	1.5–2.0	0.5–1.5	0.5–1.0	1.5	0–2.0
Wetlands — subsurface flow	0.5–3.0	1.0–3.0	N/A	1.5–2.0	1.5–2.0	0.5–1.0	1.0–3.0	N/A

N/A = not available; UV = ultraviolet
a Reductions depend on specific features of the process, including detention times, pore size, filter depths, disinfectant
Sources: WHO (1989), Rose et al (1996, 2001), NRC (1998), Bitton (1999), USEPA (1999, 2003, 2004), Mara and Horan (2003).

3.4.3 Reducing exposure through preventive measures at site of use

Most existing recycled water guidelines and regulations specify a range of preventive measures that reduce risk by lowering exposure to recycled water. These preventive measures can include:

- restricting uses of recycled water
- controlling methods of application
- setting withholding periods between application of recycled water and use of irrigated areas or harvesting of produce
- controlling public access during application or use of recycled water
- using signage, labelling and communication to minimise accidental exposure.

Each of these approaches is discussed in more detail below. Estimates of microbial hazard reductions provided by measures applied at the site of application are given in Table 3.5;

however, there is limited information on the effectiveness of these preventive measures 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.

Restricting use

Restricting uses of recycled water can have large impacts on exposure. For example, using recycled water to irrigate only crops that are cooked or processed before consumption (eg potatoes or cereals) will result in much lower exposures to microbial hazards than using such water to irrigate salad vegetables. Similarly, using recycled water to irrigate crops with skins that are removed before consumption (eg citrus) will result in lower exposures than using the water to irrigate crops where the skin is eaten (eg stone fruit). Even the physical characteristics of crops will influence potential exposures. Shuval et al (1997) estimated that 10.8 mL of recycled water could be retained per 100 g of lettuce following spray irrigation, but only 0.36 mL per 100 g of cucumber. An Australian study found water retention within this range, with three types of cabbage holding an average of 3.3–8.9 mL per 100 g and broccoli 1.9 mL per 100 g (A Hamilton, Research Fellow, Deakin University, pers comm, 2005).

Controlling methods of application

Methods of application will influence exposure. Conservative estimates suggest that drip irrigation will reduce exposure by at least 2 logs compared with spray irrigation, and that subsurface irrigation will provide a further 2-log reduction. Where harvested portions of crops are raised above ground level, the reductions achieved by drip or subsurface irrigation will be even greater (Mara and Horan 2003).

Setting withholding periods

Setting withholding periods between application of recycled water and use of irrigated produce or lawn areas can reduce exposure. Estimates of decay rates of viruses from recycled water indicate that concentrations decrease by about 0.5 log per day after irrigation of surface crops (Asano et al 1992, Tanaka et al 1998, Petterson et al 2001). Similar reductions probably occur for bacterial pathogens, whereas concentrations of protozoa will decrease substantially if desiccation occurs.

Withholding periods for lawn and garden irrigation will probably reduce exposure even more because of the combined impacts of desiccation and adsorption into soils. Ingestion associated with use of irrigated parks will be very low. Exposure and ingestion will be even lower where irrigated areas are not used for sporting activities.

Controlling public access

Methods to reduce exposure include controlling public access during irrigation of parks and gardens, and using buffer zones between areas that are spray irrigated and points of public access. Modelling of airborne distribution of contaminants suggests that buffer zones can reduce exposure by at least 1 log. Spray drift away from the site of application can also be reduced by using:

- modern spray equipment designed to produce larger droplets
- low-throw sprinklers
- microsprinklers

- part-circle sprinklers (180° inward throw)
- screens of trees or shrubs
- anemometer switching systems.

Table 3.5 Exposure reductions provided by on-site preventive measures

Control measure	Reduction in exposure to pathogens
Cooking or processing of produce (eg cereal, wine grapes)	5–6 log
Removal of skins from produce before consumption	2 log
Drip irrigation of crops	2 log
Drip irrigation of crops with limited to no ground contact (eg tomatoes, capsicums)	3 log
Drip irrigation of raised crops with no ground contact (eg apples, apricots, grapes)	5 log
Subsurface irrigation of above ground crops	4 log
Withholding periods — produce (decay rate)	0.5 log/day[a]
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 after (non-grassed areas) (eg food crop irrigation)	3 log
Buffer zones (25–30 m)	1 log

a Based on virus inactivation. Enteric bacteria are probably inactivated at a similar rate. Protozoa will be inactivated if withholding periods involve desiccation.
Source: Based on: Asano et al (1992), Tanaka et al (1998), Haas et al (1999), van Ginnekin and Oron (2000), Petterson et al (2001), Mara and Horan (2003).

Cross-connection controls

Prevention of cross-connections and installation of backflow prevention devices where appropriate are important mechanisms for preventing contamination of high-quality waters, including mainswater and sources of drinking water. These are general measures that should be applied in all schemes where a potential for cross-connection exists. Cross-connection controls and backflow prevention devices should be applied in accord with Australian and New Zealand Standard AS/NZS 3500 (*Plumbing and Drainage Code*, AS/NZS 2003), *WSAA Water Supply Code* (WSAA 2002b) and *WSAA Dual Water Supply Systems, Version 1.2* (WSAA 2005).

Tables 3.3 and 3.7 incorporate default values for exposure associated with cross-connections. These exposures could be increased or decreased depending on the nature of dual reticulation (ie indoor and outdoor use, indoor use only, outdoor use only) and the extent of control measures applied.

Using signage, labelling and communication to minimise accidental exposure

Accidental exposure can be reduced through the use of measures such as:

- signage at irrigation sites, indicating that recycled water is being used and is not suitable for drinking
- labelling of infrastructure such as valves and piping, indicating that they are being used to distribute recycled water

- communication to users, providing advice on appropriate and inappropriate uses of recycled water.

These are general measures applied to recycled water schemes; log reductions have not been identified for selective application.

3.4.4 Reducing occupational exposures to recycled water

Occupational exposures associated with the use of recycled water can be managed by minimising ingestion and exposure to aerosols. Persons engaged in any operation involving source waters or recycled water should:

- avoid consumption of recycled water and unnecessary exposures to sprays and aerosols
- wash hands with soap and clean water before eating, drinking or smoking, and at the end of each working day
- cover any wounds, open cuts or broken skin
- wear appropriate protective clothing and use equipment appropriate to tasks being undertaken.

All employees and contractors should be advised of limitations placed on the use of recycled water and of the precautions that need to be taken to protect their health.

In some cases, specific health-based targets may need to be determined for occupational exposures, particularly where the capacity to apply preventive measures may be limited, such as in the case of industrial use or firefighters (WSAA 2004).

3.5 Treated sewage

This section looks at the following aspects of treated sewage as a source of recycled water:

- microbial hazards (Section 3.5.1)
- microbial health-based targets (Section 3.5.2) and preventive measures to manage microbial risk (Section 3.5.3)
- chemical hazards (Section 3.5.4)
- preventive measures to manage chemical risk (Section 3.5.5).

3.5.1 Microbial hazards in treated sewage

Untreated sewage will always contain microbial hazards, including large numbers of enteric pathogens that can cause gastroenteric illness through ingestion. The sewage may also include environmental microorganisms such as *Legionella* spp and mycobacteria.

Pathogen density in untreated sewage is highly variable because it reflects the level of infection and illness in the community, and the relative contributions of domestic waste, stormwater and industrial discharges. Reported numbers of pathogens and indicator organisms in sewage are shown in Table 3.6.

Table 3.6 Numbers of microorganisms in raw sewage

Organism	Numbers in sewage (per litre)
Bacteria	
Escherichia coli (indicators)	10^5–10^{10}
Pathogenic *E. coli*	Low
Enterococci (indicators)	10^6–10^7
Shigella	10^1–10^4
Campylobacter	10^2–10^5
Salmonella	10^3–10^5
Clostridium perfringens (indicator)	10^5–10^6
Viruses[a]	
Enteroviruses	10^2–10^6
Adenoviruses	10^1–10^4
Noroviruses	10^1–10^4
Rotaviruses	10^2–10^5
Somatic coliphages (indicators)	10^6–10^9
F–RNA coliphages (indicators)	10^5–10^7
Protozoa and helminths	
Cryptosporidium	0–10^4
Giardia	10^2–10^5
Helminth ova	0–10^4

a Colony-forming units for bacteria, plaque-forming units for bacteria, oocysts for *Cryptosporidium* and cysts for *Giardia*
Source: Feacham et al (1983), Geldreich (1990), NRC (1996), Bitton (1999)

3.5.2 Calculation of microbial health-based targets for recycling from treated sewage

This section describes the setting of health-based performance targets for achieving microbial quality in recycled water derived from treated sewage, and the measures that can be applied to meet compliance with the tolerable risk of 10^{-6} DALYs per person per year. Performance targets are expressed in terms of required log reductions.

The two variables required for calculation of performance targets are pathogen concentrations in sewage and exposures associated with identified uses of treated sewage:

- As shown in Table 3.6, pathogen concentrations can vary over a wide range, and 95th percentiles should therefore be used in determining health-based targets. Analyses from two Australian schemes indicate that sewage contains 2000 *Cryptosporidium*, 8000 rotavirus and 7000 *Campylobacter* per litre (95th percentile) (unpublished data, SA Department of Health and Melbourne Water). These concentrations are consistent with international data and can be used as default values in determining performance targets.
- Indicative exposures associated with particular uses of recycled water are provided in Table 3.3.

These default values were used to determine the performance targets shown in Table 3.7, following the approach described in Appendix 2. System-specific data on pathogen concentrations can be used, as an alternative to the default values, to calculate performance targets using these formulae or using the graph in Appendix 2. It is likely that other uses and combinations of uses of recycled water will be identified, and that exposures will vary under different local conditions. Specific exposure data can be used as an alternative to the defaults in Table 3.3.

Table 3.7 Log reductions for priority uses of recycled water from treated sewage

Activity	Route of exposure	Exposure (litres) × freq (per year)	Log reduction *Cryptosporidium*	Log reduction Rotavirus	Log reduction *Campylobacter*
Commercial food crops	Ingestion – Lettuce – Other produce	0.005 × 70 0.001 × 140			
	Total	**0.49**	**4.8**	**6.1**	**5.0**
Dual reticulation					
Garden irrigation	Ingestion of sprays Ingestion – Low – High	0.0001 × 90 0.001 × 90 0.1 × 1			
	Total	**0.2**	**4.4**	**5.8**	**4.6**
Garden food crops	Ingestion – Lettuce – Other produce	0.005 × 7 0.001 × 50			
	Total	**0.09**	**4.0**	**5.3**	**4.2**
Internal uses					
Toilet flushing	Ingestion of sprays	0.00001 × 1100	3.1	4.5	3.3
Washing machine	Ingestion of sprays	0.00001 × 100	2.1	3.5	2.3
Cross-connections	Ingestion	1 × 0.365	4.7	6.1	4.8
Total internal use (no garden use)		0.38	4.7	6.1	4.8
Total residential use (garden + internal)		0.67	4.9	6.3	5.1
Municipal irrigation	Ingestion of sprays	0.001 × 50	3.7	5.2	4.0
Dual reticulation plus municipal irrigation	Ingestion water and sprays	0.72	5.0	6.4	5.1
Fire fighting	Ingestion water and sprays	0.02 × 50	5.1	6.5	5.3

Log reduction calculations
Cryptosporidium = Log (number of organisms in sewage × exposure (L) × frequency ÷ 1.6×10^{-2})
Rotavirus = Log (number of organisms in sewage × exposure (L) × frequency ÷ 2.5×10^{-3})
Campylobacter = Log (number of organisms in sewage × exposure (L) × frequency ÷ 3.8×10^{-2})

Table 3.7 shows that viruses require the highest log reductions. This reflects the high infectivity of viruses compared to bacteria and the higher disease burden of viruses compared with protozoa (in rare cases, rotavirus infections can be fatal, and *Cryptosporidium* causes self-limiting diarrhoea with no long-term impacts for the general population). Table 3.7 also shows that the possibility of cross-connections represents a significant proportion of the exposure associated with dual-reticulation systems. Decreasing the likelihood of cross-connections would reduce the required log reductions.

Industrial use of recycled water has not been included in Table 3.7 because exposures will vary depending on the particular type of use. However, recycled water can be used for purposes such as cooling, process water and washdown water. In these situations, potential occupational and public exposures need to be determined on a case-by-case basis, and used to calculate log-reduction requirements (using the approach described in Appendix 2).

3.5.3 Preventive measures to manage microbial risk

Recycled water guidelines commonly specify combinations of treatment processes (see Table 3.4) together with on-site controls and use restrictions (see Table 3.5) to provide water of acceptable quality for identified uses.

Using treatment (eg filtration-based processes) as the primary means of minimising risk from microbiological hazards focuses control within a treatment plant. However, treatment is relatively expensive, and management of this type of facility requires a high degree of technical expertise.

Employing on-site controls and use restrictions reduces the focus on treatment. Controls can be used in combination with standard recycled water treatment processes that are often used for treating sewage (eg secondary treatment, storage lagoons and disinfection), with or without recycling of the final product. In this way, recycling can be introduced at existing facilities without the need for expensive retrofitting or treatment upgrades. However, when on-site controls and use restrictions are employed, preventive measures are spread over a much broader area, and some measures might need to be implemented at a local user level. As a result, there is a greater need for observational monitoring, user education, surveillance and auditing.

The preventive measures chosen will be determined by issues such as:

- cost
- intended use
- existing treatment facilities
- technical expertise
- availability of land (eg if buffer zones are to be used)
- public access (eg use in tourist areas within capital cities compared with recycling in rural towns)
- public perception and requirements.

Table 3.8 summarises typical combinations of preventive measures that can be used for various types of recycling. In this table, the log reductions attributed to treatment processes such as filtration are narrower than those shown in Table 3.4. This requires adherence to design specifications and water quality limits, detailed below.

- Advanced treatment, including coagulation and dual-media filtration, will typically need to comply with design criteria relating to aspects such as coagulant dosing, media depths and hydraulic flows. These will normally be accompanied by continuous operational monitoring for compliance with turbidity limits, to ensure that effective performance is maintained. The design specifications and operational limits will be set on a case-by-case basis; however, one example is provided by the Californian regulations (State of California 2001).
- Disinfection associated with advanced treatment will typically need to comply with dose specifications (eg UV light at $100 mJ/cm^2$ for 2-log virus kill) or Cts for disinfectants such as chlorine. Manuals such as those published by the United States Environmental Protection Agency (USEPA) can be used to identify appropriate disinfection regimes (USEPA 1999, 2003). Disinfection associated with advanced treatment will normally be subject to continuous monitoring for compliance with operational limits.

- *E. coli* (or alternatively thermotolerant coliforms) is used in this table in its traditional role as an indicator organism. It is not being used as a reference pathogen (most *E. coli* are non-pathogenic). Other parameters, such as disinfectant, lagoon detention, biochemical oxygen demand (BOD) and suspended solids, are also surrogates for performance relating to pathogen reduction. The log reductions attributed to the various combinations of treatments should thus be achieved, provided that design criteria are met and compliance with water quality objectives is achieved.

Table 3.8 includes a range of recycled water uses, indicative treatment processes, achievable log reductions, on-site preventive measures, exposure reductions and water quality objectives that support the fit-for-purpose approach adopted in these guidelines (see Section 1.2.4). The table indicates how treatment processes can be used alone or in combination with on-site preventive measures to meet health-based log reduction targets. The table also demonstrates one of the limitations of a classification system. For example, it describes a range of uses with high levels of treatment and minimal controls on public access or application (eg dual reticulation, spray irrigation of salad crops and municipal irrigation with unrestricted access). The required log reductions vary between the different uses.

Table 3.8 Treatment processes and on-site controls for designated uses of recycled water from treated sewage

Log reduction targets (V, P, B)[a]	Indicative treatment process	Log reductions achievable by treatment (V, P, B)	On-site preventive measures	Exposure reduction[b]	Water quality objectives[c]
Use — Dual reticulation, toilet flushing, washing machines, garden use					
6.5 5.0 5.0	Advanced treatment required, such as: • secondary, coagulation, filtration and disinfection • secondary, membrane filtration, UV light	6.5 5.0 5.0	Strengthened cross-connection controls required including ongoing education of householders and plumbers		• To be determined on case-by-case basis depending on technologies • Could include turbidity criteria for filtration, disinfectant Ct or dose (UV) • *E. coli* <1 per 100 mL
Use — Dual reticulation — outdoor use only *or* indoor use only					
6.0 4.5 5.0	Advanced treatment required; for example: • secondary, coagulation, filtration and disinfection • secondary, membrane filtration, UV light	6.0 4.5 5.0	Strengthened cross-connection controls required, including ongoing education of householders and plumbers		• To be determined on case-by-case basis depending on technologies • Could include turbidity criteria for filtration, disinfectant Ct or dose (UV) • *E. coli* <1 per 100 mL
Municipal use — open spaces, sports grounds, golf courses, dust suppression, etc *or* unrestricted access and application					
5.0 3.5 4.0	Advanced treatment required; for example: • secondary, coagulation, filtration and disinfection • secondary, membrane filtration, UV light	5.0 3.5 4.0	No specific measures		• To be determined on case-by-case basis depending on technologies • Could include turbidity criteria for filtration, disinfectant Ct or dose (UV) • *E. coli* <1 per 100 mL

Table 3.8 (continued)

Log reduction targets (V, P, B)[a]	Indicative treatment process	Log reductions achievable by treatment (V, P, B)	On-site preventive measures	Exposure reduction[b]	Water quality objectives[c]
Municipal use, with restricted access and application					
	• Secondary treatment with disinfection	2.0–3.0 1.0 >6.0	Restrict public access during irrigation **and one** of the following: • no access after irrigation, until dry (1–4 hours) • minimum 25–30 m buffer to nearest point of public access • spray drift control; for example, through low-throw sprinklers (180° inward throw), vegetation screening, or anemometer switching	2.0 1.0 1.0 1.0	• BOD <20 mg/L[d] • SS <30 mg/ L[d] • Disinfectant residual (eg minimum chlorine residual) or UV dose[e] • *E. coli* <100 cfu/100 mL
Municipal use, with enhanced restrictions on access and application					
	• Secondary treatment with >25 days lagoon detention or primary treatment with >50 days lagoon detention • Secondary treatment	1.0–3.0 1.0–3.0 3.0–4.0 0.5–2.0 0.5–1.0 1.0–3.0	Restrict public access during irrigation **and combinations** of: • no access after irrigation, until dry (1–4 hours) • minimum 25–30 m buffer to nearest point of public access • spray drift control, eg through low throw sprinklers (180° inward throw), vegetation screening, or anemometer switching	2.0 1.0 1.0 1.0	• BOD <20 mg/L[d] • SS <30 mg/ L[d] • *E. coli* <1000 cfu/100 mL (disinfection may be required to achieve this concentration)

Table 3.8 (continued)

Log reduction targets (V, P, B)[a]	Indicative treatment process	Log reductions achievable by treatment (V, P, B)	On-site preventive measures	Exposure reduction[b]	Water quality objectives[c]
Landscape irrigation — trees, shrubs, public gardens, etc					
5.0 3.5 4.0	Secondary treatment or primary treatment with lagoon detention	0.5–2.0 0.5–2.0 1.0–3.0	Combinations of: • microspray • drip irrigation • no public access	 2.0 4.0 3.0	• BOD <20 mg/L[d] • SS <30 mg/ L[d] • *E. coli* <1000 cfu/100 mL (if not disinfected)
Commercial food crops consumed raw or unprocessed					
6.0 5.0 5.0	Advanced treatment to achieve total pathogen removal required (eg secondary, filtration and disinfection)	6.0 5.0 5.0	• None required, although pathogen reduction will occur between harvesting and sale • The recycled water can be used for all crop applications, including spray irrigation of salad crops	0.5 V, B	• To be determined on case-by-case basis, depending on technologies • Could include turbidity criteria for filtration, disinfectant Ct or dose (UV) • *E. coli* <1 per 100 mL
Commercial food crops					
6.0 5.0 5.0	Secondary treatment with >25 days lagoon detention and disinfection	3.0–4.0 2.0–4.0 >6.0	Consumers • Crops with limited or no ground contact and eaten raw (eg tomatoes, capsicums) — drip irrigation and no harvest of wet or dropped produce • Crops with ground contact with skins removed before consumption (eg watermelons) — if spray irrigation, minimum 2 days between final irrigation and harvest • Pathogen reduction between harvesting and sale *Public in vicinity of irrigation area*[5] • No access and drip or subsurface irrigation • No access during irrigation and if spray irrigation, minimum 25–30 m buffer	 3.0 3.0–4.0 0.5/day V, B 6.0 4.0	• BOD <20 mg/L[d] • SS <30 mg/ L[d] • Disinfectant residual (eg minimum chlorine residual) or UV dose[e] • *E. coli* <100 cfu/100 mL

Table 3.8 (continued)

Log reduction targets (V, P, B)[a]	Indicative treatment process	Log reductions achievable by treatment (V, P, B)	On-site preventive measures	Exposure reduction[b]	Water quality objectives[c]
			distance between irrigation area and nearest public access point		
Commercial food crops					
6.0 5.0 5.0	Secondary treatment with disinfection	2.0–3.0 1.0 >6.0	Consumers • Above-ground crops with subsurface irrigation • Crops with no ground contact and skins removed before consumption (eg citrus, nuts) – no harvest of wet or dropped produce – if spray irrigation, minimum 2 days between final irrigation and harvest • Pathogen reduction between harvesting and sale *Public in vicinity of irrigation area*[f] • No access and drip or subsurface irrigation No access during irrigation and if spray irrigation, minimum 25–30 m buffer distance between irrigation area and nearest public access point	 4.0 4.0 0.5/day V, B 6.0 4.0	• BOD <20 mg/L[d] • SS <30 mg/ L[d] • Disinfectant residual (eg minimum chlorine residual) or UV dose[e] • *E. coli* <100 cfu/100 mL

Table 3.8 (continued)

Log reduction targets (V, P, B)[a]	Indicative treatment process	Log reductions achievable by treatment (V, P, B)	On-site preventive measures	Exposure reduction[b]	Water quality objectives[c]
Commercial food crops					
6.0 5.0 5.0	Secondary treatment or primary treatment with lagoon detention	0.5–1.0 0.5–2.0 1.0–3.0	Consumers		• BOD <20 mg/L[d] • SS <30 mg/ L[d] • *E. coli* <1000 cfu/100 mL
			• Crops with no ground contact and heavily processed (eg grapes for wine production, cereals)	5.0–6.0	
			• Crops cooked/processed before consumption (eg potatoes, beetroot)	5.0–6.0	
			• no harvest of wet or dropped produce consumption (eg citrus, nuts) – no spray irrigation		
			• Crops with no ground contact and skin removed before	6.0	
			• Raised crops (eg apples, apricots, grapes) – drip irrigation and no harvest of wet, dropped produce	5.0	
			• Pathogen reduction between harvesting and sale	0.5/day V, B	
			Public in vicinity of irrigation area[e]		
			• No access and drip irrigation	6.0	
			• No access during irrigation and, if spray irrigation, minimum 25–30 m buffer distance between irrigation area and nearest public access point, and spray drift control (eg through part circle sprinklers with 180° inward throw, vegetation screening, or anemometer switching)	5.0	
			or		
			• Extended buffer distances to >50 m		

Table 3.8 (continued)

Log reduction targets (V, P, B)[a]	Indicative treatment process	Log reductions achievable by treatment (V, P, B)	On-site preventive measures	Exposure reduction[b]	Water quality objectives[c]
Nonfood crops — trees, turf, woodlots, flowers					
5.0	Secondary treatment or primary treatment with lagoon detention	0.5–1.0	Public in vicinity of irrigation area		• *E. coli* <10 000 cfu/100 mL
3.5		0.5–2.0	• No access and drip irrigation	6.0	
4.0		1.0–3.0	• No access during irrigation and, if spray irrigation, minimum 25–30 m buffer distance between irrigation area and nearest point of public access, and spray drift control (eg through part cycle sprinklers with 180° inward throw, vegetation screening, or anemometer switching	5.0	
			or		
			• Extended buffer distances to >50 m		

B = enteric bacteria; BOD = biochemical oxygen demand; cfu = colony forming unit; Ct = disinfectant concentration × time; P = enteric protozoa; SS =suspended solid; V = enteric virus; UV = ultraviolet

a Log reduction targets are minimum reductions required from raw sewage based on 95th percentiles from Table 3.7.

b Exposure reductions are those achievable by on-site measures as listed in Table 3.3.

c Water quality objectives represent medians for numbers of *E. coli* and means for other parameters.

d BOD and SS are an indication of secondary treatment effectiveness.

e Aim is to demonstrate reliability of disinfection and ability to consistently achieve microbial quality

f Log reductions for public in the vicinity of commercial food crop irrigation areas should comply with total log reductions required for municipal use.

3.5.4 Chemical hazards in treated sewage

Sewage can contain a wide array of chemicals including inorganic and organic chemicals, pesticides, potential endocrine disruptors, pharmaceuticals and disinfection byproducts. Processes used to treat sewage before recycling can reduce the concentration of chemical contaminants.

The 2004 *Australian Drinking Water Guidelines* (NHMRC–NRMMC 2004) (ADWG) can be used to assess potential health risks associated with a broad range of inorganic and organic substances. The health-related guideline values in the ADWG are derived from assessments of acceptable daily intakes of chemicals; they assume an oral intake of 2 litres of drinking water per person per day for an adult, and 1 litre per person per day for a child. This equates to 350–700 litres per year, which is 500–1000 times the exposure associated with uses of recycled water discussed in this chapter (see Table 3.3). Chemical guideline values for these uses of recycled water can therefore be much higher than those used for drinking water.

Analyses of treated recycled water and associated water recycling schemes indicate that chemical quality generally complies with drinking water quality requirements for most parameters, including heavy metals, organic chemicals, pesticides and disinfection byproducts (NRC 1996, NRC 1998, USEPA 2004). This is confirmed by unpublished Australian data, which show the following:

- Average concentrations of nutrients, metals and trihalomethanes (THMs — produced as byproducts of disinfection) in filtered and chlorinated water from the Virginia Pipeline Scheme in South Australia essentially conform with ADWG values. Concentrations of pesticides, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), general organics and non-THM disinfection byproducts were largely below levels of detection. Nitrogen occasionally exceeded ADWG values, but nitrogen is a nutrient for which there is a recommended upper limit but no guideline value.
- Average concentrations of metals in sewage from treatment plants in Adelaide and rural South Australian also generally complied with ADWG values. Concentrations of pesticides, PCBs, PAHs, general organics and disinfection byproducts in treated sewage from the Adelaide plants were largely below levels of detection.
- Concentrations of chemicals in sewage from a treatment plant in Melbourne were mostly below ADWG values. Chemicals tested included nutrients, heavy metals, phenol, toluene, benzene and total PAH. Only nitrate and PAH concentrations exceeded ADWG values; total PAH levels were up to 4 µg/L (the ADWG value for the individual PAH, benzo(a)pyrene is 0.01 µg/L).

These studies indicate a high rate of compliance with guideline values. Chemical concentrations that exceeded the values in the ADWG were acceptable, taking into account the reduced exposure to recycled water compared with drinking water, discussed above.

Less data are available for on-site systems. Surveys of metals indicate that concentrations are variable, with some individual results exceeding ADWG values (unpublished data from the South Australian Department of Health). Average concentrations generally complied with ADWG values, except in the case of lead. However, chemical concentrations were acceptable, again taking into account the reduced exposure to recycled water compared with drinking water.

Emerging chemicals and complex mixtures

In assessing chemical risk for treated sewage, it is important to take into account emerging chemicals, for which there is insufficient toxicological information. Such chemicals include:

- endocrine disrupting chemicals (EDCs)
- pharmaceuticals
- new disinfection byproducts (eg nitrosodimethylamine — NDMA)
- complex mixtures.

Each of these types of chemical is discussed below.

Endocrine disrupting chemicals

A very broad range of chemicals have been identified as having the potential to alter normal endocrine function in humans and wildlife; these chemicals are referred to as EDCs. Candidate EDCs include both synthetic and naturally occurring chemicals, such as surfactants, plasticisers, pesticides, PCBs, synthetic steroids, human and animal steroid hormones, and phytoestrogens. Reviews of EDCs have been published by the WHO (WHO 2005) and by the Cooperative Research Centre for Water Quality and Treatment (CRCWQT), in the context of Australian drinking water (CRCWQT 2003).

EDCs have been detected in sewage treatment plant effluent, and in water bodies receiving effluent and other urban discharges (Kolpin et al 2002, CRCWQT 2003) and have been shown to affect aquatic biota; this is discussed in more detail in Chapter 5. At this stage, there is no evidence that environmental exposure to low levels of potential EDCs affects human health. In addition, sewage treatment processes, including secondary treatment, substantially reduce concentrations of endocrine disrupting chemicals (Leusch et al 2005).

Although comprehensive data are lacking, analyses of recycled water have generally found that levels of pesticides, PCBs and other organic chemicals identified as candidate EDCs are below limits of detection. In recycled water schemes that are properly designed and managed, health impacts from these chemicals should be minimal for the uses discussed here, because of the relatively low exposures.

More research is needed on potential human health impacts of EDCs, their presence in treated sewage and their removal by treatment processes.

Pharmaceutical chemicals

Pharmaceutical chemicals and their metabolites raise similar issues to EDCs, and some pharmaceuticals are potential EDCs. Pharmaceuticals and metabolites excreted by humans would be greatly diluted by the total volume of effluent collected by sewerage systems. However, low concentrations of these compounds have been detected in waters receiving urban discharges and effluent from sewage treatment plants (Kolpin et al 2002, Brun et al 2006). There is some evidence that treatment processes can reduce concentrations of some of these compounds (Brun et al 2006), but further work is required in this area.

As with EDCs, if recycled water schemes are properly designed and managed, health impacts from pharmaceuticals should be minimal for uses discussed here, because of the relatively low exposures.

Complex mixtures

Complex mixtures of chemicals in drinking water and recycled water could have additive, synergistic or even antagonistic effects, even when the concentrations of the individual chemicals comply with ADWG values. Further research is required on the health effects of complex mixtures of chemicals. However, at the low exposures associated with the uses discussed here, complex mixtures should not represent a human health risk.

3.5.5 Preventive measures to manage chemical risk

The risk to human health from chemicals in treated sewage is low, providing that preventive measures (eg trade-waste programs) are established and maintained to ensure that industrial discharges do not lead to elevated chemical concentrations in recycled water.

Small treatment plants and on-site recycled water treatment plants are more susceptible than large plants to unauthorised discharges of industrial and domestic origin. Greater vigilance is required to minimise the occurrence of unauthorised discharges if small plants are used as sources of recycled water. For on-site systems in particular, preventive measures should include providing owners of systems with educational material about the need to avoid inappropriate discharges of household chemicals.

3.6 Treated sewage as a source of recycled water for use with livestock

Recycled water has many potential applications in the agricultural sector and is frequently used for pasture, fodder and crop irrigation, livestock drinking water, and shed or stockyard wash down.

Source waters for recycling can potentially contain pathogenic organisms that pose a risk to the health of livestock, although the ‘species barrier’ means that many human pathogens, including human enteric viruses, are not of significant concern for livestock health. There are some exceptions to this, such as the eggs of the helminthic parasites *Taenia saginata* and *Taenia solium*, which may be present in sewage and other source waters contaminated with human faeces.

Abattoir or saleyard waste is a potential source of health risk for livestock. The primary concern relates to Johne’s disease, a particular risk to the cattle industry in some Australian states.

A limitation in approaching the management of livestock health risks associated with recycled water use is that virtually no dose–response models are available for infection in animals. Therefore water quality objectives cannot be derived using quantitative risk assessment tools.

A practical approach can overcome this limitation. The livestock industry has traditionally used specific controls to manage key hazards and, since these controls have been effective, it is proposed that they continue to be adopted.

Risks and management controls for the main hazards are discussed below and summarised in Table 3.9.

3.6.1 *Taenia saginata*

Cattle exposed to ova (eggs) of *Taenia saginata*, the human tapeworm, may develop the parasitic cysts of ‘beef measles’, or *Cysticercus bovis*. *Cysticercus bovis* not only causes cysts in cattle, but also has potential to affect human health — eating poorly cooked, contaminated meat can result in infection with the tapeworm. In addition to human-health risks, the detection of *T. saginata* in export beef can have economic implications by affecting trade.

The control of *T. saginata* in treated sewage that is to be used in contact with cattle has previously been prescribed through either 25 days of detention in waste stabilisation ponds or equivalent treatment (NHMRC and ARMCANZ 2000). This has seen effective management of the risk posed by *T. saginata*. However, there is no guidance on what constitutes ‘equivalent treatment’.

Using the empirical model described by Ayres et al (1992),[4] a mean hydraulic retention time of 25 days equates to approximately 4-log removal of helminth ova. Therefore, this is the target that alternative treatment processes to waste stabilisation ponds should meet if *T. saginata* requires specific management.

3.6.2 *Taenia solium*

Taenia solium ova from human faeces can infect pigs, causing cysticercus, which may result in human infection with the pig tapeworm if undercooked meat is consumed. *T. solium* infection can cause a severe neurological disease in humans — neurocysticercosis — which is particularly significant in developing countries.

The incidence of *T. solium* infection in Australia is extremely low. However, the approach to managing the risk of a cycle of infection with *T. solium* becoming established in Australia is to prohibit all use of sewage-derived recycled water for fodder or drinking water for pigs, due to the severity of the disease.

The prohibition on the use of recycled water from treated sewage for pig drinking or fodder should be observed, unless there is sufficient data to indicate the risks for a specific case can be managed.

3.6.3 Bovine Johne’s disease

Bovine Johne’s disease, a fatal wasting disease of cattle caused by the bacterial pathogen *Mycobacterium paratuberculosis*, needs specific consideration because of the common use of recycled water in the dairy and cattle industry. Cattle are susceptible to infection when they are less than 12 months of age, although the disease may not manifest until years later.

M. paratuberculosis may be present in waste containing animal faeces, such as that derived from abattoirs or livestock saleyards. It is not present in human faeces and is therefore not a risk for many recycling schemes, unless the source water contains waste from livestock.

M. paratuberculosis can survive for long periods under favourable conditions (up to 12 months in moist or wet areas).

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[4] $R=100[1-0.41\exp(-0.49\theta+0.0085\ \theta\ 2)]$, where R equals the percentage removal of helminth eggs and θ equals the detention time, in days.

Cattle up to 12 months of age should be excluded from areas irrigated with recycled water that has been derived from sources containing livestock waste, unless there is sufficient data to indicate the risks for a specific case can be managed.

3.6.4 Contamination of milk via recycled water use in dairy operations

While not a risk to livestock health, the use of recycled water in dairy operations can potentially contaminate milk and pose a risk to human health.

Pasteurisation of milk will effectively kill bacterial pathogens, but may be inadequate for inactivating the viral and protozoan pathogens present in human faeces. Therefore, if recycled water is derived from sewage or source water contaminated with human faeces, lactating dairy cattle should be excluded from areas irrigated with recycled water until the pasture is dry; also, recycled water should not be used for wash down of milking machinery.

Table 3.9 Treatment processes and additional controls for use of recycled water in association with livestock (excluding pigs)

Use	Indicative treatment processes	On-site preventive measures	Water quality objectives
Livestock drinking water	• Secondary treatment with helminth reduction (>25 days of lagoon detention or an equivalent filtration process) and disinfection or • Primary treatment with >50 days of lagoon detention and disinfection	• Recycled water not to be used for consumption by cattle under 12 months of age if the source of water contains animal (eg abattoir or saleyard) waste	• soluble BOD_5 <20 mg/L • SS <30 mg/L • Disinfectant residual (eg minimum chlorine residual) or UV dose[a] • *E. coli* <100 per 100mL
Dairy shed wash down	• Secondary treatment with helminth reduction (>25 days of lagoon detention or an equivalent filtration process) and disinfection or • Primary treatment with >50 days of lagoon detention and disinfection	• Recycled water not to be used for wash down of milking machinery (unless specifically considered in human health risk assessment)	• soluble BOD_5 <20 mg/L • SS <30 mg/L • Disinfectant residual (eg minimum chlorine residual) or UV dose[a] • *E. coli* <100 per 100 mL

Table 3.9 (continued)

Use	Indicative treatment processes	On-site preventive measures	Water quality objectives
Pa sture or fodder crop irrigation (including hay, silage and commercial fodder production). Limited withholding period	• Secondary treatment with helminth reduction (>25 days of lagoon detention or an equivalent filtration process) and disinfection or • Primary treatment with >50 days of lagoon detention and disinfection	• Exclude lactating dairy cattle from pasture for four hours or until pasture is dry. • Fodder dried or ensiled (not for human consumption) *Public in vicinity of site* • No public access during irrigation • 25–30 m buffer distance to nearest public access point • Spray drift control, eg through low-throw sprinklers, microsprinklers, drippers, part circle sprinklers (180º inward throw), vegetation screening, or anemometer switching	• soluble BOD_5 <20 mg/L • SS <30 mg/L • Disinfectant residual (eg minimum chlorine residual) or UV dose[a] • *E. coli* <100 per 100 mL
Pasture or fodder crop irrigation (including hay, silage and commercial fodder production). With withholding period.	• Secondary treatment with helminth reduction (>25 days of lagoon detention or an equivalent filtration process) or • Primary treatment with >50 days of lagoon detention	• Exclude grazing animals for 5 days after irrigation. • Fodder dried or ensiled (not for human consumption) *Public in vicinity of site* • No public access during irrigation • 25–30 m buffer distance to nearest public access point • Spray drift control, eg through low-throw sprinklers, microsprinklers, drippers, part circle sprinklers (180º inward throw), vegetation screening, or anemometer switching	• soluble BOD_5 <20 mg/L • SS <30 mg/L • *E. coli* <1000 per 100 mL

BOD_5 = biochemical oxygen demand over 5 days; SS =suspended solid; UV = ultraviolet
a Aim is to demonstrate reliability of disinfection and ability to consistently achieve microbial quality

3.7 Greywater

This section looks at the following aspects of greywater:

- microbial and chemical hazards (Section 3.7.1)
- health-based targets used to manage microbial and chemical risk (Section 3.7.2)
- preventive measures used to manage microbial and chemical risk (Section 3.7.3).

3.7.1 Microbial and chemical hazards in greywater

Recycling of greywater has received a great deal of attention in recent years, particularly in periods of drought. The perception is that greywater is relatively benign and that recycling is safe. This perception has led to some people adopting informal recycling by using buckets, hose systems or diversion systems to water parts of their garden with greywater. It has also led to a call for greater use of greywater.

In some areas, restricted recycling of untreated greywater is permitted. However, this practice could pose risks to human health and the environment unless strict controls are applied to materials discharged into greywater. The use of greywater must also be managed to minimise runoff, surface ponding and waterlogging.

Caution is needed because concentrations of microbial and chemical hazards in greywater vary over a wide range (see Table 3.10). In the worst cases, concentrations of faecal microorganisms are almost as high as those found in sewage. The reason for this variation is that both microbial and chemical quality depend on human behaviour and individual control of materials discharged into greywater.

Microbial quality depends on the amount of faecal material that enters greywater from activities such as washing nappies or other types of soiled clothing. Chemical quality depends on the nature of detergents, shampoos, soaps and household cleansers used, and on products that might be inappropriately discharged into greywater, such as oil, grease, garden chemicals and solvents.

Materials that may enter greywater collection systems include:

- bathroom — soaps, shampoos, hair dyes, toothpaste, mouth wash, antiseptics, hair, oils, body fats, faecal microorganisms
- laundry — soaps, detergents, bleach, grease, oils, lint and cloth materials, faecal microorganisms
- kitchen — dishwashing chemicals and detergents, cooking oils and grease, household cleaners, food particles, microorganisms associated with food (note: some greywater guidelines exclude the use of kitchen waste)
- other sources — pet hair, cleaning products, household and garden chemicals, automotive products.

Table 3.10 Comparison of greywater quality and sewage

Parameter	Greywater		Sewage
	Range	Mean	
Escherichia coli/thermotolerant coliforms (per 100 mL)	10^1–10^7	No value	10^6–10^8
Suspended solids (mg/L)	2–1500	99	100–500
BOD (mg/L)	6–620	430	100–500
Nitrite	<0.1–4.9	No value	1–10
Ammonia (mg/L)	0.06–25.4	2.4	10–30
Total Kjeldahl nitrogen (mg/L)	0.06–50	12	20–80
Total phosphorus (mg/L)	0..04–42	15	5–30
pH	5.0–10.0	8.1	6.5–8.5

BOD = biochemical oxygen demand; NTU = nephelometric turbidity units
;Source: Jeppesen and Solley (1994), A-Boal et al (1995), Department of Health WA (2002), Eriksson et al (2002), Gardner and Millar (2003), Palmquist and Jönsson (2003), Landloch (2005)

3.7.2 Calculation of microbial health-based targets for greywater used as a source of recycled water

The principles of setting health-based targets are the same for greywater as for other sources of recycled water, and the same formulae (Appendix 2) could be used. However, determination of health-based targets is complicated by a lack of data.

It is difficult to establish performance targets for control of microbial quality because of the large variability of greywater. The variability in individual domestic systems will be greater than that in large systems (eg in apartment buildings); however, even in large systems, variability could be substantial. In addition, most of the limited data available are based on measurement of indicator organisms such as *E. coli* and thermotolerant coliforms. Little or no data are available on presence of specific pathogens. In addition, as discussed above (Section 3.2.1), one study has suggested that indicator organisms might regrow due to the presence of organic material, leading to an overestimation of faecal contamination (Ottoson and Stenstrom 2003). However, the authors also considered that there could be regrowth of pathogenic bacteria such as *Salmonella* and *Campylobacter*.

In large decentralised greywater schemes it may be possible to test for pathogens, but for most greywater schemes a modified approach needs to be adopted to determine performance targets. Three factors need to be considered:

- large variability in *E. coli* concentrations
- very limited data on pathogen concentrations
- the expense and practicality of obtaining pathogen data, particularly from small schemes.

A practical approach is to use mean *E. coli* concentrations detected in greywater to determine the amount of faecal material present in terms of a percentage equivalent of sewage (by comparison with a mean concentration of 10^7 *E. coli* per 100 mL for raw sewage). Conventionally, 95th percentiles or medians are used for assessing microbial quality; however, due to the very large variability in greywater quality, the former are likely to be very conservative and to overestimate general levels of microbial contamination, and the use of medians may underestimate contamination by discounting peak values. Means are considered to provide a balanced assessment of microbial contamination.

Using this approach, log reductions required for greywater use can be determined by applying a correction factor to those calculated for sewage (see Section 3.5). Hence, if greywater quality for a particular scheme is shown to contain 10^5 *E. coli* per 100 mL (equivalent to 1% sewage), the reductions shown in Table 3.7 could be reduced by 2 logs. If greywater contained 10^4 *E. coli* per 100 mL, the reductions shown in Table 3.7 could be reduced by 3 logs. The reductions could be determined for each recycling scheme, with the concentrations of *E. coli* verified in precommissioning testing.

A further decrease in log reduction requirements could be applied to on-site greywater systems serving single domestic dwellings. These systems represent a lower risk than those servicing multiple dwellings due to the lack of exposure of third parties either directly or through cross-connections. When applying this reduction, it is important to ensure that mains water systems are protected from inadvertent contamination, particularly when greywater is plumbed into dwellings for purposes such as toilet flushing. In this case, as discussed in Section 3.4.3, backflow prevention devices should be installed on drinking water supplies.

It is hoped that in the longer term, sufficient data on greywater quality will be available to allow typical concentrations of indicator organisms and reference pathogens to be generically established with some confidence. This will enable scheme proponents to establish performance targets without needing to characterise the microbial quality of greywater for their specific scheme, in the same way that targets have been established for use of treated sewage as a source of recycled water.

As for treated sewage (see Section 3.5.5), the risk to public health from chemicals in greywater should be low providing that inappropriate discharge of domestic chemicals is prevented.

3.7.3 Preventive measures to manage microbial and chemical risk from greywater

Wherever possible, a preventive approach should be used to reduce concentrations of hazards in greywater and this is a common theme in establishing greywater systems. Various guidelines (eg Jeppesen and Solley 1994, NSW Health 2000, Queensland DLGPSR 2002, WA 2002) dealing with greywater include advice on materials and products that should be kept out of greywater collection systems.

From a human health perspective, this advice can include:

- not collecting water from the laundry after washing nappies or other laundry items soiled by potentially infectious matter, such as faeces or vomit
- not disposing of household or garden chemicals into greywater systems
- excluding kitchen waste.

Implementation of this type of advice needs support in the form of education and educational material for owners of on-site systems, residents in community based or apartment building systems, or occupants of buildings connected to greywater schemes. This needs to be an ongoing process through the life of such schemes — a single campaign associated with the commencement of a project will not be sufficient. In addition, surveillance mechanisms need to be established to ensure that preventive measures applied at the point of discharge to greywater schemes are maintained.

Even with education and surveillance systems in place, management of public behaviour has limitations and is unlikely to remove all hazards associated with greywater. Additional barriers to ensure safe and sustainable use of greywater are required.

The tendency in existing guidelines is either to restrict the use of untreated greywater, to minimise human exposure, or to require levels of treatment approaching those used for sewage (see NSW Health 2000, Queensland DLGPSR 2002, WA 2002).

On-site restrictions are generally less expensive and require less expertise to maintain than treatment-based approaches. Combinations of treatment and on-site restrictions can be selected using a similar approach to that described for sewage in Section 3.5.

Following this approach, untreated greywater could be used, providing substantial on-site and use restrictions are applied, including:

- only allowing subsurface or, in some cases, drip irrigation systems with restricted uses
- not allowing irrigation of vegetables
- limiting storage capacities and times.

As shown in Table 3.5, subsurface irrigation of trees, shrubs and grassed areas provides an estimated 5–6-log reduction in exposure, and this is likely to provide sufficient levels of protection from untreated greywater. Drip irrigation of trees and shrubs provides a 4-log reduction in exposure and this is also likely to be relatively safe, provided that it is combined with reasonable levels of control applied to materials discharged into greywater systems and low-level treatment.

Where applications involving potentially higher exposures are proposed — such as residential garden watering or household use — more extensive treatment will be required. Ottoson and Stenstrom (2003) concluded that the health risks from contact with greywater (0.001–0.0026 litres per year) from publicly accessible ponds or irrigation of sports fields was unacceptably high, even after treatment including activated sludge, biofiltration and pond storage. Additional treatment, such as chemical precipitation or ozonation, was recommended.

The selection of treatment processes should follow the same approach as that given in Section 3.5. The water quality targets shown in Table 3.8 could be used as a guide for operational and verification monitoring.

As described in Section 3.4.2, if new or non-standard treatment processes are to be used, validation will normally be needed to demonstrate that water quality targets consistent with intended uses are achieved. As for all types of validation, this could incorporate the use of published data, but it may also require direct testing. Validation may need to demonstrate removal or inactivation of pathogenic viruses, protozoa and bacteria. Testing for *E. coli* alone will generally not be sufficient for this purpose and other indicators or surrogates will need to be used to demonstrate removal of viruses and protozoa (see Chapter 5).

Important considerations in greywater treatment include reliability of processes, ease of maintenance and capability of operators to manage treatment processes.

3.8 Monitoring in recycled water treatment and use

Within a risk management plan, monitoring is used to assess whether health-based targets are being met. Different types of monitoring can include:

- validation (Will it work?)
- operational monitoring (Is it working now?)
- verification (Did it work?).

In relation to guideline values for chemical hazards, monitoring will generally include direct measurement of hazard concentrations in recycled water.

In relation to performance targets for microbial hazards, monitoring can include direct measurement of hazards, but this approach has disadvantages, and methods more commonly used for microbial hazards are:

- use of surrogates and indicators to assess the effectiveness of treatment processes
- use of observational monitoring to assess compliance with on-site controls (eg use of drip or subsurface irrigation rather than spray irrigation).

Chapter 5 provides detailed information on monitoring for health risks in recycled water treatment and use.

4 Managing environmental risks in recycled water

This chapter is intended to help waterway managers, water authorities, regulatory authorities, councils and resource managers to assess planning, design and operation of recycled water schemes and minimise risks to the environment. The chapter covers:

- the general principles involved in safe reuse of water (Section 4.1)
- environmental risk assessment (Section 4.2)
- preventive measures for management of environmental risks associated with recycled water in general (Section 4.3), including determination of critical control points, critical limits and target criteria
- assessment and management of environmental risks from water recycled from treated sewage (Section 4.4) and greywater (Section 4.5)
- monitoring of environmental hazards in recycled water treatment and use (Section 4.6).

Safe use of recycled water requires potential environmental risks to be reduced to acceptable levels. The rest of this chapter explains how this can be achieved, using a risk assessment and management approach.

4.1 General principles

4.1.1 Focus of approach

The process outlined in this chapter for assessing and managing the environmental risks associated with the use of recycled water is applicable to any type of recycled water. However, here the focus is particularly on water recycled from treated sewage and greywater. Also, the focus is on chemical rather than microbial hazards, because all sources of recycled water can contain a wide range of inorganic and organic chemical agents. Chemical hazards pose a greater risk to the environment than microbial hazards, although there are emerging areas of concerns with respect to microbial hazards, such as transfer of antibiotic resistant bacteria through waste to environment.

Human health is at far greater risk from microbial than from chemical hazards, particularly for non-drinking uses. Therefore, compliance with guidelines for microbial risks to human health (see Chapter 3) will minimise most of the environmental risks posed by microbial hazards.

4.1.2 Environmental guidelines

Many of the environmental-related guidelines currently available can help in meeting the main objectives of *Australia's National Strategy for Ecologically Sustainable Development* (Environment Australia 2001), which are to:

- enhance individual and community wellbeing and welfare by following a path of economic development that safeguards the welfare of future generations
- provide for equity within and between generations

- protect biological diversity and maintain essential ecological processes and life-support systems.

The achievement of these objectives is supported in each state and territory by assessment and decision-making mechanisms, such as resource planning, environmental impact assessment and various environmental guidelines that set out guideline values, benchmarks or quality standards that should not be exceeded. Environmental guideline values are generally expressed as concentrations or as the measurement of a physical or chemical characteristic of water, air or soil. The values are based on present knowledge of concentrations or characteristics that do not result in any significant risk to any physical or biological component of the environment.

Environmental guideline values are related to impacts on specific endpoints or receptors within the environment, and any exceedance of such values should trigger action. The guideline values can be applied to marine and freshwater quality where location-specific values are not available (ANZEC and ARMCANZ 2000a), and to groundwater (NEPC 1999) and plant nutrition (Creswell and Weir 1997, Creswell and Huett 1998). The values may need to be modified in the light of site-specific environmental considerations (see Section 5.4.1). For example, the concentration of plant-available phosphorus may already exceed a trigger value for phosphorus of 150 mg/kg soil (Table A5.23) because of excessive fertiliser application before recycled water use. Calculaton of nutrient requirements for a carrot crop indicates that the recycled water should contain <1.0 mg/L phosphorus, as there is sufficient in the soil reserve for this year. However, in the following years, as the crop removes the element, 10 mg/L of phosphorus in recycled water would be low risk. Over a three-year period, the improved nutrient budgeting (which includes the phosphorus applied with recycled water) due to recycled water use will lower the overall risk associated with execessive historical phosphorus applications.

Environmental guideline values can also provide a trigger value between 'no appreciable risk' and a risk level that needs further investigation, for specific reuse systems. The values inform the risk assessment process set out in these guidelines, supplementing (rather than substituting for) a risk-based approach to recycled water management.

The environmental risk section of the guidelines focuses on the use of qualitative risk assessment (Table 2.5, 2.6 and 2.7). However, in some specific situations, a quantitative risk assessment may be possible if there is sufficient data on the most sensitive endpoints identified for the specific reuse scheme to be assessed.

4.2 Environmental risk assessment

This section should be read in conjunction with Section 2.2 of Chapter 2, which covers Element 2 of the framework for management of recycled water quality and use: 'Assessment of the recycled water system'.

This section outlines a method for assessing the environmental risks posed by the use of recycled water in urban and rural environments. The process should be applied at all stages in the planning, design and operation of recycled water schemes.

The process used here for assessing environmental risks is consistent with the approach outlined in Chapter 2, and is similar to that given in the Australian Standard 4360 *Risk Management* (AS/NZS 2004c) using qualitative or semiquantitative risk assessment. It involves the following four stages:

- water sources, uses, users and routes of exposure assessment
- recycled water system assessment

- water quality data assessment
- hazard identification and risk assessment.

The rest of this section looks in detail at the first and last components of the risk assessment process (in Sections 4.2.1 and 4.2.2, respectively), supplementing the general information given in Chapter 2 with information specific to the assessment of environmental risks.

4.2.1 Water sources, uses, users and routes of exposure

This section should be read in conjunction with Section 2.2.1 of Chapter 2.

Identifying the source, uses, users and routes of exposure through which the recycled water will be treated, reticulated and applied (directly or indirectly) to the environment provides information crucial to the assessment and management of environment risks associated with the inevitable return of the water to the environment.

Identify source of water

It is important to identify the source of water because different sources will pose different risks. Particular issues associated with the two types of recycled water covered by these guidelines (treated sewage and greywater) are discussed in Sections 4.4 and 4.5.

Identify intended uses and receiving environments

The different uses of recycled water (summarised in Table 1.1, in Chapter 1) lead to different pathways by which recycled water enters the environment. It is important to look at both the initial receiving environment for recycled water and the final location (ie the point where an impact could be identified) — known as the environmental endpoint. In assessing environmental risk, a large number of endpoints must be considered (in contrast to assessing health risk, which focuses on a single endpoint in humans, as described in Chapter 3). Environmental risk assessment can be simplified by grouping the endpoints into the broad categories of air, soils, plants (a specific biota), biota (all other aquatic and terrestrial biota), groundwater, surface water and infrastructure. In some cases, consideration may need to be given to recycled water re-entering a sewage treatment plant, as the water may increase the salt loads entering the sewage treatment plant and ultimately impact on environmental endpoints where the recycled water is used.

An example of endpoints for a specific recycling scheme is shown in Box 4.1.

Box 4.1 Example of specific environmental endpoints

In the case of recycled water being used to irrigate an oval and nearby municipal gardens containing a range of native plant species, the specific endpoints might be:

- the species of grass used on the oval — for example, kikuyu (*Pennisetum clandestinum*)
- the specific soil type in which the grass is grown — for example, sandy loam, which drains freely to 1.5 metres
- the specific native species grown in the municipal area — for example, grey box (*Eucalyptus macrocarpa*) and red box (*Eucalyptus polyanthemos*) eucalypts, and Merrall's wattle (*Acacia merrallii*).

Box 4.1 (continued)

Irrigation water could potentially leach to groundwater, or runoff to surface water bodies nearby; these water bodies would also be specific endpoints for the recycled water and hazard being assessed.

Identify potential for inadvertent and unauthorised use or discharge

It is important to consider inadvertent or unauthorised use or discharge of the water. For example, cross-connections could result in drinking water being inadvertently contaminated or replaced by recycled water, and the failure of storage or reticulation systems could lead to unintentional discharge.

4.2.2 Hazard identification and risk assessment

This section should be read in conjunction with Section 2.2.4 of Chapter 2.

As explained in Chapter 2, hazard identification and risk assessment involves using the following steps to establish priorities for managing risks and applying preventive measures:

- identifying and documenting hazards and hazardous events
- estimating the likelihood that a hazardous event will occur
- estimating the consequences (ie the impact) of the hazardous event occurring
- characterising the overall risk by combining the hazards and hazardous events with their likelihood and consequence.

This section looks in detail at how these four steps can be applied specifically to environmental risks. It deals predominantly with chemical hazards (because these represent the greatest risk to the health of the environment), but also covers some pathogen risks.

The hazard identification and risk assessment process should reiterate through three phases:

- an initial screening-level risk assessment
- a maximum risk assessment (in the absence of preventive measures)
- a residual risk assessment (in the presence of preventive measures).

These phases are outlined in Figure 4.1. An initial screening-level risk assessment can be undertaken by comparing hazard concentrations in the recycled water with known guideline values for hazards in recycled water. A worse-case scenario can be used for this exercise, in which the 95th percentile (or maximum recorded concentration) of the hazard is compared with the lowest guidelines value for the hazard (eg most sensitive environmental endpoint). If the hazard concentration exceeds the relevant guideline value, then the impact should be considered moderate (see Table 2.7 in Chapter 2). Logically, if the likelihood of exposure and the impact is in any category other than 'unlikely', the initial screening risk will be moderate or greater. This initial finding triggers the second phase of the process, where a maximal risk assessment is undertaken using similar principles, but with detailed site information. The maximum risk assessment also helps decide on sampling frequencies and monitoring points in the environment (Chapter 5.4).

The initial screening-level risk assessment can be useful in selecting a site and assessing risks when developing a reuse scheme. However, the trap to avoid in a screening-level assessment is becoming too lost in detail and minutiae.

Identify and document hazards and hazardous events

This section should be read in conjunction with:

- Appendix 4, which provides a detailed risk assessment for key environmental hazards
- Appendix 5, which provides reference tables for environmental risk assessment.

The quality of recycled and greywater can vary considerably from treatment plant to treatment plant, or from household to household. Available technology allows recycled water treatment (described in detail in Appendix 3) to produce water of almost any specified quality. The issue is to establish what constituents need either to be prevented from entering the recycled water or removed from it, and to what extent, which in turn depends on the intended use of the water and the initial state of the environment it will enter.

Table 4.1 lists the many potential contaminants in recycled water that may affect the environment, through various pathways. Because the type and quality of effluent will vary significantly, Table 4.1 is only an indication of possible quality. The extent of the impact will depend on whether the hazard is present and, if so, its concentration, the length of exposure and the sensitivity of the environmental endpoint. Ultimately, these factors define whether the risk to the environment is acceptable (low) or unacceptable (moderate, high and very high — as defined in Table 2.7, Chapter 2). There are risks associated with all scenarios, including the ‘do nothing’ scenario.

Figure 4.1 Detail of the systems analysis and management component (Elements 2, 3, 4, and 5) from the framework for management of recycled water quality.

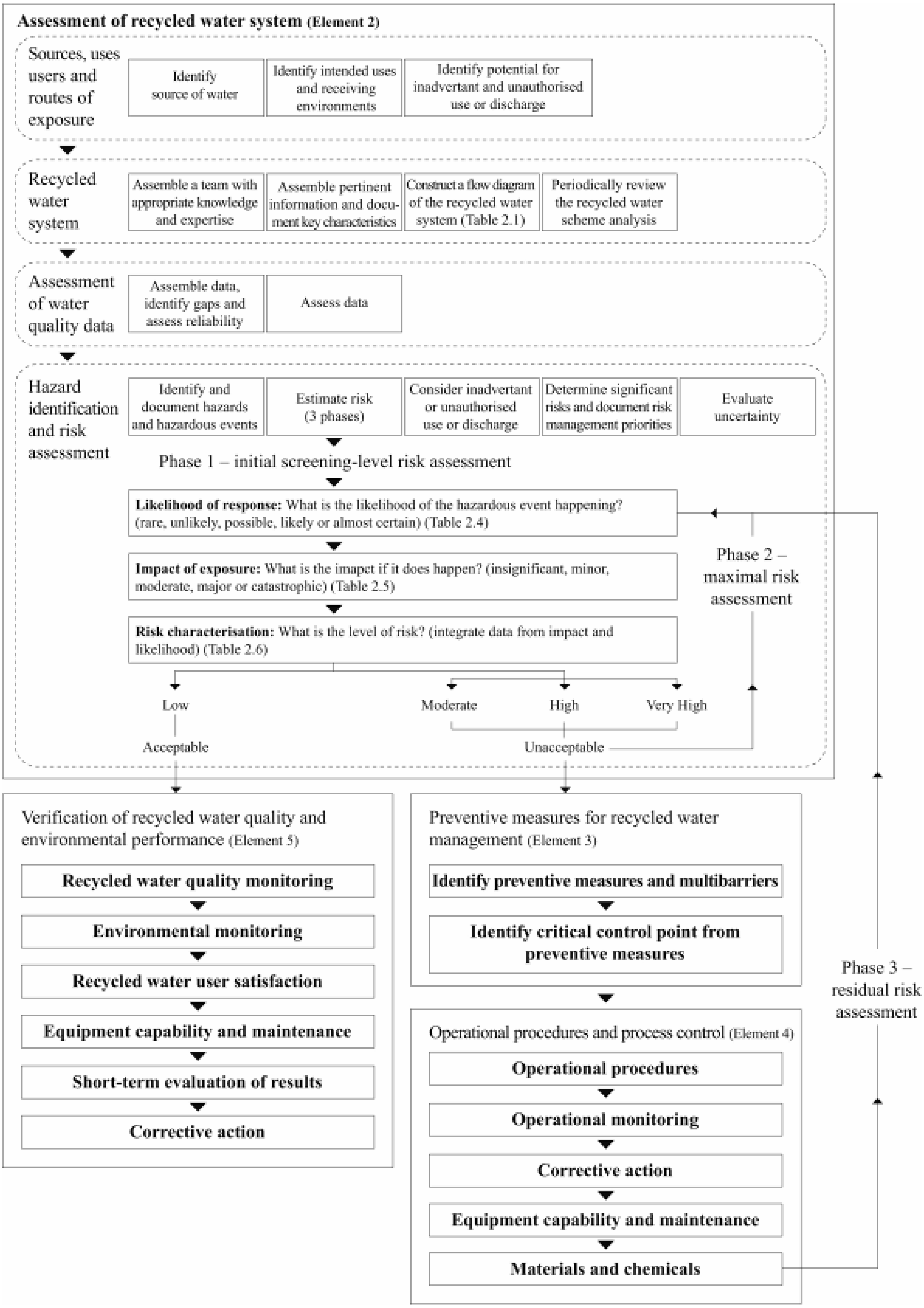

Table 4.1 Constituents potentially found in recycled water, which could pose a risk to the environment

General		
• Biochemical oxygen demand (BOD) • Dissolved oxygen • Hardness ($CaCO_3$) • Hydraulic load	• Odour • pH • Suspended solids • Temperature	• Total dissolved salts (TDS) • Total organic carbon (TOC) • Turbidity
Nutrients		
• Boron • Calcium • Chloride • Iron	• Magnesium • Nitrogen • Phosphorus • Potassium	• Sodium • Sulfur
Metals/metalloids/halides		
• Aluminium • Arsenic • Barium • Beryllium • Bromate • Cadmium • Chromium	• Copper • Cyanide • Fluoride • Iodine/iodide • Iron • Lead • Manganese	• Mercury • Molybdenum • Nickel • Selenium • Silver • Tin • Zinc
Surfactants		
• Alkane ethoxy sulfonates (AES)	• Linear alkylbenzene sulfonates (LAS)	• Secondary alkane sulfonates (SAS)
Organic compounds		
• Acrylamide • Alkyl phenols • Alkyltins compounds • Bisphenol A • Chlorinated dioxins • Chlorobenzene	• Dichlorobenzenes • Ethylenediaminetetraacetic acid (EDTA) • Epichlorohydrin • Hexachloro-butadiene • Nitrilotriacetic acid • Phthalates	• Polyaromatic hydrocarbons • Polychlorinated biphenyls • Styrene • Trichlorobenzenes • Vinyl chloride monomer
Volatile organics		
• Benzene • Carbon tetrachloride • Dichloroethanes • Dichloromethane	• Ethylbenzene • Tetrachloroethene • Toluene • 111-trichloroethane	• Trichloroethene • Xylenes
Pesticides or their metabolites (some examples)		
• 2,4-D • Aldicarb • Aldrin/dieldrin • Atrazine • Chlordane	• Chlorpyrifos • Diazinon • Dichloro-diphenyl-trichloroethane (DDT) • Diuron • Endosulfan	• Heptachlor and epoxide • Lindane • Organic mercurials • Pyrethroids • Other insecticides, fungicides and herbicides
Algal toxins		
• Cylindrospermopsin • Microcystins	• Nodularin	• Saxitoxins

Table 4.1 (continued)

Disinfection byproducts		
• Chloral hydrate • Chlorate • Chlorine dioxide • Chlorite • Chlorophenols • Chloropicrin	• Cyanogen • Formaldehyde • Haloacetic acids • Haloacetonitriles • Haloaldehydes • Halogenated furanones	• Haloketones • Monochloramine • Trihalomethanes
Radionuclides		
• Radium — 226 and 228	• Radon — 222	• Uranium generated (Cs137, Sr90, etc)
Pharmaceuticals		
• Analgesics – Ibuprofen – Ketoprofen – Morphine – Naproxen – Paracetamol	• Antibiotics – Amoxicillin – Cefaclor – Cephalexin – Metronidazole	• Cardiovascular drugs – Atenolol – Beta blockers
• Cholesterol-lowering drugs – Gemfibrozil – Simvastatin	• Histamine H receptor agonists – Ranitidine	• Oral contraceptives – Ethinylestradiol – Levonorgestrel
• Sedatives – Temazepam	• Other pharmaceuticals – Carbamazepine – Methamphetamine – Phenytoin – Radiopharmaceuticals	
Estrogenic and androgenic hormones		
• 17β estradiol	• Estrone	• Testosterone
Antiseptics		
• Triclosan	• Salicylic acid	

Note: Endocrine disruption can be caused by a range of chemicals, including many of those that may be listed under various headings in this table.
Source: Adapted from Radcliffe (2004)

A comprehensive database on potential environmental hazards and the guidelines that address them can be found in the *National Chemical Reference Guide* produced by the Australian Government Department of the Environment and Heritage.[5] This online guide is the first resource of its kind for Australia. It brings together information from around the world, on a range of environmental standards and guidelines. The comprehensive, searchable database contains more than 600 chemicals, encompassing various environmental standards for air, water, soil, sediment and biota (including plants).

The online chemicals guide also provides practical and concise summaries of:

- different ways in which environmental standards and guidelines have been developed and should be applied
- the standard and guideline documents used in the database
- the status of each standard and guideline

[5] Available online at http://www.deh.gov.au/chemicals-guide

- technical terms used.

Key environmental hazards

In developing these guidelines, the hazards in Table 4.1 were reviewed for certain uses of recycled water in Australia, including agricultural, municipal, residential and fire control. The review identified nine key environmental hazards that should be priorities for assessing the environmental risk associated with the specific uses of recycled water. These nine hazards are shown in Table 4.2, together with their environmental endpoints and effects on the environment.

A detailed risk assessment for each of these nine key hazards is given in Appendix 4, which includes, for each hazard:

- general information
- consideration of environmental risks
- one or more tables showing control points, preventive measures, target criteria, critical limits, critical controls points and verification procedures.

The review that identified the hazards listed in Table 4.2 did not cover environmental allocation of recycled water (ie allocation directly to waterways or water bodies to benefit the environment) in detail because, in some states and territories, such allocations would be regulated under water allocation plans or under discharge rules for effluent from recycled water treatment plants. However, the review did include an initial screening-level risk assessment (Phase 1 in Figure 4.1) of chemical parameters in recycled water, with the aim of assessing whether these chemicals posed a hazard for environmental allocation of recycled water.

For the review, the screening assessment for environmental allocation assumed:

- no dilution when the recycled water entered the water body to which it was allocated (in some cases it may be appropriate to include dilution in mixing zones when these are established and accepted)
- 99% protection of biota in the water body (see Table A5.2 in Appendix 5) as the trigger to step from insignificant impact to minor impact, and 95% protection of biota in the water body as the trigger to step from minor impact to moderate impact (see Table 4.4, below, for an explanation of qualitative measures of consequence or impact)
- maximum observed median concentrations of the chemicals listed in Table 4.2.[6]

The screening-level risk assessment identified nine additional hazards associated with use for environmental allocation, which are listed in Table 4.3, together with the nine key environmental hazards identified in the full risk assessment process.

There are many other issues associated with intentional or other environmentally beneficial release of recycled water that are not covered in these guidelines.

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[6] Note: Had the screening used the maximum concentration reported from a single sewage treatment plant (rather than the median from several sewage treatment plants across Australia), the assessment could be considered a worse-case scenario. Such an assessment would be appropriate if the recycled water were being allocated to a sensitive freshwater aquatic environment.

Table 4.2 Key environmental hazards, environmental endpoints and common effects on the environment when using recycled water for agricultural, municipal, residential and fire-control purposes

Hazard	Environmental endpoint	Effect or impact on the environment
Boron	Accumulation in soil	Plant toxicity
Cadmium	A low risk with respect to cadmium concentrations in recycled water, but cadmium already in soils can be made more readily available to plants if chloride concentrations increase. Chloride can be measured indirectly, but reliably, as salinity (see the salinity section below).	
Chlorine disinfection residuals	Plants	Direct toxicity to plants
	Surface waters	Toxicity to aquatic biota
Hydraulic loading (water)	Soil	Waterlogging of plants
	Groundwaters	Waterlogging of plants
	Groundwaters	Soil salinity (secondary)
Nitrogen	Soils	Nutrient imbalance in plants
	Soils	Pest and disease in plants
	Soils	Eutrophication of soils and effects on terrestrial biota
	Surface waters	Eutrophication
	Groundwaters	Contamination
Phosphorus	Soils	Eutrophication of soils and toxic effects on phosphorus sensitive terrestrial biota (native plants)
	Surface waters	Eutrophication
Salinity	Infrastructure	Salinity may cause rising damp or corrosion of assets; this can also arise from excessive hydraulic load (secondary salinity)
	Soils	Plants stressed from osmotic affects of soil salinity
	Soils	Contamination of soils by increasing plant availability of cadmium that is already in the soil
	Surface water	Increasing the salinity of fresh groundwaters
	Groundwater	Increasing the salinity of fresh surface waters
Chloride	Plants	Direct toxicity to plants when sprayed on leaves
	Soils	Plant toxicity via uptake through the root
	Surface water	Toxicity to aquatic biota
Sodium	Plants	Direct toxicity to plants when sprayed on leaves
	Soils	Plant toxicity via uptake through the root
	Soils	Soil structure decline due to sodicity

Table 4.3 Summary of environmental hazards identified in these guidelines

Key environmental hazards[a]	Additional hazards associated with use for environmental allocation[b]
Boron	Ammonium
Cadmium	Aluminium
Chloride	Arsenic
Chlorine disinfection residuals	Copper
Hydraulic loading (water)	Lead
Nitrogen	Mercury
Phosphorus	Nickel
Salinity	Surfactants — ie linear alkylbenzene sulfonates (LAS) and alcohol ethoxylated surfactants (AE)
Sodium	
	Zinc

a Hazards as listed in Table 4.3, identified by review of constituents listed in Table 4.2
b Hazards identified by initial screening-level risk assessment of constituents listed in Table 4.2 for fresh water. Many emerging chemicals that could be endocrine disrupting have not been measured in the wastewaters analysed in Table 4.2. These and other similar chemical may need consideration if recycled water is used for environmental allocations.
Note: Boron use in detergents is being reduced and the significance ofthis element as a key hazard could be reassessed in future revisions of these guidelines.

The environmental hazards listed in Table 4.3 represent most of those that will need to be assessed and managed in recycled water. However, the type and quality of recycled or greywater will vary significantly, depending on local factors, source water and regulatory controls. Thus, a wide range of hazards may be found in recycled water, at varying concentrations. Because of this situation, an initial screening-level risk assessment of all hazards for all intended uses may need to be undertaken where there is a risk that other hazards may be present (eg presence of a specific industry in sewage catchment). The sections on treated sewage (Section 4.4) and greywater (Section 4.5) provide tables showing the water quality likely to be found in those sources of water in Australia.

New hazards and those requiring a watching brief

For some hazards, little information is available, making risk assessment problematic. In addition, a watching brief is required for new or suspected contaminants of concern. If any part of a recycled water system changes, or new hazards are identified through the recycled water quality monitoring program (described in detail in Chapter 5), then a full risk assessment may need to be completed to:

- ensure the hazard is not a significant environmental risk
- confirm that the modification to the recycled water system has not introduced new specific endpoints and associated environmental risks.

A recent assessment by WHO has revealed that our current understanding of the effects of endocrine disrupting chemicals (EDCs) on the ecosystem is incomplete (WHO 2005). There is evidence that high-level exposure may affect wildlife and ecosystems, indicating that these hazards require further attention and that a watching brief should be maintained with respect to water recycling. Currently, there is some uncertainty over the possible effects of chronic, low-level exposures to a number of chemicals with endocrine disrupting potential. Risk assessments for EDCs will be difficult while information on the species that are most vulnerable to the effects of these hazards, and our understanding of how low-level toxicity affects individual populations and communities, remains limited.

At this stage, a watching brief should be included in reviews of the risk assessment completed for recycling water. These national guidelines should also be updated or amended as ongoing research in Australia and elsewhere leads to a better understanding of the impacts of EDCs.

More information on the current state of our knowledge of EDCs can be found on the websites of the WHO[7] and the Water Environment Research Foundation.[8]

Estimate likelihood of hazardous event occurring

Table 2.5 in Chapter 2 describes qualitative measures of likelihood.

This step involves estimating the likelihood that an environmental endpoint will be exposed to the hazard in sufficient concentrations to cause a detrimental effect; a step that requires adequate information and suitable expertise. The descriptors and definitions outlined in Table 2.5 (Chapter 2) are then used to rate the likelihood of an event occurring.

Likelihood of exposure to the environmental endpoint can often be determined by previous experience documented in reports (eg pipe bursts per year, tank leakage in other systems, cross-connections in other reuse schemes) or from professional opinion. For example, qualitatively, the likelihood of watering a lawn with recycled water is 'almost certain' (E in Table 2.5). To assess the likelihood of a main pipe bursting, it is necessary to check the age of the pipe and what it is made from, and compare that information with major pipe bursts identified from records kept within the relevant water authority. If the age and construction of the pipe are similar to those involved in major bursts, then the assessment may be that the likelihood is 'possible' (C in Table 2.5).

To assess the likelihood that a selected environmental endpoint will be exposed to concentrations sufficient to cause a detrimental effect, the concentration or total load of the hazard will need to be calculated and compared with known guideline values (these guideline values will be used to set the target criteria or critical limits discussed in Section 2.3.2).

Estimate consequences of hazardous event occurring

Table 2.6 in Chapter 2 describes qualitative measures of consequences or impact.

This section describes how to determine the consequences (or impact) of exposure to a hazard by considering:

- the size and nature of the environmental population exposed to the hazard (ie specific endpoints)
- the route, amount and duration of exposure.

The impact should be put into an environmental context by using Table 4.4 (below) to help determine, qualitatively, what the impact is.

[7] See http://www.who.int/ipcs/publications/new_issues/endocrine_disruptors/en/index.html
[8] See http://www.werf.org/pdf/04WEM6a.pdf

Table 4.4 Qualitative measures of consequence or impact

Level	Descriptor	Example of description
1	Insignificant	Insignificant impact or not detectable.
2	Minor	Minor impact for small population. Potentially harmful to local ecosystem with local impacts contained to site. Short-term reversible environmental impacts. No detectable change to ecology. Can be readily managed but nevertheless requires immediate action to minimise impacts. For example, a minor leakage of recycled water (fit for forestry irrigation) overland into a nearby creek causing some nuisance impacts (eg odour) or some stress to native plants (eg phosphorus-sensitive natives). Some manageable disruption to normal use or discharge.
3	Moderate	Minor impact for large population. Potentially harmful to regional ecosystem with local impacts primarily contained to on-site. Possible minor impacts on adjacent areas. Medium-term, generally reversible environmental impacts. Should the event occur, the environmental impacts could be readily contained or mitigated (eg eutrophication of waterway from runoff when irrigated with recycled water). Significant modification to normal disruption, affecting normal use or discharge, increased monitoring.
4	Major	Major impact for small population. Potentially lethal to local ecosystem. Predominantly local, but potential for off-site impacts. Medium- to long-term environmental impacts. Potentially reversible over a duration of several years. Significant impact on ecosystems. Should the event occur, the environmental impacts would be difficult to contain or mitigate (eg major fish kills, widespread death of flora and fauna). Significant modification to normal disruption, affecting normal use or discharge. Possible cessation of use. High level of monitoring required.
5	Catastrophic	Major impact for large population. Potentially lethal to regional ecosystem or threatened species. Widespread, on and off-site impacts. Catastrophic harm, should the event occur, the environmental impacts would be extremely difficult, if not impossible, to contain or mitigate (eg catastrophic impacts on World Heritage areas, or species, populations or ecological communities identified as threatened). Major failure of system leading to cessation of use.

Note: This table expands on Table 2.6.

The first step is to identify the pathway the hazard may take to enter the environment and its specific endpoint in the environment. Table 4.5 (below) illustrates what a standard risk assessment template might look like for identifying the pathway for a particular hazard (boron), with one entry point (irrigation) into the environment, and the potential effect.

Table 4.5 Standard risk assessment sheet for identifying exposure pathways and impact of a particular hazard

Hazard, exposure pathway, endpoint and effect					
Potential hazard	**Use or exposure pathway entry point**	**Receiving environment or receptor**	**Environmental endpoint**	**Most sensitive specific endpoint**	**Effect or impact on the environmental endpoint**
Boron	Irrigation	Air	Biota — aquatic		
			Biota — terrestrial		
			Infrastructure		
			Plants		
			Soils		
			Water — ground		
			Water — surface		
		Infrastructure	Biota — aquatic		
			Biota — terrestrial		
			Infrastructure		
			Plants		
			Soils		
			Water — ground		
			Water — surface		
		Plants	Biota — aquatic		
			Biota — terrestrial		
			Infrastructure		
			Plants		
			Soils		
			Water — ground		
			Water — surface		
		Soils	Biota — aquatic		
			Biota — terrestrial		
			Infrastructure		
			Plants		
			Soils		
			Water — ground		
			Water — surface		
		Water bodies	Biota — aquatic		
			Biota — terrestrial		
			Infrastructure		
			Plants		
			Soils		
			Water — ground		
			Water — surface		

Constituents of recycled water can affect the environment in several ways (see Table 4.6, below). In determining the potential impact, there are a number of factors to consider:

- What is the specific endpoint in the environment that will be exposed? What is the size and nature of the environmental population or component exposed to the hazards? For example, is it a sensitive waterway containing threatened species that rely on this water source to survive, or is it a garden pond with introduced species that can be readily obtained from a pet shop?
- What amount of the hazard will be involved? What are the concentrations or total amounts applied to the specific environmental endpoints being considered? For example, a pipe burst (unintentional discharge) that releases recycled water with a high sodium adsorption ratio (eg SAR = 8) on to a loamy clay soil along the reticulation route may expose the soil to an unacceptable high SAR, but pipe bursts can be fixed quickly if there is a good incident-management program. Therefore, the amount of water to which the soil will be exposed will be relatively low.
- How long will the exposure be for? Is this a once-off exposure or continual exposure for a long term? In the example above, the time the soil is exposed to the recycled water is relatively low, considering that pipe bursts infrequently happen in the same location and that continued irrigation for a number of years would be required to see sodic effects from a recycled water of this SAR.

Table 4.6 Common effects of key hazards in recycled water on the environment

Effects or impact	Description	Examples of impacts on the environment
Concentration	Increase in the amount or strength of something in recycled water, either through evaporation or more recycled water being added to a lesser volume.	If greywater is used in a household for toilet flushing, it could increase the salinity of effluent in a sewage system. Alternatively, if recycled water is stored in open shallow dams for long periods before use, the salinity and concentration of other key hazards could increase through evaporation.
Contamination	Increasing concentrations of unwanted constituents in environmental endpoints (eg soils, plants, water bodies, biota, etc).	Increased salinity concentrations in water can increase uptake of cadmium already in the soil by some plants that are then used for food. If sufficient cadmium is taken up by the plant, the concentration can exceed maximum permitted concentrations set by Food Standards Australia New Zealand (FSANZ). The food crop will then be unsuitable for human consumption (ie it will be contaminated with cadmium).
Eutrophication	Nutrient enrichment leading to increased productivity. Typically in the form of nitrates and phosphates, and most often from human sources such as agriculture, recycled water and urban runoff.	For example, in aquatic ecosystems eutrophication leads to excessive algal growth (blooms) with severe environmental impacts, such as shading light-depend organisms, which can result in the release of toxins, depleted oxygen levels in water, substantial mortality of biota and health risks to humans and other wildlife. Many natural water bodies are generally dominated by macrophyte plant communities. However, they can switch to being algal dominated under nutrient-enriched conditions, with cyanobacteria (which may produce toxins) being dominant in some cases. In native terrestrial systems that have developed in a low-nutrient environment, eutrophication typically results in a loss of biodiversity and an increase in weed invasion.
Loss of biodiversity	Mortality of native biota resulting in reduced ecosystems, species or genetic diversity.	For example, high phosphorus levels entering nutrient-deficient environments may cause excessive competition from introduced weeds, killing native vegetation.
Nutrient imbalance	Unbalanced supply of plant mineral nutrients resulting in plant deficiencies and toxicities.	For example, oversupply (fertilisation) with nitrogen may result in excessive vegetative growth and reduced fruit set for crops, or delays in maturation. Some fruits can also become pulpy or grainy. Leafy vegetable crops can also suffer from pests and diseases where canopies become shaded and retain high humidity, providing an ideal moist, nutritive environment for pests and diseases to thrive, especially fungi (Baier and Fryer 1973). Such problems may be exacerbated by sprinkler irrigation. Where too much nitrogen is supplied, plants may encounter deficiencies of other nutrients such as phosphorus or potassium if they are not provided in appropriate ratios. Uncontrolled and lush growth in the turfgrass industry can result in a soft, thatchy and disease-prone turfgrass.
Odour	A smell, especially one that is unpleasant.	For example, stagnant water bodies rich in nutrients can produce unpleasant smells.
Pest and disease	An insect or animal that destroys plants and an illness affecting plants, animals or other biota.	For example, sprinkler irrigation of crops, if excessive vegetative growth has occurred, may lead to pest and disease issues from humid microclimates around plants. If recycled water is used for animal husbandry (watering animals) or for fodder and pasture crops grazed by animals, pigs and cattle can be at risk of pig and beef measles.

Table 4.6 (continued)

Effects or impact	Description	Examples of impacts on the environment
Salinity	The presence of soluble salts in soils or waters. Electrical conductivity and total dissolved salts are measures of salinity.	For example, plants vary considerably in their susceptibility to osmotic and toxicity effects from salinity (Table A5.12–A5.16 in Appendix 5). As soils dry out, the salinity of the remaining soil water tends to increase, and so the effects become more severe. Plants affected by salinity have a reduced growth rate and show signs of water stress (eg wilting). Different stages of growth (seedling, juvenile, mature) can change a plant's tolerance to salinity. Leaves may suffer burning along the margins due to the combined effects of salinity, chloride and sodium toxicity (discussed below). Increases in salinity or more specifically chloride concentrations in the soils can potentially mobilise cadmium already present in the soil and lead to cadmium contamination (see above) of the plant.
Sodicity	Soil with excessive exchangeable sodium (>6%), leading to poor soil structure.	For example, the application of irrigation water with a high ratio of sodium to calcium and magnesium (measured as the sodium adsorption ratio or SAR), and low salinity, can make soils sodic. The risk (and occurrence) of soil sodicity in sandy soils is much lower than for clay soils, since sandy soils usually have only small amounts of clay, and readily leach sodium ions due to greater hydraulic conductivity and a low capacity to hold on to ions in the soil (low cation-exchange capacity). Conversely, clay soils tend to hold on to sodium ions on clay particles and do not readily leach excess ions if permeability is low. Consequently, clay soils are much more likely to display sodic properties. When a soil becomes sodic, plants have difficulty extending their roots through them and may also suffer from waterlogging and anoxia. Sodic soils are prone to runoff of irrigation and rain waters due to surface sealing and low hydraulic conductivities (permeability). Greater extremes of SAR will be found in greywater (Table 4.10 and 4.11) depending on the cleaning products used. High carbonate concentration can also increase sodicity by precipitation of calcium, increasing the SAR.
Toxicity	The extent to which a compound is capable of causing injury or death, especially by chemical means, to plants and other terrestrial or aquatic biota.	For example, boron toxicity can be displayed in sensitive plants, although growth and yield reduction are likely before toxicity symptoms are visually apparent. Toxicity symptoms usually appear first in older leaves, and include a yellowing and brown speckling pattern found between veins near the edge of the leaf, followed by the edge of the leaf gradually turning brown. It usually occurs first on older leaves. Other symptoms may include small brown necrotic spots over the cupping of leaves, and a red, purple or pink band (anthocyanins) surrounding necrotic tissue.
Waterlogging	Saturation of soil with water.	Where excess water is applied to the soil surface and it percolates down through the soil (leaching), it can cause ‘hydraulic loading’ to the extent that local or regional watertables rise. When the watertable reaches within <2 m of the surface, the plant rooting-zone, soils can easily become saturated (waterlogged). Perched watertables can have the same effect if the water applied exceeds the permeability of the soil.

Impact can be assessed semi-quantitatively; for example, by using appropriate data from reference tables (see Appendix 5), or qualitatively using expert advice. Catchment managers and state jurisdictions may apply different levels of protection to different environment or ecosystem conditions, relative to the baseline conditions.

Another approach to establishing predicted environmental concentrations is the use of fugacity modelling techniques. Fugacity and modelled risk are more quantitative risk assessments that can be used where there is appropriate data. More information on fugacity type and other modelling approaches can be found on the website of the Canadian Environmental Modelling Centre.[9] However, the environmental section of these guidelines focuses on a qualitative approach for this first step.

Assessment of impacts will involve setting or using target criteria or critical limits (discussed in Section 2.3.2) for the hazard being assessed. The criteria or limits considered, combined with the exposure time and total dose exposed to the specific environmental endpoint, should allow a qualitative or semiquantitative assessment of the impact. These target criteria and critical limits can then also be used for operational or verification monitoring (see Chapter 5).

Characterise risk

Table 2.7 in Chapter 2 provides a qualitative risk analysis matrix, used to determine level of risk.

The final step of the risk assessment is to characterise the risk by integrating the data on hazards, likelihood and consequence, obtained through the steps described above. Once the rating for likelihood and consequence are determined, a risk assessment matrix (see Table 2.7 in Chapter 2) can be used to determine the level of risk. Any risk that is rated as 'moderate' to 'very high' requires one or more preventive measures (described below in Section 4.3) to reduce the residual risk to levels sufficiently low as to be acceptable, as outlined in Figure 4.1.

The use of Table 2.7 can be illustrated by considering different situations. For example, if watering a lawn with recycled water using overhead sprinklers, the likelihood of the runoff entering a garden pond with a raised edge and causing eutrophication could be determined as 'unlikely'. Also, the impact of any algae bloom caused by eutrophication in a garden pond that has a small number of introduced aquatic species could be determined as 'minor'. Therefore, in this case, the risk would be considered to be 'low' (see Table 2.7, 'unlikely' × 'minor' = 'low risk').

However, if runoff from garden irrigation could enter a sensitive waterway nearby and cause an algal bloom (ie 'possible'), this could expose threatened species in the area to algal toxins, killing them or making their water undrinkable. In this case, the impact would be considered 'catastrophic'; thus, the risk would be considered 'very high' (see Table 2.7, 'possible' × 'catastrophic' = 'very high risk').

Table 4.7 shows examples of risk characterisations based on hazard identification, likelihood of a response and impact of exposure. Although the table does not include a screening-level risk assessment, such an assessment was used to identify salinity as a hazard requiring maximum and residual risk assessment. A range of preventive measures are indicated in Table 4.7 for each exposure pathway, endpoint and effect. The number and type of preventive measures that are appropriate depends on the site. For example, if existing preventive measures are insufficient to decrease the residual risk to low, other preventive measures should be sought, or a combination of measures used. If all preventive measures (or combinations) together do not decrease the residual

[9] See http://www.trentu.ca/cemc/

risk to low, then the site should be considered inappropriate for the specified use of this recycled water, and an alternative site should be assessed.

Appendix 5 provides examples of a more detailed risk assessment for risks determined to be moderate to high. In the tables given in Appendix 5:

- all risks determined to be low have been removed, to highlight the higher risk pathways identified through a general initial-screening risk assessment undertaken as part of developing these guidelines
- no specific endpoints have been identified, because this was a general risk assessment.

The pathway and risks considered for residential, municipal, agricultural and environmental use (see Figure 4.2) vary considerably from those for greywater use in a single household (see Figure 4.3).

Figure 4.2 Typical environmental risks to be assessed and managed for recycling water from treated sewage for residential, municipal, agricultural and environmental uses

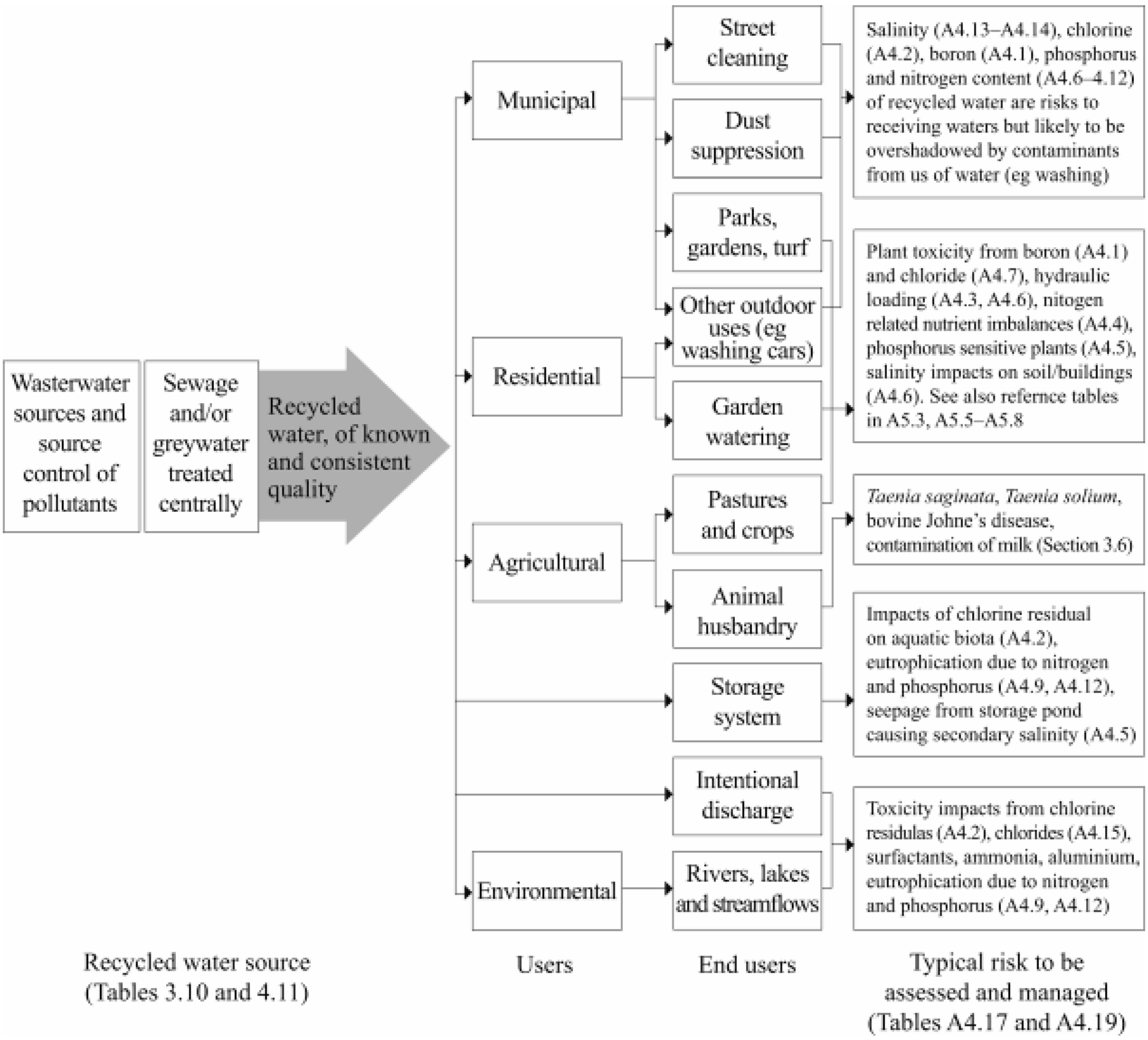
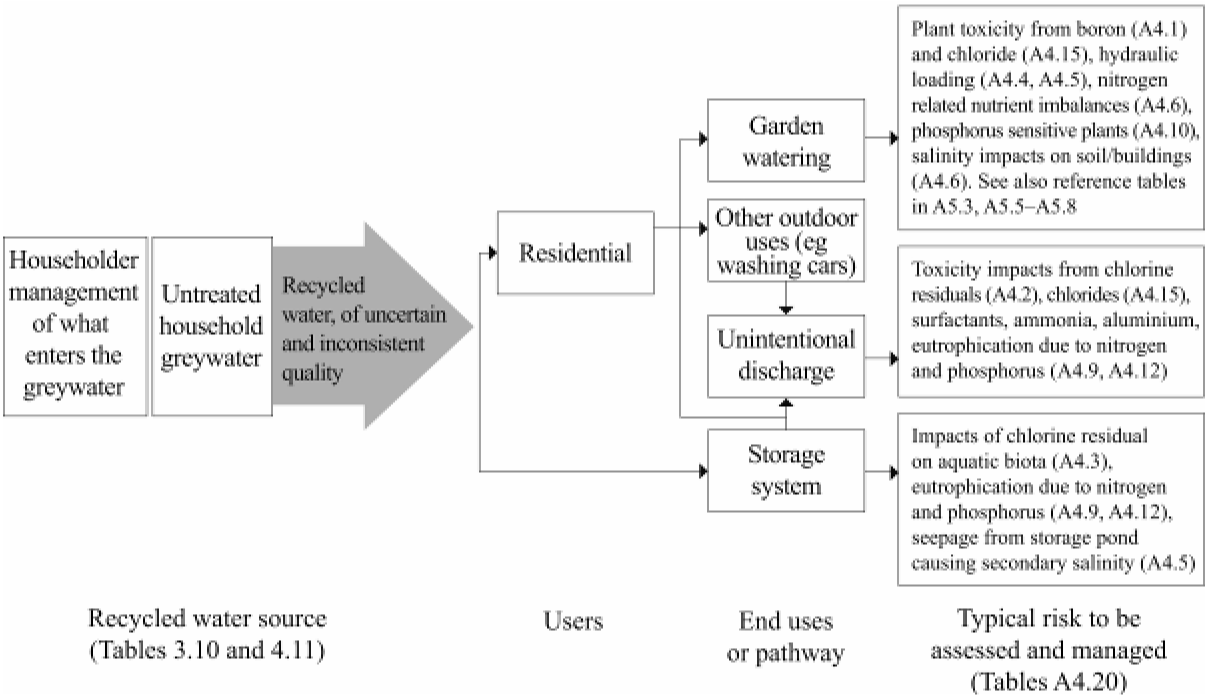


Figure 4.3 Typical environmental risks of residential use of single household greywater



Summary of hazard identification and risk assessment

In assessing environmental risks from recycled water, the many endpoints must be combined with the many key hazards, their possible impacts, the range of uses of the water and the pathways by which the water may enter the environment. Obviously, this combination of factors means that assessment of environmental risk can be a complex task. The level of detail in a risk assessment should be tailored to the scale and type of scheme. For very large schemes, many risk analyses may be needed, and each analysis may require preventive measures to ensure that the level of risk is reduced to acceptable levels.

The levels of detail and focus of the risk assessment should increase as the hazards are defined, risks identified and preventive measures instigated. The full risk management process must consider the factors listed in Table 4.8, and the steps shown in Figure 4.4.

Table 4.7 Example of an environmental risk assessment for sodium

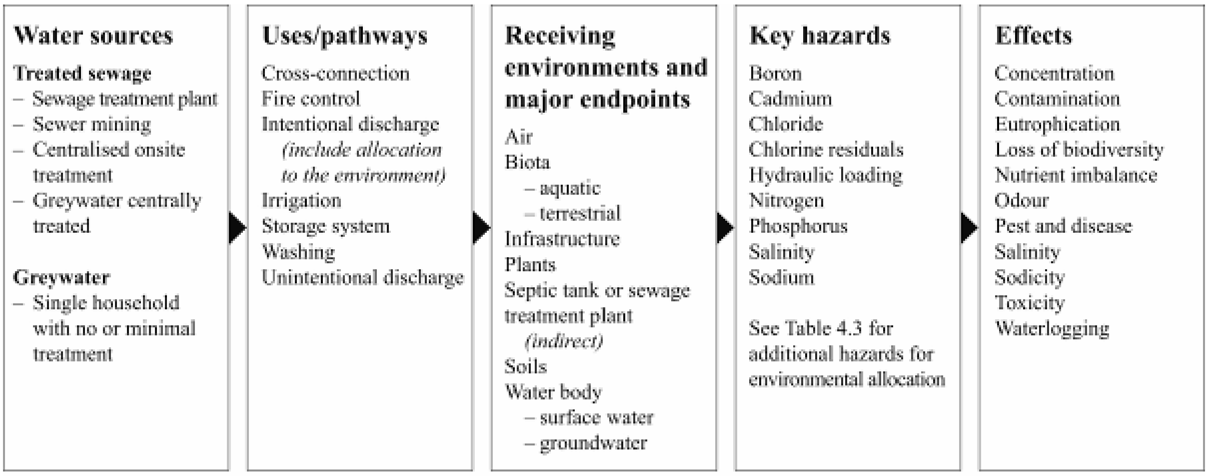
Hazard				Maximum risk (ie no preventive measures, uncontrolled)					Residual risk (ie with preventive measures)		
Use or exposure entry	Receiving environment or receptor	Environ-mental endpoint	Effect	Likelihood	Impact	Maximum risk[a]	Critical CP or CP in environmental pathway	Preventive measure/s	Likeli-hood	Impact	Resid-ual risk
Salinity											
Cross-connect-ion	Air		None								
	Plants	Plants	Toxicity	Rare	Minor	Low					–
	Soils	Plants	Salinity	Unlikely	Minor	Low					–
Irrigation	Air		None								–
	Infrastructure	Infrastructure	Salinity	Possible	Minor	Moderate	Soils	Site selection	Unlikely	Minor	Low
	Plants	Plants	Salinity	Unlikely	Minor	Low					–
	Soils	Plants	Salinity	Likely	Minor	Moderate	Plants	Crop/plants grown	Possible	Moderate	High
				Likely	Minor	Moderate	Irrigation	Irrigation tools	Possible	Moderate	High
				Likely	Minor	Moderate	Soils	Site selection	Unlikely	Minor	Low
				Likely	Minor	Moderate	Influent to sewage treatment plant	Hazard source control	Unlikely	Minor	Low
			Contamination	Possible	Moderate	High	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Possible	Moderate	High	Treatment process	Decrease concentration	Unlikely	Minor	Low
				Possible	Moderate	High	Soils	Soil ameliorant	Unlikely	Minor	Low
		Soils	Salinity	Unlikely	Minor	Low					–
			Sodicity	Possible	Moderate	High	Soils	Soil ameliorant	Unlikely	Minor	Low
				Possible	Moderate	High	Distribution system	Shandy — saline water	Unlikely	Minor	Low
				Possible	Moderate	High	Treatment process	Water treatment	Unlikely	Minor	Low
		Water — ground	Salinity	Possible	Moderate	High	Irrigation	Irrigation tools	Possible	Moderate	High
				Possible	Moderate	High	Soils	Site selection	Possible	Moderate	High
		Water — surface	Salinity	Unlikely	Moderate	Moderate	Irrigation	Irrigation tools	Rare	Moderate	Low
				Unlikely	Moderate	Moderate	Soils	Site selection	Rare	Moderate	Low
Storage system	Infrastructure		None								–
	Plants		None								–
	Soils		None								–
	Water body	Water — ground	Salinity	Unlikely	Moderate	Moderate	Storage system	Buffer distances/strips			
				Unlikely	Moderate	Moderate	Treatment process	Decrease concentration			
				Unlikely	Moderate	Moderate	Soils	Site selection			
Discharge uninten-tional or intentional	Air		None								–
	Infrastructure		None								–
	Plants	Plants	Toxicity	Rare	Minor	Low					–
	Soils	Plants	Salinity	Unlikely	Minor	Low					–
	Soils	Water — surface	Salinity	Unlikely	Minor	Low					
	Water body	Water — ground	Salinity	Possible	Moderate	High	Storage and distribution system	Design	Unlikely	Minor	Low
				Possible	Moderate	High	Groundwater	Monitoring	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Monitoring			
Washing	Air		None								–
	Infrastructure		Salinity	Possible	Minor	Moderate	Infrastructure	Monitoring	Rare	Minor	Low
	Water body	Water — surface	Salinity	Unlikely	Minor	Low					–
	Plants	Plants	Toxicity	Rare	Minor	Low					–
	Soils	Plants	Salinity	Unlikely	Minor	Low					–

CP= control point
Highlighting indicates a high or moderate maximum risk
a If low, no preventive measures are required and therefore no residual risk assessment is required

Table 4.8 Factors to be considered in a full risk assessment process

Hazards		
Consider all hazards that do not pass the initial screening level of the risk assessment; key hazards are:		
• boron	• chlorine residuals	• phosphorus
• cadmium	• hydraulic loading	• salinity
• chloride	• nitrogen	• sodium
Uses		
Consider the entry point of the hazard into the environment:		
Entry point	Example	
cross-connection	– connection of recycled water systems with higher quality sources of water (eg drinking water), producing a mixed supply	
backflow prevention device	– devices to prevent flow of recycled water into other water sources; this may be most relevant for human health if the water source is a drinking water supply	
• discharge (intentional or unintentional)	– intentional allocation for the benefit of the environment, equipment maintenance, pressure release, cleaning of pipes; failure of storage facilities or reticulation systems	
• fire control	– controlling fires in urban environments	
• irrigation	– watering roads to suppress dust, irrigation of crops, gardens and parks	
• storage system	– holding recycled water before reticulation, or storage on a property before use	
• washing	– streets, equipment, infrastructure	
Receiving environments and major endpoints		
Consider the initial receiving environment or endpoint (where the hazard potentially impacts on the environment):		
• air	• plants	• recycled water treatment plant or greywater reuse in-house
• biota — aquatic	• soils	
• biota — terrestrial	• water bodies — groundwater or surface water	
• infrastructure		
Effect		
Consider what the effect will be on:		
• concentration	• nutrient imbalance	• sodicity
• contamination	• odour	• toxicity
• eutrophication	• pest and disease	• waterlogging
• loss of biodiversity	• salinity	

Figure 4.4 Factors to be considered in environmental risk assessment



4.3 Preventive measures to manage risk

This section should be read in conjunction with Section 2.3 of Chapter 2.

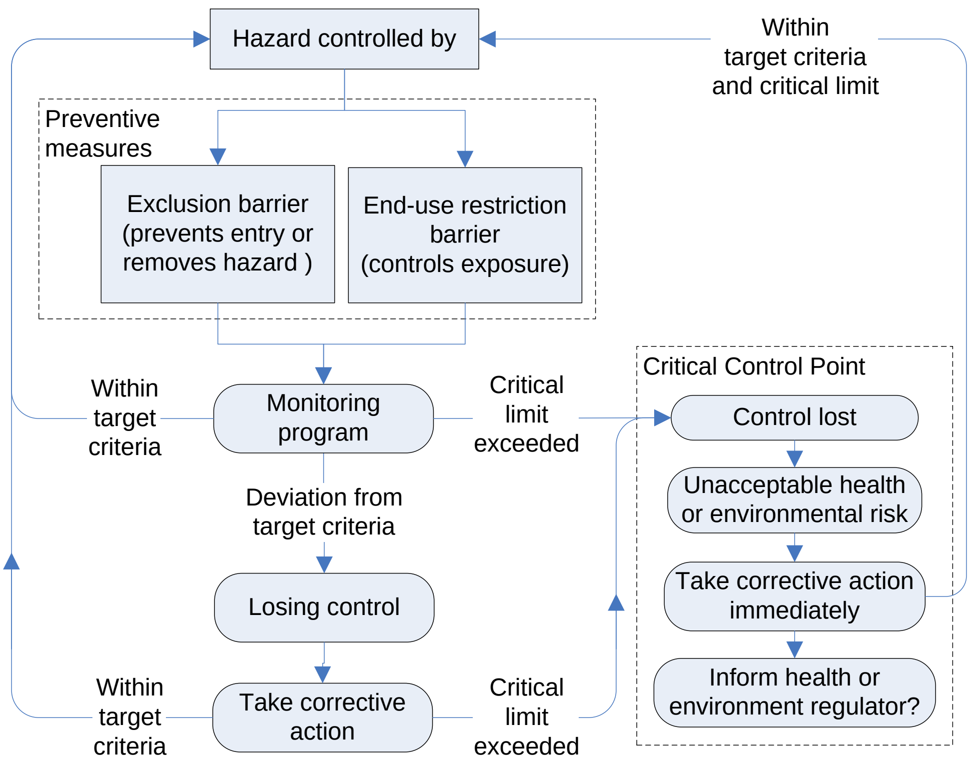
Preventive measures are used to manage the risk of detrimental impacts on the environment by reducing the risk to acceptably low levels. The measures for recycled water can be either exclusion barriers or end-use restriction barriers, as discussed in Chapter 2. Preventive measures are particularly important where an assessment of maximum risk has shown that risks are unacceptable.

The preventive measures used will generally depend on the source water quality and how water is managed on-site. Due to the wide array of environmental endpoints, the measures are generally framed in terms of one of the following:

- the most sensitive, specific endpoint for the recycled water (eg crops or plant to be irrigated with the recycled water)
- known environmentally sensitive targets (eg groundwater beneath the irrigation area, or environmentally sensitive water bodies nearby).

As described in Chapter 2 (Section 2.3.2), a critical control point is an activity, procedure or process where controls can be applied, and that is essential for preventing or reducing risk to acceptable levels. Target criteria can be defined for operational monitoring and control, and used as summarised in Figure 4.5.

Figure 4.5 How preventive measures and critical control points relate to target criteria and critical limits



Box 4.2 completes the example shown above in Box 4.1 for the four different plant species chosen as specific endpoints in the case of recycled water being used to irrigate an oval and nearby municipal gardens containing various native plant species.

Box 4.2 Example of determination of target criteria

The endpoint that is most sensitive to the hazard being assessed will often define the critical limits or target criteria for that hazard. In the example given in Box 4.1 (above), the sensitivity of the four plants to salinity varies, as shown by the ECe (electrical conductivity of a soil paste extract) and the ECi (electrical conductivity of irrigation water) in a sandy loam soil (see Tables A5.11 and A5.14 in Appendix 5):

- kikuyu — ECe of 2–4, ECi of 1.7
- grey box — ECe of 2–4, ECi of 1.7
- red box — ECe of < 2, ECi of 1.3
- Merrall's wattle — ECe of 4–8, ECi of 3.4.

It is clear from these values that red box eucalypt is the most sensitive plant (ie has the lowest salinity tolerance of the plants considered); therefore, the target criteria for recycled water salinity on this sandy loam soil would be set at an EC of 1.3 deci-Siemens (ds) per metre.

Examples of a range of critical control points and preventive measures that should be considered in managing environmental risks posed by recycled water are shown in Table 4.9, below. Most of these preventive measures are exclusion barriers (either hazard source control or recycled water treatment). Critical limits for recycled water quality can be defined by determining the most sensitive specific environmental endpoints using guideline values (see reference tables in

Appendix 5) or nutrient budgeting, generally for nitrogen and phosphorus (ie balancing nutrient loads from recycled water with plant nutrient requirements while minimising movement of nutrients off-site (see Appendix 5).

Table 4.9 Summary of preventive measures and critical control points

Preventive measures	Description	Critical control point
Exclusion barriers — preventing entry		
Hazard source control	Water and wastes entering the recycled water from where the water is to be recycled. For example, greywater systems may have a diverter switch to allow the householder to choose the frequency and content of greywater entering the garden. Some household detergents are lower in concentrations of specific hazards than others (Landloch 2005), or sewage treatment plants may have an agreement with industries to prevent hazards entering the sewerage system.	Particularly for greywater use, as there is possibly limited treatment available
Exclusion barriers — removing hazards		
Treatment processes	Decrease concentration	Possibly at the point of release into the recycled water reticulation system. Depends on the hazard and effect on the specific environmental endpoint.
End-use restriction barriers (note that none of these barriers are critical control points)		
Buffer distances/strips	Distances between water use and areas where the recycled water enters sensitive endpoints (Appendix 6).	
Design	The design of the systems is appropriate for the delivery of the required function in the recycled water pathway (ie treatment to user endpoints, such as storage and reticulation)	
Drainage	Constructed or natural system to intercept or allow water moving through, or stored in, the soil profile to drain to a specified location, leading to reduction in the water content of that soil and production of drainage water	
Crop/plants grown	Plants for harvest as food, feed or forage, or for ornamental uses such as gardens or municipal areas	
Incident management	Planned response to unplanned event (incident)	
Irrigation tools	Irrigation scheduling devices and controls that monitor and/or control water application rates, soil moisture and water movement through the soil	
Interception system	A system that intercepts the movement of hazards off-site, preventing the exposure of the hazards to sensitive environmental endpoints	
Light reduction	Decrease light exposure to aquatic organisms (eg used for algae growth control in nutrient-rich waters)	
Maintenance	Programs in place that help maintain infrastructure associated with the recycled water pathway through the environment, from production to use and final endpoint in the environment	
Nutrient balancing or budgeting	Matching nutrients supplied to a plant or crop with its nutrient demands, taking into account existing reserves in the soil and estimated productivity of the plant or crop	
Odour control	Controlling smells or odours so they do not reach sensitive organisms	
Ground cover	Plants grown or material placed on the ground to prevent erosion of topsoil or to slow the movement of water over the soil	
Shandy or mixing with other water sources	Mixing water with other sources to decrease or, in rare cases, increase hazard concentrations (eg if salinity is too low for the sodicity of the water)	
Site selection	Selection of site or soils that are better suited to the type of recycled water to be used.	
Soil ameliorant	Product that can be added to soils to improve chemical or physical properties (eg lime to increase pH, or dolomite or gypsum to reduce soil sodicity)	

Table 2.4 (continued)

End-use restriction barriers (note that none of these barriers are critical control points)	
Stormwater control	Management of runoff from rainfall events to control its path through the environment
Treatment process	Allow time to dissipate chlorine disinfection residuals or use a commercial chlorine neutraliser (some aquatic biota are sensitive to chlorinated disinfection residuals)
Training	Teaching and learning to improve knowledge and develop skills related to the treatment, reticulation and use of recycled water
Washing	Using to clean equipment, infrastructure, plant and for any other allowed cleaning use

Note: These lists are not definitive; other critical control points and preventive measures may be more appropriate for a specific reuse scheme. Education and training are an important component of implementing and maintaining prevention measures. See Appendix 3 for a detailed description of preventive measures for specific hazards and recycled water uses.

For environmental risk management, target criteria can also be set for verifying recycled water quality and environmental performance. The criteria should relate to the preventive measure implemented. For example, in a situation where lettuce is assumed to be the most sensitive specific environmental endpoint and the soil has a texture of light clay, the following limits might be set:

- a critical limit for recycled water salinity of 0.7 dS/m (Table A5.15)
- a target criterion for operational monitoring for recycled water of 0.65 dS/m (ie just below the critical limit of 0.7 dS/m)
- a target criteria for verification with environmental monitoring of soil with an ECe not more than 1.3 dS/m (Table A5.15).

Chapter 5 provides more information on verification and operational monitoring in general, and on monitoring for environmental risk management specifically.

4.4 Treated sewage

This section looks at the following aspects of water recycled from treated sewage:

- quality of treated sewage (Section 4.4.1)
- environmental risks(Section 4.4.2)
- microbial hazards (Section 4.4.3).

4.4.1 Quality of treated sewage

The physical, chemical and biological properties of recycled water vary considerably, depending on the treatment process, source water quality and inputs into the recycled water stream. Table 4.10 shows the average median values reported for some chemical properties from up to 40 different water treatment plants in Australia. The minimum and maximum median values are also included, to give an indication of the range and variability in water quality parameters. Information for this table was received from water treatment plants in all states of Australia, ranging in size from those treating less than 1 ML of water per day to those treating more than 100 ML treated per day. At this gross scale, the different treatment processes did not show clear effects on the water quality, probably due to variability in the source water quality and the level of treatment provided.

Table 4.10 Chemical constituents of sewage that could be used as a source of recycled water

			From reported median			
Parameter	**Symbol**	**Units**	**Average**	***n***	**Minimum**	**Maximum**
Total nitrogen	N_{tot}	mg/L	15.2	40	2.8	39.0
Ammonium	NH_4	mg/L	8.4	11	0.1	34.0
Total phosphorus	P_{tot}	mg/L	5.9	40	0.0	12.0
pH		pH	7.9	31	6.2	9.8
Total dissolved salts	TDS	mg/L	675	25	145	1224
Electrical conductivity	EC	dS/m	1.3	15	0.2	2.9
Sodium adsorption ratio	SAR	$(mmol_c/L)^{0.5}$	6	15	3	12.2
Sodium	Na	mg/L	181	12	62.0	312.0
Calcium	Ca	mg/L	35	13	10	74.0
Magnesium	Mg	mg/L	19	13	6	40.0
Chloride	Cl	mg/L	135	10	9.3	340.0
Aluminium	Al	µg/L	227	10	11.0	665.0
Arsenic	As	µg/L	1.9	7	0.0	4.0
Barium	Ba	µg/L	9.7	5	1.0	37.5
Boron	B	µg/L	289	9	90	480
Cadmium	Cd	µg/L	0.3	8	0.1	0.5
Chromium	Cr	µg/L	9.4	9	1.0	21.0
Cobalt	Co	µg/L	0.7	5	0.4	1.3
Copper	Cu	µg/L	23.5	15	2.0	91.0
Cyanide	CN	µg/L	<1.0	4		
Iron	Fe	µg/L	722	11	30	4725
Lead	Pb	µg/L	5.4	10	1.0	20
Manganese	Mn	µg/L	35.2	7	19.0	69
Mercury	Hg	µg/L	0.1	6	0.1	0.2
Molybdenum	Mo	µg/L	9.8	5	1.0	21
Nickel	Ni	µg/L	7.0	14	2.0	20
Silver	Ag	µg/L	2.6	2	0.1	5.0
Zinc	Zn	µg/L	48	16	4.9	110
Selected organics						
Anionic surfactants		µg/L	200	2	200	200
Phenol		µg/L	4.6	2	0.5	7

n = number of samples for a particular parameter

Note: Possible recycled water sources surveyed from 40 sewage treatment plants across Australia

4.4.2 Environmental risks associated with recycling water from treated sewage

Tables A4.17–A4.20 in Appendix 4.9 provide examples of generic risk assessments for various uses — agricultural, municipal and residential; fire control; environmental allocation; and domestic use on a single residential property.

The tables in Appendix 4.9 show only the risks determined to be moderate to very high. The tables do not include low-risk pathways (to highlight those risks that will generally require preventive measures), and do not identify specific environmental endpoints (because of the generic nature of the risk assessment). If the full risk assessment table were shown (ie including risks determined to be low), there would be many cases where the pathways identified lead to no effect on the environment. The tables in Appendix 4 are a guide to some of the hazards and risks commonly associated with various uses of water recycled from treated sewage. They are not a definitive list and should not be treated as such.

Any risk assessment needs to take into account:

- the site-specific nature of the source water, treatment methods
- the final quality of the recycled water
- the final specific environmental endpoint identified as the most sensitive.

All environmental risk assessments should begin with an initial screening-level assessment, followed by a maximum and then a residual risk assessment.

4.4.3 Microbial hazards to the environment in water recycled from treated sewage

At this stage, environmental impacts of microorganisms from treated sewage have not been identified. Human health impacts are discussed in Chapter 3. If receiving waters are used for purposes involving human exposure, then risk assessments should be undertaken as described in Chapter 3.

4.5 Greywater within a single property

This section looks at the following aspects of water recycled from greywater:

- quality of untreated greywater (Section 4.5.1)
- environmental risks associated with greywater (Section 4.5.2)
- microbial hazards associated with greywater (Section 4.5.3).

4.5.1 Quality of untreated greywater

There are limited data on the constituents of greywater. Table 4.11 summarises the hazards that could be found in greywater and their likely concentrations, based on data from Australia and overseas. The data shown here were used to identify the key hazards and the environmental risks associated with the recycling of greywater in Australia. However, because of the large variability in greywater quality parameters and the site-specific nature of greywater risk assessments, each user should carefully consider what other hazards might be in their greywater. Householders should pay particular attention to the chemical components of products they use in the household, because these may add significant loads of the hazards outlined in Table 4.11 to soils. If householders are in any doubt, they should contact the manufacturer of the products they intend to use.

Recommendations that minimise human health risks (Chapter 3) considerably restrict the uses of greywater, and consequently reduce environmental exposure and risk.

Table 4.11 Chemical constituents observed in greywater in Australia and internationally

Parameter	Abbreviation or symbol	Units	Mean	*n*	Minimum	*n*	Maximum	*n*
Suspended solids	SS	mg/L	99.2	14	2	10	1500	11
Biochemical oxygen demand (5 days)	BOD_5	mg/L	429	10	6	7	620	7
Total organic carbon	TOC	mg/L	276.8	8	30	2	92	2
Total Kjeldahl nitrogen	TKN	mg/L		0	0.6	4	50	4
Total nitrogen	N_{tot}	mg/L	14.6	15	0.6	3	16	4
Ammonium	NH_4-N	mg/L	2.4	23	0.06	6	25.4	14
Nitrite	NO_2	mg/L		0	0	2	4.9	4
Total phosphorus	P_{tot}	mg/L	15.0	9	0.04	8	42	9
Phosphate	P-PO_4	mg/L	34.4	13		0		0
Sulfate	SO_4	mg/L		0	4	3	168	5
pH		mg/L	8.1	6	5	13	10	13
Electrical conductivity	EC	dS/m	0.4	1	0.08	5	1.3	5
Total dissolved salts	TDS	mg/L		0	52	3	5960	3
Sodium adsorption ratio	SAR		6.4	8	0.79	7	32.2	8
Sodium	Na	mg/L	89.9	9	7.4	8	1090	9
Calcium	Ca	mg/L	20.9	8	2.3	7	824	8
Magnesium	Mg	mg/L	5.8	8	0.7	7	19	8
Chloride	Cl	mg/L		0	3.1	3	136	3
Fluoride	F	mg/L		0	0.49	2	1.6	2
Potassium	K	mg/L	20.2	7	1.1	2	17	2
Sulfur	S	mg/L		0	1.2	2	40	2
Aluminium	Al	mg/L	1.5	5	0.02	2	44	6
Iron	Fe	mg/L	0.4	1	0.79	1	28	4
Arsenic	As	µg/L	0	1	0.2	2	13	3
Boron	B	µg/L	630	3	0	0	0	0
Cadmium	Cd	µg/L	0.45	4	0	0	50	3
Copper	Cu	µg/L	135.7	10	18	3	490	7
Cobalt	Co	µg/L	0.9	2	0	0	1.5	1
Chromium (total)	Cr	µg/L	3.7	1	0	0	5.5	1
Mercury	Hg	µg/L		0	0	0	0.02	1
Manganese	Mn	µg/L	23	2	0	0	14.3	1
Molybdenum	Mo	µg/L	1.1	1	0	0	0	0
Nickel	Ni	µg/L	11	1	0	0	28	1
Selenium	Se	µg/L	0.2	1	0	0	0	0
Strontium	Sr	µg/L	60.3	1	0	0	0	0
Zinc	Zn	µg/L	300	10	90	5	13000	7
Lead	Pb	µg/L	0	4	0	0	150	2

n = number of sample available from the studies reviewed for a specific parameter. The values of *n* vary for mean, minima and maxima because data were published in different formats (eg some just provided maxima, others just provided means, etc).

Source: Jeppesen and Solley (1994), A-Boal et al (1995), Department of Health WA (2002), Eriksson et al (2002), Gardner and Millar (2003), Palmquist and Jönsson (2003), Landloch (2005)

4.5.2 Environmental risks associated with greywater

Appendix 4 provides examples of generic risk assessments (undertaken using the principles outlined in Section 4.2) for greywater reuse on the property where it is produced.

As explained above for water recycled from treated sewage, the tables in Appendix 4 show only the risks determined to be moderate to very high for recycling water from greywater. The tables do not include low-risk pathways, and do not identify specific environmental endpoints. If the full risk assessment table were shown (ie including risks determined to be low) there would be many cases where there the pathways identified would not lead to an effect on the environment. Table A4.20 is a guide to some of the hazards and risks commonly associated with the use of water recycled from greywater; it is not a definitive list and should not be treated as such.

Source control that is constantly maintained is a useful preventive measure for recycling water from greywater. For example, if water from clothes washing machines is recycled for garden use, detergents that are low in sodium and boron should be used. Alternatively, a flow diverter should be used so that the wash cycle is directed into the sewer and the rinse cycle to the garden. Both these preventive measures will minimise the amounts of hazards entering the garden environment.

Any greywater risk assessment needs to consider:

- site-specific conditions (soil, rainfall, slope, etc)
- nature of the water source water
- any treatment
- final quality of the greywater in relation to the site where it enters and then passes through the environment
- the final specific environmental endpoint identified as most sensitive for each hazard.

All environmental risk assessments should begin with an initial screening-risk assessment, followed by a maximum risk assessment and then a residual risk assessment.

4.5.3 Microbial hazards in greywater

At this stage, environmental impacts of microorganisms in greywater have not been identified. Human health impacts are discussed in Chapter 3. If receiving waters are used for purposes involving human exposure, then risk assessments should be undertaken as described in Chapter 3.

4.6 Monitoring

Within a risk management plan, monitoring is used to assess whether preventive measures reduce or maintain risks at acceptable levels. Chapter 5 discusses monitoring, and includes a section on monitoring of environmental risks.

5 Monitoring

This chapter describes the requirements for monitoring recycled water systems. It considers both general monitoring requirements and those specific to health and the environment. The chapter covers:

- general principles (Section 5.1)
- types of monitoring (Section 5.2)
- monitoring of management of health risks (Section 5.3)
- monitoring of management of environmental risks (Section 5.4)
- quality control and quality assurance (Section 5.5)
- laboratory and data analyses (Section 5.6 and 5.7)
- reporting, reviewing and information dissemination (Sections 5.8 and 5.9).

5.1 General principles

Monitoring can be undertaken for a range of purposes; for example, it can be used to:

- obtain baseline information (to underpin the risk assessment process)
- determine whether recycled water systems will be safe and not have adverse effects on human health or the environment (validation)
- ensure that preventive measures are working (operational monitoring)
- determine whether the recycled water system has operated effectively, achieved compliance with management requirements, and has not represented a risk to public health or had detrimental effects on the environment (verification)
- provide information needed for investigation, follow-up and research.

Monitoring may also form part of the surveillance undertaken as a statutory requirement under licence or approval from a regulatory authority.

Detailed guidance on the designed and development of monitoring programs is provided in the *Australian Guidelines for Water Quality Monitoring and Reporting* (ANZECC and ARMCANZ 2000b). In the context of recycled water quality management, good monitoring programs should:

- have clearly defined objectives of monitoring, set within the context of the recycled water management plan
- be carefully designed, to ensure that the stated monitoring objectives will be met
- make clear what data will be gathered, how it will be obtained and how results will be used
- use sampling and analytical techniques that are reliable and sufficiently sensitive
- include analysis and reporting of data, to provide valuable information to inform the operation of the recycled water system

- be developed in conjunction with stakeholders with whom confidence needs to be built, such as users and regulators or authorities responsible for auditing the performance of the recycled water system.

The range of parameters and the frequency of testing included in monitoring programs will depend on a range of factors, including the size of the scheme and the potential exposure associated with the end use. Monitoring programs for large urban sewage treatment plants providing recycled water for dual reticulation or unrestricted municipal irrigation will be far more extensive than those for rural sewage treatment plants providing recycled water for drip irrigation of grape vines. A practical and pragmatic approach needs to be adopted in designing monitoring programs.

5.2 Types of monitoring

The principal types of monitoring are:

- baseline monitoring (ie 'Where are we now?')
- validation monitoring (ie 'Will it work?')
- operational monitoring (ie 'Is it working now?')
- verification monitoring (ie 'Did it work?').

The main functions of each of these types of monitoring are given in Table 5.1 below.

Table 5.1 Purpose of main types of monitoring

Type of monitoring	Main functions
Baseline	Gather information that will underpin the risk assessment process and provide a basis for assessing potential impacts of the use of recycled water on the environment
Validation	Obtain evidence that the elements of the recycled water quality management plan will achieve performance requirements
Operational	Conduct a planned sequence of observations or measurements of control parameters to assess whether a preventive measure is operating within design specifications and is under control
Verification	Apply methods, procedures, tests and other evaluations, in addition to those used in operational monitoring, to determine compliance with the recycled water quality management plan, and to determine whether the plan needs to be modified

Baseline monitoring is undertaken before establishing recycled water systems, whereas validation, operational and verification monitoring are undertaken when establishing and running a recycled water system. These latter forms of monitoring are common to risk management systems, such as the hazard analysis critical control point (HACCP) approach, and can be defined as shown in Figure 5.1, below.

The remainder of this section looks in detail at each of the types of monitoring.

Figure 5.1 Characteristics of different types of monitoring in a recycled water scheme

Validation monitoring ('proving' or 'testing'):

- is intensive; it takes place before the scheme goes live and again after changes are made; it is linked to commissioning
- is likely to focus on microbial indicators (sometimes pathogens) to demonstrate that the scheme performs as designed with respect tolog reductions
- *for health* — may assess the practicality and acceptability of usage controls, to demonstrate that they are realistic and workable.

Operational monitoring:

- focuses on the performance of all preventive measures, particularly those associated with critical control points
- needs to be of an intensity commensurate with the variability and criticality of the specific preventive measure
- is likely to include a broad range of parameters, with observation, inspection and electrochemical devices being used to demonstrate that the system is operating as intended
- can be in the form of laboratory microbial and chemical analysis if turnaround times are adequate to give warning of nonconformance before recycled water is supplied.

Verification monitoring:

- is independent of operational monitoring
- generally takes place at the point where treatment is considered complete, either at the end of the system or before discharge into open storages
- includes auditing of plant operations, and on-site usage controls to test compliance
- *for health* — involves using microbial indicators, and sometimes pathogens, to demonstrate that the scheme is continuing to perform as designed with respect to log reductions.

5.2.1 Decentralised systems still require centralised monitoring

In extremely small systems, such as single household systems, monitoring of every system can be impractical. In such cases, the oversighting agency should take representative samples from typical schemes at the recommended frequencies through a centralised monitoring program. For example, if an agency permits the recycling of household greywater, local-scale sewer mining or some other form of decentralised water recycling in an area, that agency should undertake, or require, monitoring of:

- the quality of the recycled water
- compliance with system performance, plumbing and usage controls
- the effect of recycled water use on the receiving environment.

The monitoring would not cover every system, but would need to be undertaken at representative locations at sufficient sites to provide statistical confidence in the results. Ideally, some of the centralised monitoring program would be undertaken at reference sites to provide long-term data, and some would be scattered across additional random sites to help detect unanticipated issues.

5.2.2 Baseline monitoring

This section should be read in conjunction with Section 2.2 of Chapter 2.

Baseline monitoring is used to provide information for the risk assessment. Both the source of recycled water and the receiving environment need to be characterised. Baseline monitoring needs to be sufficiently exhaustive that sources of variation, such as seasonal and diurnal effects, are captured and so that trends can be detected.

The purpose of baseline monitoring of the source of recycled water is to establish what hazards are present, at what concentrations and how they vary with time and conditions. It is advisable to consider both published information on the types of contaminants likely to be present in the recycled water source as well as undertaking monitoring of the specific source. A combination of these two sources of data and information will be required in undertaking the risk assessment.

The initial purpose of baseline monitoring of the receiving environment is to define properties of the receiving environment that would inform the risk assessment. In addition, in the longer term, the baseline monitoring provides a point of reference to test for environmental impacts as part of verification monitoring.

5.2.3 Validation monitoring

This section should be read in conjunction with Section 2.9 of Chapter 2.

Validation monitoring is used to determine whether preventive measures are capable of adequately controlling recycled water quality and exposure levels within the bounds required to achieve health and environmental target criteria. As far as practicable, validation monitoring should be completed before recycled water is supplied for its ultimate intended uses, although it may continue into a pilot-testing period.

Because full validation is usually only performed once for each system configuration, it should be thorough; for example, it might involve checking that every recycled water pipe, connection, tap and irrigation system is properly marked, and that fittings and labelling methods used to control use are as intended. Although this is an extensive initial activity, it can be delegated to appropriately skilled professionals.

Once the setup of the whole system has been validated, it is generally sufficient to monitor and audit samples of the system, as part of operational and verification monitoring. However, further validation is needed for variations such as seasonal changes, and all new processes and configurations should be validated to confirm that a modified recycled water system achieves the required results.

Validation should be performed, or at least overseen in detail, by an independent and appropriately qualified professional or group of professionals. For example, validation of a disinfection system would require expertise in microbiology. The work would need to be overseen by someone independent of any organisation with a stake in the system and of the laboratory that does the microbial validation testing. Similarly, validation of cross-connection controls would require expertise in plumbing and would need to be overseen by someone independent of the plumbers that initially installed the fittings. Such oversight provides independent assurance that both the system being validated, and the sampling strategies and laboratory techniques being applied are sound.

One of the objectives of validation monitoring is to prove that the system delivers the expected water quality and usage controls when operational monitoring results are specified. Therefore, operational monitoring, discussed below, is generally performed at the same time as validation monitoring, to provide a point of comparison.

5.2.4 Operational monitoring

This section should be read in conjunction with Section 2.4 of Chapter 2.

Operational monitoring is the routine monitoring of control parameters identified in the sewer, stormwater or greywater catchment, the treatment systems and the recycled water usage steps, to confirm that processes are under control. It provides advance warning that systems may be deviating to a point where control will be lost. A properly designed operational monitoring program should provide a timely warning to the manager of a recycled water scheme of any problems, allowing corrective action to be taken before unsafe recycled water reaches the point of use, or before users accidentally misuse recycled water in an unsafe manner. Operational monitoring should therefore be reported as frequently as necessary to maintain a low risk through the use of the preventive measures.

Online operational monitoring

As far as is practical, operational monitoring should take place more frequently than the time required to complete the protective response component of the corrective action. This often means that online monitoring is required, although this is not always the case. In general, for online monitoring, electrochemical or physical monitoring devices are used to confirm that some physical or chemical property of the recycled water is within the safe range for the intended use. Monitoring devices must be reliable; also, they must be properly and regularly calibrated, and compared with laboratory determinations of reference meters. Polling intervals to alarm systems are likely to be between 15 seconds and several minutes, and out-of-specification readings are likely to raise alarms within 5–30 minutes, depending on the system. Some alarms will be false, caused by factors such as instrument errors, blockages and air bubbles. However, all must be treated as real alarms until a problem can be ruled out. As a result, standby systems may need to come online, recycled water may need to be rerouted, or the system may need to be shut down until the problem has been identified and resolved. The solution to excessive false alarms is improved instrumentation and control algorithms, rather than prolonged and less-urgent responses.

Observational operational monitoring

Observational monitoring usually involves either a check of the system before an action (eg checking that a sprinkling system is pointing in the correct direction before an irrigation system is turned on), or a routine check of systems that do not rapidly fail critically (eg checking that the barriers to birds and vermin nesting in recycled water tanks are intact).

5.2.5 Verification monitoring

This section should be read in conjunction with Section 2.5 of Chapter 2.

The purpose of verification monitoring is to confirm compliance with the recycled water quality management plan. Verification of recycled water quality assesses:

- the overall performance of the recycled water system
- the ultimate quality of recycled water being supplied or discharged
- the quality of the receiving environment.

Verification includes monitoring recycled water quality for compliance with the risk assessment. This can include water quality criteria, soils, plants, terrestrial and aquatic biota, ground and surface water, the infrastructure associated with application or receiving environments and assessment of satisfaction of users of recycled water. Routine verification monitoring is a general requirement for centralised systems, but is less common for on-site systems or single household greywater use.

Verification monitoring is often combined with validation during the initial operation of recycled water schemes, at which stage verification assesses whether a scheme is performing and validation assesses whether a scheme will perform. Verification monitoring is often conducted more frequently during the first weeks and months of operation, to demonstrate that water quality and receiving environment targets are being achieved, and to provide confidence that the target criteria for water quality will be reliably achieved in the future.

Verification provides:

- confidence for users of recycled water and regulators in the quality of the water supplied and the functionality of the system as a whole
- confidence that environmental targets are being achieved
- an indication of problems and a trigger for any immediate short-term corrective actions, or incident and emergency responses.

For long-term environmental target criteria, the ultimate verification of a sustainable system may require years of annual monitoring data.

Verification needs to provide evidence that there are no detrimental effects on the environment from the use of recycled water. Such effects can be measured as:

- changes in the environment that have a demonstrative detrimental effect on the environment, now or in the future
- exceedences of relevant target criteria or critical limits for environmental protection.

Such changes need to be assessed relative to baselines determined before recycled water use, highlighting the importance of obtaining such baseline data. In some cases, aquatic or terrestrial environmental indicators may exceed trigger values before the commissioning of a recycled water scheme. In these cases, further specified changes in hazard concentrations from the recorded baseline (eg a 20% increase above the baseline) can be set as target criteria or critical limits.

Auditing is an essential part of a recycled water quality management plan. The aim of auditing in verification monitoring is to verify compliance in the activities of the water supply entity (eg to verify that treatment plant operators are following the appropriate practices, calibration schedules are being adhered to and users are adhering to their user agreements). Auditing should be undertaken by suitably qualified or skilled people. Regulatory authorities may require copies of audit reports to be submitted as evidence of compliance with approval or licence conditions.

5.3 Monitoring for management of health risks

5.3.1 Validation monitoring for health risks

Because of the magnitude of potential health risks from use of recycled water, log reductions assured by designers and manufacturers of treatment systems, or by user group representatives, cannot be assumed to be valid — some objective empirical evidence of the log reductions is required. The precise nature of this evidence depends on the nature of the barriers. Table 5.2 gives examples of validation monitoring for health risks.

Table 5.2 Examples of validation monitoring for health risks

Process step to be validated	Validation monitoring	Associated monitoring (items that will subsequently be routinely monitored during operational monitoring)
Sewer catchment trade-waste controls	On-site inspection of the trade waste and sewer protection controls at major hazard facilities and examination of their technical validity	• Trade-waste licence agreements
Secondary treatment system	Inlet and outlet microbial indicator concentrations[a] (monitoring should at the very least include *E. coli*, would ideally include coliphage and clostridial spores, and may include some pathogens)	• Flow rate through the system • Sludge blanket depth
Lagoon	Tracer studies to demonstrate residence times Inlet and outlet microbial indicator concentrations[a] (monitoring should at the very least include *E. coli*, would ideally include coliphage and clostridial spores, and may include some pathogens)	• Flow rate through the system • Toxic blue-green algal levels and toxin concentrations • Microbial indicator concentrations
Media filtration plant[b]	Establishment of optimal filter run times and associated operational envelope Establishment of optimal ripening periods and associated operational envelope Inlet and outlet microbial indicator concentrations[a] (monitoring should at the very least include *E. coli*, would ideally include coliphage and clostridial spores, and may include some pathogens)	• Turbidity upstream and downstream of system • Head loss across system • Particle counts on outlet • pH and temperature • Coagulant dosage rate • Streaming current
Membrane plant	Inlet and outlet microbial indicator concentrations[a] (monitoring should at the very least include *E. coli*, would ideally include coliphage and clostridial spores, and may include some pathogens)	• Turbidity upstream and downstream of system • Head loss across system • Particle counts on outlet
Ultraviolet plant	Establishment of operational envelope with respect to factors such as lamp age, lamp power, flow, UV transmissivity and turbidity Inlet and outlet microbial indicator concentrations[a] (monitoring should at the very least include *E. coli*, would ideally include coliphage and clostridial spores, and may include some pathogens)	• Turbidity upstream of disinfection system • UV transmissivity • UV intensity and/or calculated dose • Flow rate to enable calculation of retention times • Ballast functionality, lamp power and lamp status

Table 5.2 continued

Process step to be validated	Validation monitoring	Associated monitoring (items that will subsequently be routinely monitored during operational monitoring)
Chlorination plant[b]	Inlet and outlet microbial indicator concentrations[a] (monitoring should at the very least include *E. coli*, would ideally include coliphage and clostridial spores, and may include some pathogens)	• Turbidity upstream of disinfection system • Free chlorine, temperature and pH at downstream monitoring point, certainly well after the point at which the immediate chlorine demand has been satisfied, and ideally at a point representing a significant proportion of the total required contact time • Flow rate to enable calculation of Ct
Cross-connection control	Check every drinking water property connection by turning off the drinking water supply at each property in series, leaving the recycled supply turned on (charged with drinking water); then check all drinking and recycled water outlets to confirm that only the recycled water outlets on the property are live and that no drinking water outlets are live	• Flow rate measured through meters
Accidental ingestion control	Confirm that minimum heights, labelling, colouring, threads and fittings are in use by inspecting all connected properties and their outlets	• Inspection of labels and fittings
User agreements	Confirm that all users have been bound by their user agreements by direct telephone interview or through written reply and signature	• Oversight of usage practices

Ct = disinfectant concentration × time

a If inlet microbial indicator concentrations are too low to enable validation of the required log reduction, seeding of challenge microorganisms is required.

b For conventionally filtered or membrane-filtered effluent with a turbidity that does not exceed 2 NTU (nephelometric turbidity units), or lagoon-treated water with a turbidity that does not exceed 5 NTU, partly theoretical validation based on the objective measurement of Ct and what is known about microbial inactivation is acceptable and microbial indicator validation is not essential; some such monitoring will be undertaken as part of verification monitoring.

Microbial validation monitoring

For microbial monitoring, a statistically valid number of samples are generally taken to allow averages and standard deviations to be calculated for every data point. Both inlet and outlet samples should be taken to provide a basis for determining log reductions (the difference between the average of the log-10 inlet and the average of the log-10 outlet concentrations). At least three, and ideally five, samples should be taken at each sample point to enable calculations of averages and standard deviations. Thus, there should be a total of at least six, and ideally ten, samples for each condition validated.

A range of conditions should generally be tested (eg high, low and intermediate conditions of flow rate). Interpolation between conditions tested is often acceptable, but extrapolation is not acceptable, because unpredictable things can happen at extremes. For example, flow pathways may change and short-circuiting may occur at higher or lower flow rates than those validated; or tailing effects may arise during inactivation at doses of disinfectant higher than those validated.

Microbial pathogens

Pathogens are often monitored as part of validation because, after treatment, there is only an approximate relationship between levels of pathogens and levels of microbial indicators. Provided that monitoring methods are adequate, monitoring of pathogens can provide extra confidence and prove the performance of novel combinations of treatment processes. The reference pathogens identified in Section 3.2.1 of Chapter 3 as indicators for different groups of microorganisms are:

- adenoviruses and enteroviruses — as representatives of viral pathogens; if only one virus is monitored, adenovirus should be selected because of its relative resistance to UV light inactivation and the presence of high numbers in sewage
- *Cryptosporidium* and *Giardia* — as representatives of protozoal pathogens; tests for these organisms are often performed simultaneously using combined antibody tests; if only one is monitored, the choice should be *Cryptosporidium* because it is more difficult to remove.

Bacterial pathogens are seldom monitored because there is a relatively robust relationship between *Escherichia coli* removal and inactivation during treatment, and the loss of the important bacterial pathogens.

Microbial indicators

Pathogens can be monitored as part of validation monitoring, but the results can be misleading if the methods used do not meet the quality assurance (QA) and quality control (QC) requirements identified below. More commonly, microbial indicators are used, as described in Chapter 3, and reviewed in detail by Gleeson and Gray (1997). For a particular monitoring budget, use of indicator organisms allows considerably more tests than pathogen testing, and produces more reliable results. Table 5.3 lists microbial indicators.

Table 5.3 Microbial indicators

Application	Comments
Escherichia coli	
Escherichia coli (or thermotolerant coliforms) is the default indicator that is representative of faecally derived bacteria in general. *E. coli* monitoring should always be undertaken during validation and can often be used alone for low-exposure recycled water applications.	In some circumstances, faecal streptococci or enterococci are monitored instead of, or as well as, *E. coli*. For practical purposes, these organisms can be used interchangeably for recycled water validation. *E. coli* is usually slightly more numerous in the source water but is generally slightly less resistant to inactivation during treatment than faecal streptococci or enterococci.
Coliphages	
For higher exposure applications, the next priority is to monitor coliphages (viruses that infect coliform bacteria).	Coliphages are considered to be representative of faecally derived viruses. There are many types of coliphages, and the choice of which to monitor depends on the situation. However, usually one or both of two groups, somatic coliphages and FRNA coliphages, are monitored. If only one of the two groups of coliphage is monitored, the somatic coliphage is generally more conservative than the FRNA coliphages. The somatic coliphages are usually more numerous in lagoons and secondary treatment systems, and may even multiply in these environments. This greater potential for somatic coliphages to multiply in sewage means that they can provide some additional conservatism in some systems. FRNA coliphages are therefore sometimes preferred for large systems, such as large municipal sewage recycling schemes, if only one of the coliphage groups is monitored. However, FRNA coliphages are less prevalent in human faeces than somatic coliphages. Therefore, for small systems, somatic coliphages are clearly the preferred indicator if only one type of coliphage is monitored, since FRNA coliphages are likely to be less numerous and more sporadic in their presence.
Clostridia	
For the highest exposure applications, the final priority is to monitor spores of sulphite-reducing clostridia or spores of *Clostridium perfringens* as representative of faecally derived protozoan oocysts.	*Clostridia* have a greater resistance to inactivation than bacterial and viral pathogens and should not be used as indicators for these organisms.
Seeded organisms	
If microbial indicators are not present at high enough concentrations to reliably validate the log reduction required, seeded organisms, such as FRNA coliphages or *Bacillus subtilis* bacteria, are used as seeds	Challenge testing with seeded organisms is often undertaken by the manufacturers of treatment systems to meet overseas regulations. Therefore, for many treatment processes challenge testing is not required. However, for novel configurations and technologies, challenge testing is essential since the indigenous microbial indicators are likely to be present at too low a concentration, and are too poorly understood, to provide a sound basis for validation.

FRNA coliphage = F-specific ribonucleic acid coliphage

5.3.2 Operational monitoring for health risks

Unacceptable risks from microbial infections can arise from even very brief, single exposures. Therefore, there is no room for even momentary failures in the barriers that protect users of recycled water from agents of disease. Fortunately, enough is known about most of the treatment processes and some of the usage control processes to ensure that operational monitoring can detect problems before excessive exposure has taken place. For example, this can mean online monitoring of processes such as filtration and disinfection. However, in lagoon systems, days to weeks may pass before water that has been tested will reach users, providing a window for less frequent monitoring and the use of microbial testing as part of operational monitoring. Table 5.4 gives further examples of operational monitoring and supporting programs.

Table 5.4 Examples of operational monitoring and supporting programs for health risks

Process step to be monitored	Operational monitoring	Supporting programs
Media filtration plant	• Turbidity downstream of system • Head loss across system • pH and temperature	• Instrument calibration • Asset maintenance program
Primary settling system	• Flow rate through the system • Solids depth	• Instrument calibration • Asset maintenance program
Secondary treatment system	• Flow rate through the system • Sludge blanket depth	• Instrument calibration • Asset maintenance program
Lagoon	• Flow rate through the system • Toxic blue-green algal levels and toxin concentrations • Microbial indicator concentrations	• Instrument calibration • Asset maintenance program
Membrane plant	• Turbidity downstream of system • Head loss across system • Particle counts on outlet	• Instrument calibration • Asset maintenance program
Ultraviolet (UV) plant	• Turbidity upstream • UV transmissivity • UV intensity and/or calculated dose • Flow rate • Ballast functionality • Lamp power • Lamp status • Cleaning frequency	• Instrument calibration • Asset maintenance program
Chlorination plant	• Turbidity upstream • Free chlorine, temperature and pH at downstream monitoring point • Flow rate to enable calculation of Ct	• Instrument calibration • Asset maintenance program
Over-irrigation control	• Soil moisture content • Irrigation time	• Instrument calibration • Asset maintenance program
Accidental ingestion control	• Timing of irrigation • Direction of sprinkler throw before application • Wind direction before application • Presence, currency and comprehension of user agreements • Presence, integrity and clarity of fittings, signage and other end-user controls	• Instrument calibration • Asset maintenance program

5.3.3 Verification monitoring for health risks

Verification monitoring needs to assess compliance with water quality requirements as well as compliance with specific good practices. For example, the water quality at the point of supply or treated water delivery point needs to be verified. Compliance with important operational aspects of the recycled water quality management plan also needs to be verified.

Microbial monitoring is used to verify that water quality meets the target for microbial indicators and, potentially, pathogens. As with validation monitoring, the microbial groups monitored are likely to vary, depending on the sensitivity of the end use. For low-exposure uses, *E. coli* should be monitored for verification; for high-exposure uses, *E. coli*, coliphages and clostridial spores should be monitored.

Microbial indicators should be monitored weekly for high-exposure schemes and monthly for low-exposure schemes. Pathogen monitoring (if required) might be at monthly or quarterly intervals, and only if methodologies meet the prerequisite criteria discussed under the quality assurance and quality controls described below. Table 5.5 provides general examples of verification monitoring and Table 5.6 provides a summary of typical sampling frequencies and determinands (ie any definable factors that effect a change in a health condition or other characteristic).

Table 5.5 Examples of verification monitoring

Process steps	Examples of verification monitoring
At recycled water treatment plants	• Check that calibration schedules comply with requirements for monitoring equipment used for operational monitoring • Check that preventative maintenance schedules are being adhered to for equipment that controls recycled water quality • Check that nonconformances detected during operational monitoring are being responded to in a timely manner and that the details of the corrections and corrective actions taken in response to any deviations detected are recorded and reported
At the point of supply immediately downstream of the completion of final disinfection, but upstream of any open lagoons or basins	Monitoring of the microbial indicator concentrations should include *E. coli* weekly or monthly for small, low-exposure schemes. For higher exposure schemes systems (eg for a typical dual-reticulation system) *E.coli* testing could be undertaken more frequently and monitoring would ideally include weekly testing for coliphage and clostridial spores (median *E. coli* <1 per 100 mL, somatic coliphage <1 plaque forming unit per 100 mL, *Clostridium perfringens* <1 per L), and in some cases may include monthly or quarterly pathogen testing (eg *Cryptosporidium*, viruses).
At the point of use	Check that nonconformances detected during operational monitoring of user controls are being responded to in a timely manner and that the details of the corrections and corrective actions taken in response to any deviations detected are recorded and reported

Table 5.6 Typical sampling program for operational monitoring of health protection barriers and verification of health water quality targets

	Sampling frequency[a]						
Typical parameter	**Continuous**	**Daily**	**Weekly**	**Monthly**	**Biannually**	**Annually**	**Biennially**
Operational monitoring							
Disinfection system performance (low-exposure schemes)		√					
Disinfection system performance (intermediate-exposure and high-exposure schemes)	√						
Filtration system performance (low-exposure schemes)		√					
Filtration system performance (intermediate-exposure and high-exposure schemes)	√						
Settling system performance (low-exposure schemes)			√				
Settling system performance (intermediate-exposure schemes)		√					
Settling system performance (high-exposure schemes)	√						
Turbidity or suspended solids (low-exposure schemes)			√				
Turbidity or suspended solids (intermediate-exposure schemes)		√					
Turbidity or suspended solids (high-exposure schemes)	√						
BOD_5 (low- and intermediate-exposure schemes)				√			
BOD_5 (high-exposure schemes)			√				
Flow (low-exposure schemes)			√				
Flow (intermediate-exposure schemes)		√					
Flow (high-exposure schemes)	√						
Catchment-input controls (such as trade-waste agreements)						√	
End-user controls (low-exposure schemes)					√		
End-user controls (intermediate-exposure schemes)				√			
End-user controls (high-exposure schemes)			√				
Cross-connection hydraulic controls (low-exposure schemes)		√					
Cross-connection hydraulic controls (intermediate-exposure and high-exposure schemes)	√						
Cross-connection plumbing controls						√	
Verification monitoring							
Escherichia coli (small low-exposure schemes)				√			
E. coli (all other schemes)			√				
Somatic coliphage (high-exposure schemes)			√				
Clostridial spores (high-exposure schemes)			√				
Adenovirus (high-exposure schemes)				√			
Cryptosporidium oocysts (all large, high-exposure schemes)				√			
Audit of calibration activities				√			
Audit of preventive maintenance activities						√	
Audit of operational monitoring activities				√			

a Sampling frequency and hazards will depend on scheme-specific considerations and historical data (see text). Samples should be taken after the final step in the recycling process or at the point where water is delivered to the user. For extremely small systems, such as single-household systems where monitoring of every system becomes impractical, representative sampling from typical schemes should be undertaken at the recommended frequencies through a centralised monitoring program by the oversighting agency.

5.4 Monitoring of management of environmental risks

Two major factors influence environmental monitoring requirements — the size of the recycled water scheme and the level of risk being managed.

As the size of the recycled water system increases, the number of environmental components that the water comes into contact with also increases, meaning that more endpoints are potentially affected. Therefore, as the size of the system increases, the extent of the monitoring program generally increases. However, monitoring will also be influenced by the level of risk, which depends on the variability and hazards associated with the specific recycled water, and the confidence in prevention measures introduced to minimise the risks associated with the hazards.

For example, for a single household using greywater, a preventive measure may be control of inputs into the water by the householder (ie an exclusion barrier), and the householder may be very confident in the source controls used. In this situation, monitoring required may be as simple as the user observing soil and plant health. In contrast, a recycled water system that supplies water to hundreds of horticulturalists (eg ~120 ML/day to more than 10 000 hectares) could potentially affect a much larger environment. In this case, users are required to include a leaching fraction in their irrigation programs, to control accumulation of salts, and recycled water salinity cannot exceed a predefined trigger value without damaging some irrigated crops. The monitoring program would require an operational and verification monitoring program for salinity, and for all other risks that require preventive measures.

For all recycled water schemes, the frequency of sampling and monitoring required is relative to the level of risk identified in the maximal risk assessment (ie the risk assessment before preventive measures are put into place) and the confidence in a specific preventive measure used to minimise the risk to acceptable levels (ie low) (see Table 2.7). For example, validation of preventive measures can give an indication of confidence in the preventive measure and assist in developing the initial monitoring program. Verification monitoring could then improve confidence with the specific preventive measures used, allowing the initial monitoring program's frequency to be modified (see Table 5.7). Double or multiple preventive measures can also increase the confidence that the specific risk controlled will remain low, minimising the monitoring program. Alternately, if a critical limit is exceeded or target criteria are continually exceeded for relevant environmental indicators (Figure 4.4), the sample frequency may need to be increased to monitor the associated risks more closely.

Table 5.7 Examples of how maximal risk assessment relates to monitoring requirements

Maximal risk	Monitoring	Sampling frequency	
		Concerned with reliability of preventive measure	**High confidence in preventive measure**
Low	Low level of monitoring required (ie limited monitoring required at catchment level)	No sampling Risk assessment reviewed in 2–5 years	No sampling Risk assessment reviewed in 5–10 years
Moderate	Moderate level of monitoring required (ie endpoints or hazard concentrations monitored at scheme or catchment level with indicator site (site specific) used to assess risks identified for specific hazard)	0.5–2 years	1–5 years
High	High level of monitoring required	1–12 months	Yearly
Very high	Greater level of monitoring required	1 week–6 months	1–12 months

Note: Some critical control points may require continuous monitoring. Monitoring also depends on the confidence in the preventive measures used to minimise the risk to an acceptable level (ie low — Table 2.7).

5.4.1 Baseline and validation monitoring for environmental risks

Baseline monitoring is an important component of establishing a recycled water scheme. Risks to the environment are often calculated and managed relative to the baseline, rather than using absolute guideline values (see Section 4.1.2). Environmental data is often highly variable because of natural annual and seasonal climatic variability. The more comprehensive the understanding of this variability, the easier it is to monitor and assess specific environmental changes introduced in the future through the use of recycled water.

In many cases, the baseline information underpins the risk assessment process. Comprehensive baseline data enables a better estimate of actual risk levels, since it allows changes in the environment to be assessed relative to the baseline. It also allows for an interpretation of guideline values for site-specific exceedences of relevant target criteria or critical limits for environmental protection.

Baseline data for large reuse scheme may consist of regional studies and historical data recorded by local or state government agencies. For greywater use, the single user may take a sequence of photos in each season to compare plant growth in areas where greywater is used.

Short-term environmental validation monitoring can be used for specific restrictive barriers, to determine whether treatment processes or source control programs are meeting environmental target values or critical limits. Short- or long-term experiments and trials can be used to validate target values and critical limits for specific environmental endpoints or end-use restrictions.

Validation is particularly important for innovative preventive measures. For example, it may be necessary to validate a new irrigation method (eg subsurface drip irrigation) if it is being used on plants that have not been grown using this method before. When growing a plant that has no known salinity sensitivities, the tolerance of the plant to the salinity of the recycled water may need to be validated.

Due to the diverse nature of environmental monitoring, and the complexities of how target criteria and critical limits relate to specific environmental endpoints, it is often important to determine baseline values for specific endpoints. These baseline values can be used to determine any changes in environmental endpoints due to the use of recycled water, as measured by the verification monitoring program (discussed below). The baseline monitoring should reflect the specific environmental endpoints and should relate directly to the verification monitoring program.

5.4.2 Operational monitoring for environmental risks

Operational monitoring for environmental risks is specific to the intended scheme and the end-use restriction barriers required. Examples of operational monitoring include application methods, the timing of irrigation, access controls and signage. Operational monitoring programs are often part of an environmental improvement plan or customer site-management plan that the users of the recycled water must comply with. Measurement of operational parameters is used to indicate whether processes relating to preventive measures are functioning effectively.

5.4.3 Verification monitoring for environmental risks

Once the recycled water has been determined to be fit for the intended purpose (ie validated), verification monitoring programs should be initiated, to check that there are no detrimental effects on the environment where the recycled water will be used.

Verification monitoring for environmental risks involves assessing the overall performance of the treatment system, the ultimate quality of recycled water being supplied or discharged, and the quality of the receiving environment. Aspects monitored include recycled water quality, soils, plants, terrestrial and aquatic biota, ground and surface water, the infrastructure associated with application or receiving environments, and the satisfaction of users of recycled water.

Although there are distinct differences in the timing of the monitoring programs, baseline, validation, operational and verification environmental monitoring programs can often be similar in what they monitor. All monitoring will be related in some way to the verification program.

In selecting environmental indicators, it is important to consider the possible effects of all of the hazards identified in the assessment of environmental risks, with particular attention to the moderate to very high risk hazards.

Frequency of sampling

Source water quality monitoring should initially be established to assess variability in water quality at hourly, daily, weekly, monthly, biannual, annual or biennial time steps. The results of the monitoring can be used to design an appropriate, ongoing monitoring program. Water quality will change over time as a function of inputs, source water quality and treatment-process efficiency. The final monitoring frequency required for each hazard may vary, depending on the observed temporal variability of the hazards and the intended use for the water.

Where environmental effects have the potential to be acute (eg chloride toxicity to foliage), frequent or, in some cases, continuous monitoring may be required (daily, weekly or monthly). Where the effects are chronic (eg soil structure loss from sodicity), less frequent monitoring may be appropriate (monthly, biannual, annual or biennial). The level of risk being controlled (low, moderate, high or very high) may also influence the frequency of sampling (see Table 5.8, below).

Finished recycled water storages (supplier or customer) should be monitored because water quality may change with time in storage due to gaseous losses; immobilisation in, or release from, sediments; microbial breakdown; and plant, algal and animal growth (aquatic and terrestrial) in storage reservoirs. Evaporative concentration may also change water quality parameters.

Generally, the higher the level of treatment required for the specified use, the more critical the quality of the water and the more frequent the monitoring required.

Biological assessment of aquatic systems

The biological assessment of aquatic systems can be a complicated, time-consuming and costly task. Usually, other avenues of monitoring and assessment should be assessed before developing biological assessment systems. However, biological assessment can provide a valuable tool for assessing the health of the aquatic environment. The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC and ARMCANZ 2000a) should be followed; for example:

- Section 3.2 of Volume 1 of those guidelines provides advice on the selection of biological indicators to apply to various water quality problems, and the analytical procedures that should be used to monitor and assess change in these indicators.
- Chapter 8 of Volume 2 of those guidelines provides information on the desired and essential attributes of generalised indicator types and the merits and potential of different taxonomic and functional groups for monitoring aquatic biota. This is followed by a list of indicators and methods recommended for assessment of water quality in aquatic ecosystems of Australia and New Zealand.

Soil analysis

Recycled water finds its way into the soil, either indirectly or through direct application. Many environmental hazards are concentrated in soil, being stripped out of the water as it moves through the soil matrix. Thus, soil analysis is essential to verify that the soil continues to remain fit for its intended use, and that it is appropriate for sustainable land use. Soil sampling, handling and analysis must be conducted according to quality assured methodologies (eg Chapter 3 of Peverill et al 1999). Soil properties are inherently highly variable in space and time, so correct sampling procedures are crucial to provide samples for analysis that are representative of the sample area. The use of correct sample protocols will help to ensure that detrimental changes in the soil environment are identified at an early stage, thus minimising or preventing effects on vegetation, surface and groundwaters.

Table 5.8 Typical sampling program for verification monitoring of environmental water quality targets for assessment of environmental allocation of recycled water

	Sampling frequency[a]						
Hazard	**Continuous**	**Daily**	**Weekly**	**Monthly**	**Biannually**	**Annually**	**Biennially**
Boron				√			
Cadmium				√			
Chlorine disinfection residuals	√						
Nitrogen (total)				√			
Nitrate				√			
Phosphorus (total)				√			
Salinity (electrical conductivity)	√						
Chloride				√			
Sodium				√			
Sodium adsorption ratio (SAR)				√			
Surfactants				√			
Endocrine disrupting chemicals				√			
Ammonia			√				
Aluminium			√				
Arsenic				√			
Copper				√			
Lead				√			
Mercury				√			
Nickel				√			
Zinc				√			
Phenol				√			

a Sampling frequency and hazards will depend on scheme-specific considerations and historical data (see text). Samples should be taken after the final step in the reclamation process or at the point where water is delivered to the user.
NoteS:
1. In this case, aluminium and chlorine disinfection residuals were considered a very high risk and initial monitoring was set at weekly intervals. Once verification of the preventive measures are in place, this could be relaxed to monthly.
2. If the end use being considered is for irrigating crops, metals (aluminium, arsenic, copper, lead, mercury, nickel and zinc) could be monitored less frequently (annually) after the treatment process and the quality of the water produced are validated.
3. Sampling frequency should also reflect the level of maximum risk and confidence in the preventive measures used.

The type of soil testing required and the sample depth will depend on the:

- land use or plants to be grown
- water quality
- hazards being considered
- soil properties and type
- data from previous samplings.

A typical soil-sampling program for monitoring environmental impacts of hazards in recycled water is outlined in Table 5.9. It may also be useful for assessing the suitability of the soils for the crops or plants to be grown.

Table 5.9 Typical sampling program for verification monitoring of environmental hazards in soil

Hazard	Depth (cm)	Sampling frequency[a]							
		Continuous	**Daily**	**Weekly**	**Monthly**	**Biannually**	**Annually**	**Biennially**	**Speical event**
pH	0–10[b]						√		
	30–50[c]								
	90–100[d]								
Salinity (electrical conductivity)	0–10[b]						√		
	30–50[c]							√	
	90–100[d]							√	
Sodium adsorption ratio (SAR) (or exchange sodium percentage)	0–10[b]						√		
	30–50[c]						√		
	90–100[d]						√		
Cadmium	0–10[b]						√		
	30–50[c]								
	90–100[d]								
Nitrogen (total)	0–10[b]						√		
	30–50[c]							√	
	90–100[d]							√	
Phosphorus (available)	0–10[b]						√		
	30–50[c]							√	
	90–100[d]							√	
Boron	0–10[b]						√		
	30–50[c]							√	
	90–100[d]								

a Sampling frequency and hazards will depend on scheme-specific considerations and historical data, see text above
b Till depth (Peverill et al 1999)
c Top of B-horizon
d A lower depth to assess movement of hazards through soils if required

Note:
1. Where baseline soil monitoring has detected existing significant concentrations of hazards, environmental risks may be higher and more frequent sampling required.
2. Where the risk of nitrate leaching is high to very high, it may be useful to collect samples at uniform increments (eg 10 or 15 cm) to capture any changes through the profile.
3. Sampling frequency should also reflect the level of maximum risk and confidence in the preventive measures used.
4. Special event sampling may also be required where other environmental indicators or events trigger an observable detrimental impact on other components or endpoints in the local environment (ie plant suffering from leaf tip burn or unexpected yield reductions).

Groundwater analysis

Any recycled water scheme that has identified risks to groundwater resources requires a comprehensive monitoring program. This program should determine baseline values for hazards deemed to be moderate to very high risk, and help to ensure that groundwaters will not be detrimentally affected by the use of recycled water. If groundwater already contains high concentrations of a specific hazard, and the relative impact from the recycled water is insignificant (ie groundwater quality and related environments will not be affected by recycled water), sampling frequency can be decreased. An indication of a sampling and analysis strategy is shown in Table 5.10.

Table 5.10 Typical sampling program for verification monitoring of environmental hazards in groundwater

Hazard	Sampling and analysis frequency[a]						
	Daily	Weekly	Monthly	Quarterly	Biannually	Annually	Biennially
Water level				√			
pH				√			
Salinity (electrical conductivity)				√			
Nitrogen (total)				√			
Nitrate				√			
Phosphorus (total)				√			
Chloride						√	
Sodium						√	
Calcium						√	
Magnesium						√	
Bicarbonate						√	
Sodium adsorption ratio (SAR)						√	
Iron						√	
Aluminium						√	

a Sampling frequency and hazards monitored will depend on scheme-specific considerations and historical data (see text) and should also reflect the level of maximum risk and confidence in the preventive measures used.

Natural variations in groundwater quality and standing water levels predating irrigation should be documented. A sampling regime of every three months for one year before the irrigation and every three months for a period of 12–18 months during irrigation is desirable. After the initial 12–18 months, the sampling frequency may be changed, depending on the results obtained. Standing water levels in boreholes should be measured before irrigation with treated effluent begins, to obtain current oscillation patterns of groundwater levels (ie a baseline). The date and water levels (in metres) should be recorded, in accordance with the specification of the government department responsible for groundwater resources in the state or territory where the reuse scheme is located.

Bore location

A typical groundwater monitoring program may involve a system of monitoring bores (three, as a minimum) installed at suitable depths and locations within the area likely to be affected by the scheme. The objective is to provide representative water level and water quality data for aquifer systems. Where appropriate, groundwater monitoring bores should be installed for a specific scheme, and data recorded from the following locations:

- up-gradient from the irrigation scheme
- beneath significant irrigation areas
- down-gradient from each irrigation area
- adjacent to the storage systems (to detect leaks).

Bore construction

Briefly, casing should be 50–100 mm slotted and/or screened, normally of low-yield construction but providing for accurate water quality sampling and water level measurements. Annulus seals and selective filter packing are used when necessary to isolate the zone being monitored. Care must be taken during drilling operations and in selecting drilling methods, to ensure that samples are not contaminated. Casing, filter pack, and sealing or grouting materials should also be selected so their chemical properties have little or no effect on proposed sampling and analysis.

The basic characteristics of monitoring bores and their construction are outlined in several Australian Standards (AS/NZS 1998ae, LWBC 2003).

Surface water monitoring

Surface water monitoring can be expensive to undertake and the results difficult to interpret due to a range of factors, such as upstream pollutant sources and large variations in indicators over time and space. Such proposals require careful assessment of the need for monitoring and careful planning to identify appropriate indicators and trigger levels.

Water quality criteria are typically concentrations of chemicals in the water, although descriptive indicators can be useful if they are carefully defined and agreed upon by stakeholders. Once the water quality objectives have been defined, sampling programs must be determined. Unlike other environmental endpoints monitored at set times (eg monthly, yearly), surface water may require monitoring in response to climatic events (eg rainfall, or warm, still conditions conducive to algae growth).

Appropriate indicators to sample and the frequency of surface water sampling will depend on the moderate to very high risks identified in the risk assessment process, which will also highlight appropriate indicators. Indicators should be selected on the basis of being directly affected by hazards if controls at critical control points fail.

The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC and ARMCANZ 2000a) provide a comprehensive guide to the protection of aquatic ecosystems, through water quality monitoring and management. There are also relevant standards published by Standards Australia (AS/NZS 1998bcd). Table 5.11 shows a typical surface water monitoring program designed to assess the environmental impact of recycled water.

Table 5.11 Typical sampling program for verification monitoring of environmental hazards in surface water

Hazard	**Sampling and analysis frequency[a]**								
	Daily	**Weekly**	**Monthly**	**Quarterly**	**Biannually**	**Annually**	**Biennially**	**Intense rain events**	**Algal bloom risk high**
pH				√				√	
Salinity (electrical conductivity)				√					
Nitrogen (total)				√					
Phosphorus (total)				√				√	
Chlorophyll-a						√			√
Aluminium				√					

a Sampling frequency and hazards monitored will depend on scheme-specific considerations and historical data (see text) and should also reflect the level of maximum risk and confidence in the preventive measures used (eg Table 5.1)

5.5 Quality control and quality assurance

Quality assurance (QA) and quality control (QC) procedures are essential components of all phases of the monitoring program. They anticipate and help to avoid likely errors and problems, and ensure that data collected are of a known quality. Quality assurance is the implementation of checks on the success of the quality control; it includes managerial activities, staff training, data validation, and audits of laboratory and data analysis and management (Table 1 in ANZECC and ARMCANZ 2000b). Quality control is the implementation of procedures to maximise the integrity of monitoring data; it includes procedures for proper collection, handling and storage of samples, replicate sampling, inspection and calibration of equipment, analysis of blank or spiked samples, and use of standards or reference materials (ANZECC and ARMCANZ 2000b). To control or minimise sampling and processing errors, a quality assurance/quality control protocol should be developed and used for each component of the monitoring program. Common quality assurance and quality control activities are outlined in Table 5.12.

Table 5.12 Common quality assurance and quality control activities

Quality assurance activities	Quality control activities
• Assignment of roles and responsibilities • Determination of the number of samples required to obtain data at a certain confidence level • Tracking sample custody from field to analysis • Development of data-quality objectives • Auditing field and laboratory operations • Maintenance of accurate records • Training of personnel in sampling techniques and equipment use	• Duplicate analytical sample analysis • Analysis of blank and spiked samples • Using replicate field samples • Regular calibration of equipment • Inspection of reagents

For data to be meaningful, samples should be collected from appropriate locations by personnel trained in procedures for collection and preservation.

Poor-quality tests used for monitoring can sometimes create false positive and false negative results. In Australia, the standard of quality assurance and quality control in water quality monitoring is not always as high as desirable, considering that the risks to public health and the environment are affected by the results of monitoring.

Sound monitoring requires that:

- the specifics of monitoring are clearly stated, including what is monitored, where and when, how and by whom
- detailed standard operating procedures are documented, so that monitoring methods can be reproduced by others if required
- monitoring methods are grounded in industry standard and published methods and approaches, to ensure consistency of results with other datasets
- monitoring is open — people responsible for monitoring are prepared to have their methods cross-checked against those used by others, and to take part in proficiency testing and peer-review programs
- only quality-assured suppliers of raw materials and equipment are used, and the quality of incoming supplies is validated before use

- all personnel are adequately trained and experienced for all stages of the monitoring process — this includes designers of the monitoring program, samplers, observers, placers of monitoring equipment, transporters and handlers of samples and equipment, analysts, interpreters and reporters
- equipment is independently calibrated at appropriate frequencies and using appropriate methodology
- methods are independently verified and the capability of the analysts to perform those methods are assessed — this could be through National Association of Testing Authorities (NATA) accreditation or by directly appointing special assessors
- reporting provides clear details of the methods used and indicates the level of certainty in the estimates given in the results.

5.6 Laboratory analyses

Chapter 5 of ANZECC and ARMCANZ (2000b) details the methodology for obtaining accurate and precise data. All analyses should be completed in laboratories that are certified as having appropriate quality assurance programs for the analyses required, for example NATA accreditation.[10] When an accredited laboratory cannot be located for the desired indicator, laboratories recognised in the area of expertise should be sought and assessed (with reference to Chapter 5 of ANZECC and ARMCANZ 2000b), to determine whether they meet standard requirements.

Analyses must be reported with accurately and appropriately determined error terms. Data integrity becomes critical when comparing changes to the environment over time or when comparing locations (eg reference areas versus potentially impacted areas). Determination of baseline data, before recycled water use, is crucial for assessing future changes in the environment from recycled water use.

5.6.1 Selection of analytical methods

The selection of analytical methods is based on the range of concentrations of the analyte to be determined, the accuracy and precision required, the time between sampling and analysis, and the cost.

Information on accepted methods can be found in publications such as *Standard Methods for the Examination of Water and Wastewater* (APHA 2005), *Australian Laboratory Handbook of Soil and Water Chemical Methods* (Rayment and Higginson 1992) and *Plant Analysis and Interpretation Manual* (Reuter and Robinson 1997).

5.7 Data analysis and interpretation

Common statistical methods for analysis of water quality data are described in Chapter 6 of the *Australian Guidelines for Water Quality Monitoring and Reporting* (ANZECC and ARMCANZ 2000b). Similar methods can be used for other environmental endpoints.

Assessment of the environment must be based on a statistically valid sampling program, and monitoring requirements need to be:

[10] Available online at http://www.nata.asn.au

- tailored to the scale of the reuse scheme
- considerate of the intended end uses of the recycled water
- developed with the relevant regulators or authorities that will be responsible for auditing the environmental performance of the reuse scheme
- frequency adjusted, in accordance with performance (eg if trigger values identified in the risk assessment are exceeded, sampling frequency should be increased; if trigger values are not exceeded, it should be decreased).

5.8 Reporting and information dissemination

Reporting requirements of recycled water schemes vary considerably between schemes and states. Chapter 7 of ANZECC and ARMCANZ (2000b) gives a thorough review of the importance, format and reporting sequence commonly required for reporting on monitoring activities for water quality. This can be used as a guide for reporting on recycled water scheme monitoring programs. However, the reporting procedure will often be primarily directed by the authority requiring the report, and generally specified in the environmental improvement plan defined for the reuse scheme. It is essential to check the specific requirements for monitoring reports used by the regulatory authority.

Reporting procedures will often relate to the activities of both the recycled water supplier and user, and will require them to:

- provide arrangements for the submission of performance reports to authorities, users and the community
- identify, as early as possible, acute or chronic health and environmental impacts
- identify incidents of noncompliance with guidelines, and ensure that the appropriate people and agencies are notified, and that incident response strategies are effective
- if required, alter management or monitoring practices to ensure the best protection available for the health of the community and the environment.

Reporting requirements are usually annual, but may vary depending on scheme-specific criteria. Typical best-practice management for reporting will require:

- a listing or register of users of recycled water
- regular inspections and maintenance of treatment, reticulation and reuse facilities or farms and recording of details
- monitoring data specific to preventive measures and environmental protection (analysis undertaken and flows recorded)
- demonstrated ongoing compliance with the objectives of the guidelines or management plans developed from the guidelines
- identification of areas of management or practice that may be improved
- suppliers making reports available for users on a regular basis
- modification to sampling and analysis undertaken as part of management plans, or preventive measures, due to results not complying with trigger level or reference.

5.9 Review

Reviewing of the monitoring and reporting program is an important element to ensure that the program remains effective and ‘on track’ to meet the stated objectives. The review process and its response should be outlined, and regular independent audits of the program should be conducted by appropriately qualified personnel.

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6 Consultation and communication

Water recycling schemes are constructed and operated for the benefit of a wide variety of stakeholders, including landowners, industry and commerce, public entities, special interest groups, customers and the community in general. Stakeholders not only benefit from water recycling schemes, they also bear much of the costs and risks associated with such schemes. Therefore, stakeholders should have access to information and be empowered to participate in decision-making processes that affect their communities.

Effective consultation and communication with stakeholders, at the planning stage and during operation, are crucial to successful, modern water recycling schemes in Australia. It is no longer acceptable for ‘experts’ to make decisions on behalf of uninformed or dissenting communities. Nor is it possible for authorities to build community support by dictating what stakeholders ‘should’ think and know.

A number of proposed water recycling schemes in Australia and overseas have failed or been drastically altered because of a lack of stakeholder support. In some cases, stakeholders believed that planning was being done secretly and that their concerns were not recognised. In others, authorities and water recycling organisations failed to adequately promote the benefits of their operations or to allay fears about possible health and environmental risks.

To assist in the process of consultation and communication, this chapter describes:

- the main factors that may influence people’s attitudes to water recycling, and that need to be taken into account when designing a program of consultation and communication (Section 6.1)
- the features needed for a successful communication strategy (Section 6.2)
- a range of possible methods for engaging stakeholders at the planning and operation stages of a water recycling scheme (Section 6.3)
- ideas for managing communication in a crisis (Section 6.4)
- questions likely to be asked by stakeholders (Section 6.5).

Appendix 7 provides two case studies of communication of recycled water schemes, one in Caboolture Shire in Queensland, the other in Adelaide in South Australia.

6.1 Factors that influence community attitudes to water recycling

6.1.1 Influence of proposed use on level of acceptance

Since the 1970s, numerous studies have characterised community attitudes to water recycling in various countries, including Australia. These studies have generally indicated strong and widespread support for using recycled water to irrigate parks, golf courses, lawns, gardens and hay pastures, and to irrigate dairy pastures and edible crops, including orchard, vineyard and vegetable crops. However, community support for water recycling projects decreases as the degree and likelihood of close personal contact with the water increases. For example, some household uses (eg toilet flushing and clothes washing) have high rates of acceptance, whereas uses with closer contact (eg swimming and bathing) have only moderate support. The lowest levels of acceptance are consistently reported for ingestive uses, such as drinking and cooking.

A problem with research into attitudes is that many studies have used hypothetical proposals and measured 'in principle' support. Where actual or pending water recycling projects are involved, factors such as environmental and conservation issues, as well as water treatment and water distribution costs tend to be more important (Bruvold 1988). Therefore, reported widespread in-principle acceptance does not automatically translate to acceptance of real projects. Table 6.1 lists factors that may influence the general community's acceptance of a water recycling scheme and factors that may lead to higher acceptance.

Table 6.1 Factors found to affect community acceptance of water recycling schemes

Factors that may influence acceptance	Factors that may lead to higher acceptance
Factors that may influence the general community's acceptance of a water recycling scheme include: • disgust (the 'yuck factor') • perceptions of risk associated with using recycled water • the specific uses of recycled water • the sources of water to be recycled • the issue of choice • trust and knowledge • attitudes towards the environment • environmental justice issues • the cost of recycled water • sociodemographic factors.	Factors that may make the community more likely to accept a water recycling scheme include: • minimal human contact • clear protection of public health and the environment • promotion of water conservation • reasonable cost of treatment and distribution technologies and systems • minimal perception of wastewater as the source of recycled water • high awareness of water supply problems in the community • clear role of water recycling in the overall water supply scheme • high perception of the quality of recycled water • confidence in local management of public utilities and technologies
Source: Po et al (2003) (literature review)	Source: Hartley (2003) (literature review)

6.1.2 Effect of instinctive and emotional responses

To fully understand community attitudes to water recycling, it is necessary to consider instinctive and emotional responses that people have to human excrement and sewage. These may explain many of the less rational perceptions that people may have about water recycling (Haddad 2004). For example, the 'law of contagion' states that things that have once been in contact with each other continue to act on each other at a distance, even after physical contact has been severed. Thus, once water has been in contact with contaminants, it can be psychologically difficult for people to accept that it has been purified. A related law — the 'law of similarity' — suggests that things similar to each other tend to be seen as a unit. This explains why many people trust their own impressions of water quality (often based on the clarity or cloudiness of the water) more than they trust medical and scientific evidence (Hartley 2003). Combined, these factors can create mental barriers to accepting recycled water as a source of pure water.

6.1.3 Effect of credibility of the organisation

The credibility of the water recycling organisation and its senior managers significantly affects stakeholder perception of proposed schemes. A recent Australian study found that an individual's trust in a water authority was proportionate to their level of confidence that a planned reticulated recycled water supply would not pose unacceptable risks to their health or garden (Hurlimann and McKay 2004). The credibility of a water recycling organisation will be judged on a number of factors, which may include perceptions of the organisation's:

- commitment to the welfare of the stakeholders

- performance record based on previous initiatives
- knowledge of the issues, as demonstrated by spokespeople
- impartiality regarding the subject matter.

Factors shown to maximise trust in situations where the community associates a high level of risk with a water recycling project are listed in Table 6.2.

Table 6.2 Factors found to maximise trust where risk is perceived as high

Factors that may increase trust
Factors that help to maximise trust include: • sustained dialogue • the community – having independent sources of information, not linked to the sponsoring agency – being able to ask questions – being involved early • information being available to everyone • decisions being made in a way that is considered to be rational and fair (ie not coercive) • everyone's opinion mattering, with a willingness to listen to all views and expand the discussion if necessary • citizens having some level of control in the process (eg by contributing to the agenda or ground rules).

Source: Renn et al (1995), Hartley (2003)

6.2 Essential features of successful communications strategies

6.2.1 Aims of communication strategy

The success of a communication strategy must be judged against its aims. A successful communication program will usually contain strategies that allow stakeholders to:

- study the evidence and draw their own conclusions about water recycling
- see both the decision-making process and the decisions themselves as being transparent and fair
- share responsibility for solving the problems of water supply, recycling water or disposing of wastewater.

Good timing of communication activities can be just as important as their content. Community confidence and trust can only be built over time, so a communications program will ideally begin when the potential to develop a recycling project is being considered. This approach will help to develop community confidence and trust within what is likely to be a neutral environment, outside the context of an imminent, controversial water recycling plan.

6.2.2 Important features of a successful strategy

Timely communication

It is important that stakeholders first hear of major developments, whether they are positive or negative, from the project managers. Delays in passing on information may spark rumours, increase concern and cause stakeholders to question the organisation's motives and intentions, all of which will undermine stakeholder trust and be detrimental to the project.

Two-way communication

For most water recycling projects, a 'we tell you what you should think and know' approach will be ineffectual at best, and highly counter-productive at worst. Therefore, communication should be established as a two-way flow between the recycling organisation and all stakeholders as soon as the decision to seriously consider a project has been made.

Listening and seeking clarification are crucial characteristics of effective communication. By providing readily accessible listening and feedback opportunities, water recycling organisations can monitor the concerns and opinions of their stakeholders. Useful avenues for communication include surveys, websites, telephone hotlines, open-house events, public forums and focus groups, all of which provide opportunities to listen to stakeholders.

Risk communication

Risk communication is an essential component of any communication program. Historically, the major goals of risk communication have been to align the community's perception of risk with that of the risk experts, and to reduce the community's fear of, and resistance to, risk-related technology (Gurabardhi et al 2004). However, the current notion is that risk communication should focus on more basic matters, such as society's values concerning procedural fairness, the way in which society makes judgments and reaches decisions, and the fairness with which risks and benefits are distributed across different sectors of the community (Gurabardhi et al 2004). Fundamental to successful risk communication is the willingness of all stakeholder groups to respect the views of others and include all concerns in the decision-making process (Renn 2004).

6.2.3 Key messages to stakeholders

In all communication strategies and educational campaigns it is good practice to identify and develop a list of key messages, to ensure that important points are communicated prominently and consistently to stakeholders. The aim is to improve stakeholder satisfaction and acceptance of proposed or operating water recycling schemes. Examples of key messages (assuming that water is recycled in accordance with these guidelines and is fit for the purpose for which it is used) are:

- recycled water will undergo a high level of treatment and testing
- management procedures are in place to ensure safety
- recycled water can replace drinking water for many applications (eg agricultural and industrial), so that every megalitre used in these schemes represents another megalitre saved from drinking water supplies
- recycling can benefit the environment (eg by conserving water, protecting waterways and allowing dissolved nutrients to be reused in agriculture, thereby reducing the need for synthetic fertilisers).

6.3 Establishing partnerships and engaging stakeholders

Stakeholder communication is vital to both the planning and operations phases of any water recycling scheme. Although many forms of communication will be relevant to both planning and operation, certain types of communication are likely to be more appropriate for the different phases. For example, the planning phase will require highly structured and sustained consultation with stakeholders, whereas the operational phase may focus more on facilitating stakeholder access to information. Although the information below has been arranged according to this distinction between planning and operations, the suggested activities are not exclusive to one phase or the other.

6.3.1 Stakeholder participation in planning

Planning a water recycling scheme requires intense and focused communication, because it may lead to substantial, long-term changes that affect stakeholders. During this phase, the water recycling organisation needs to both keep stakeholders informed and receive quality information from stakeholders. Opportunities for stakeholder input need to be well considered, focused, genuine and sufficiently frequent and accessible to meet stakeholders' needs. Some of the most effective mechanisms for obtaining input from stakeholders are described below.

Surveys

Managed inhouse or by a professional, surveys can gather information and monitor changes in stakeholder support. They need to be short, relevant to those surveyed, and use a valid sample of the target population, which may be the catchment population or a subgroup with particular interests.

Stakeholder forums

Forums can allow stakeholders to convey opinions and attitudes to a water recycling organisation, but they must be well managed and organised, and carefully planned. Using a professional facilitator can make public consultations much more comprehensive and effective. Also, it is good practice to give stakeholders another chance to comment after the forum; for example, through a feedback form.

Focus groups

If conducted by a skilled moderator, focus groups provide a flexible way to assess public opinion. Usually, the moderator works from a discussion guide and participants are given an information package, but participants can also contribute other ideas. An audiovisual presentation about water treatment and local plans can help to frame the discussion. Reporting on focus groups can range from a simple summary to a statistical analysis of issues raised.

Private discussions

Discussions with individual or representative stakeholders allow attitudes to be thoroughly explored. They are also a good way to build links with influential stakeholder groups. An agenda is normally agreed on before the meeting. Untrained personnel should not conduct such meetings or assess their outcomes.

Stakeholder (citizen) juries

In this process, 10–15 representative stakeholders consider a proposal and decide for or against it. The 'jury' takes evidence from expert witnesses and can question the witnesses directly, pursue its own lines of inquiry, and consider matters in detail. Disadvantages of stakeholder juries are the time needed, the expense and the sometimes confrontational style of the process.

Telephone hotlines

A hotline number allows stakeholders to receive targeted information and supply feedback. The issues raised by callers must be recorded to allow useful statistical analysis. Hotline staff should be adequately trained and work within agreed timeframes.

Ballots and polling

Some examples of ballots and polling are non-binding referenda in conjunction with local government elections, and polls to determine definitive opinions about water recycling or to measure the effects of information campaigns. Because questions are usually presented as simple 'yes' or 'no' options, these methods are not suitable for revealing motivation or nuanced opinion.

Stakeholder liaison personnel

A full-time liaison officer can solicit and process stakeholder information systematically, and show stakeholders that their opinions are important to the water recycling organisation. Other duties would include representing the organisation at stakeholder meetings and coordinating public information events.

Stakeholder submissions to issues papers and draft plans

When requesting formal submissions on water recycling proposals, it is helpful to publish details of proposals (eg through public displays, websites and printed documents) when calling for submissions, and give people at least a month to consider them. It is helpful for stakeholders to be able to respond either on paper or electronically. Concerns raised in submissions should be published, dealt with appropriately and addressed in revised proposals, which are again available for public comment.

6.3.2 Operational communication and education

Once a water recycling scheme has been planned and implemented, the communications emphasis may shift from giving stakeholders opportunities to voice their opinions, to providing them with access to information. Useful means of disseminating information to stakeholders are described below.

The media

The print and electronic media can be the water recycling organisations' most effective channel for promotion and for monitoring community opinion. To gain the attention of news editors, media releases and news conferences should focus on new and emerging aspects of the recycling project. A spokesperson should be available to journalists for interviews and 'backgrounding'. There may be a role for paid advertising or 'infotisements', particularly to reach special interest groups. Letters to the editor and talkback radio can be a means of monitoring stakeholders' knowledge of recycling projects and views about them.

Internet and CD ROMs

The internet can be used both to distribute and to collect information. A well-designed interactive website can meet the information needs of users at all levels. CD-ROMs can provide animation, sound and video to users who lack a high-speed internet connection.

Visual display material

Visual displays, often in conjunction with live presentations, can impart complex information quickly and efficiently, and can overcome language or educational barriers. Displays range from material on transportable display boards to more elaborate assemblies with functioning models and human operators. Transportable water recycling displays are useful for shopping centres, conferences, agricultural shows and field days. Permanent displays are often set up in the foyers of local councils and water utility buildings.

Non-media print material

Non-media print materials (eg fact sheets, newsletters, manuals, brochures, display boards and reports) can be general or targeted to special interest groups. A public organisation's annual report, which includes much certified information, also allows government and other stakeholders to assess financial viability and performance against published targets. Community newsletters and fact sheets can be distributed via letterbox drops or direct mail, perhaps with council or water rate notices.

Signage

Effective signage allows the organisation to providing mandatory warnings, but is also a means of promoting recycling projects. Typically, all signs include the organisation's logo. Signs are often designed according to a corporate design manual. The Australian Standards for design and application of water safety signs are a useful guide to design (AS 2002).

Face-to-face presentations

Presentations to live audiences, using visual aids, can impart complex information very efficiently. Up-to-date software, such as PowerPoint, also provides a way to collate new information and make a record of the meeting. Tours of recycling plants, developments with dual-reticulation systems and projects that demonstrate the use of treated sewage can increase stakeholder support. However, the presenter or guide must be well prepared to reinforce the organisation's message and deal effectively with opposing views.

Interaction with schools and tertiary institutions

Material for students should be developed in cooperation with educators, aligned with curricula and course programs, and designed to promote follow-up discussion. If site visits, models and displays are used, students should be given material to take away.

6.4 Public crisis communication

A public crisis is any situation that has the potential to cause an operational violation, a public health risk, an environmental risk, or a financial risk to the water recycling organisation. It could include any situation that might escalate intensity of the water recycling issue, lead to negative media or public scrutiny, interfere with normal operations, or damage the water recycling operation's reputation or image.

All potential crises should be dealt with in a preconsidered, organised and systematic manner. The aim should be to help resolve the current crisis, minimise damage to the reputations of the water recycling organisation and related parties, and prevent or minimise interruptions to operations.

The guiding principles for public crisis communications are listed in Box 6.1.

Box 6.1 Guiding principles for public crisis communications

- Be open, responsive, truthful and empathic, to reduce the risk of negative public perceptions.
- Put public health and the water recycling customers first.
- Deal with the crisis as quickly as possible.
- Speak with one voice — the face of the spokesperson may change, but all messages about the crisis must be consistent and come from a coordinated communications effort.
- If appropriate information is not available to answer questions accurately, say so.
- Inform customers and partners about the crisis and the water recycling organisation's actions to resolve it — arm partners with key messages when possible.
- Do not speculate. Do not guess. Do not blame.
- Communication must reinforce the water recycling organisation's mission.
- Outgoing communication must be forthcoming, assertive, focused on the most important aspects of the problem, and aim to move the process toward resolution.
- Crisis messages should be the same for all audiences and customised only as necessary.
- At all times, maintain respect for the legitimate interests of the media.

Many potential public crises occur with little or no warning, so the water recycling organisation should be prepared to deal with a very broad range of potentially damaging scenarios with minimum notice. A list of carefully prepared standby statements is indispensable, and should be provided to all personnel who may be required to provide initial responses to stakeholders, including the media. Unique responses will be tailored and updated to suit the specific circumstances dictated by each situation. The following are examples of useful standby statements.

For the receptionist:

> We're aware of the situation, but I'm not the appropriate person to answer your questions. Rather than speculate or provide you with inaccurate information, please give me your name, telephone number and email address and I'll have the appropriate person get back to you as soon as possible.

For the spokesperson:

> Because providing clean, safe water is our highest mission, we are fully cooperating with the 'authorities' to get to the bottom of this.

As soon as the crisis details are known, an interim communications strategy and related communications tools must be developed immediately. All relevant personnel should be accessible for discussion and rapid review of the strategy and tools.

Elements that should be included in the communications response to a crisis are listed in Box 6.2.

Box 6.2 Elements to include in communications response to a crisis

The communications response should include:

- a primary communications strategy
- a determined and refined list of key messages
- a prepared response statement
- a list of external experts who can be called upon to comment when appropriate
- a list of key non-media contacts to notify about the crisis
- a timeline or schedule of activities
- a list of frequently asked questions, including those that still need to be answered.

As the crisis develops (after the initial response), the organisation must monitor local and national news coverage, and continuously reassess the impact of communication activities on stakeholder perceptions. Information gained from these activities is useful in planning a continuing communications strategy, which should include a continuous review and revision of core themes and messages.

Until the crisis is properly resolved or contained, the communications strategy must be a high organisational priority. If media demand escalates, it may be necessary to prioritise media inquiries and responses and distribute formal statements as media releases.

The organisation should remain open and cooperative at all times, and arrange news conferences, individual interviews, or on-site media visits as necessary.

6.5 Frequently asked questions

Preparing answers to questions that are or are likely to be asked frequently by stakeholders is a sound communication strategy. Providing staff with model answers to questions helps the organisation to send well-informed and consistent messages to stakeholders and to improve its image. This strategy also saves time and resources: stakeholders who phone or visit the organisation can be provided with information without having to be referred to other staff members.

Frequently asked questions and their answers will need to be tailored to meet the needs of individual water recycling operations. Examples are shown in Box 6.3.

Box 6.3 Questions likely to be asked frequently by stakeholders

Is recycled water safe to drink?

Is recycled water safe for my garden?

Can I fill my swimming pool with recycled water?

What kind of testing is done on the treated water?

Has the recycled water you’re delivering ever been contaminated?

Where does the water come from?

How much water do you treat?

Box 6.3 (continued)

Where does the recycled water go?

How much do your customers pay for the recycled water?

What are the benefits of water recycling?

How much did it cost to build the water recycling scheme?

How much does the water recycling scheme cost to operate?

Are you a public or private agency?

What organisations support the project?

How do I learn more about your company and water recycling?

Can I attend a tour of the facility?

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Appendix 1 Case studies

This appendix provides five case studies, each illustrating a different use or source of recycled water. The case studies cover:

- commercial crops irrigated with recycled water from a major metropolitan sewage treatment plant (Section A1.1)
- a dual-reticulation scheme using recycled water produced from a major metropolitan sewage treatment plant (Section A1.2)
- irrigation of a golf course with recycled water produced from a small rural sewage treatment plant (Section A1.3)
- irrigation of municipal (landscape) areas with water recycled from a small community's sewage treatment plant (Section A1.4)
- use of greywater for toilet flushing and outdoor use (Section A1.5).

These case studies show how the 12 elements of the framework for risk assessment and management (described in Chapter 2) can be implemented in different situations. The sections on assessment and management of risks to health and the environment illustrate the principles detailed in Chapters 3 and 4, respectively.

A1.1 Commercial crops irrigated with recycled water from a major metropolitan sewage treatment plant

A1.1.1 Source and proposed use

In this case study, the source was treated sewage. Recycled water from a major metropolitan sewage treatment plant receiving domestic and industrial sewage was used for spray irrigation of commercial crops, including salad vegetables.

The sewage treatment plant flow was 120 ML/day. The plant originally provided secondary treatment, followed by about 20 days of lagoon storage and polishing, before discharge of most of its treated sewage to the sea.

The recycled water pipeline was commissioned in 1999 to supply treated sewage from the plant for irrigating commercial food crops. The aim was to supplement the existing use of groundwater (which was becoming depleted), while substantially reducing discharge of nutrient-rich water to the sea. The users of the treated sewage were largely commercial market gardeners who required water that could be used to spray irrigate a range of crops, including salad vegetables such as lettuce. Although the development of this scheme preceded these guidelines, a retrospective risk assessment indicates that the reuse scheme conforms to this guideline (see Table A1.1).

A1.1.2 Human-health risk assessment

The human-health risk assessment of the proposed recycled water scheme was performed in accordance with Element 2 of the framework for risk assessment and management.

Microbial quality

Microbial hazards included enteric viruses, protozoa, bacteria and helminths.

Microbial quality was identified as being paramount and the initial risk assessment indicated that secondary treated sewage did not comply with the targets identified by the health department, and hence represented an unacceptable risk. Although disability adjusted life years (DALYs) were not used, the outcome of the risk assessment was to effectively set log-reduction requirements that are consistent with those shown in Table 3.5 (Chapter 3). Additional treatment was required to meet the required log reduction (see 'Preventative measures', below).

Chemical quality

A catchment survey was used to identify industrial inputs into the sewage system. The survey did not identify major concerns with discharge in the area served by the sewage treatment plant, subject to a trade-waste control program. There were no pharmaceutical manufacturing industries in the catchment.

The potential risks of more than 200 priority chemical hazards were assessed, based on 20 years of chemical monitoring data associated with the sewage treatment plant. Most of the test results for individual parameters complied with the guideline values in the 2004 *Australian Drinking Water Guidelines* (NHMRC–NRMMC 2004). Exceedences were relatively minor and were often restricted to individual results. Based on test results, it was concluded that the chemical quality did not represent a risk to human health at the exposures involved with the proposed end use.

Preventive measures

A trade-waste control program was used to minimise the release of hazardous chemicals to the sewage treatment plant.

The original treatment system included secondary treatment followed by lagoon detention (>20 days). Treatment was expanded to include coagulation, dissolved air flotation and filtration (DAFF) and disinfection. The advantage of lagoons is that they:

- are robust and easy to maintain
- provide a 20-day buffer between secondary treatment and filtration (and an early warning of problems detected in secondary treatment)
- can dilute any transient peaks in chemical or microbial hazards
- provide reductions in concentrations of enteric pathogens.

The advantages of the lagoons meant that lower performance was required from coagulation and filtration.

On-site control measures were also applied (see Element 3, Table A1.1).

Validation

Because a nonstandard design was used, evidence that water quality requirements (and therefore performance targets) had been achieved and validated was required before the water treatment scheme could be approved. Before commissioning, the system was validated by testing for the removal of *Cryptosporidium*, *Giardia*, adenoviruses, reoviruses, enteroviruses and hepatitis A. Removal of bacterial pathogens was demonstrated by removal of *Escherichia coli*.

Results showed that untreated sewage at the plant contained 2000 *Cryptosporidium*, 20 000 *Giardia*, and 8000 viruses per litre (detected using cell culture, except in the case of hepatitis A, which was detected using the polymerase chain reaction). Treated sewage supplied to growers contained <1 *Cryptosporidium*, *Giardia* and virus per 50 litres, and <1 *E. coli* per 100 mL. This represented a 5-log reduction of *Cryptosporidium*, 5.5-log reduction of rotavirus/adenovirus, and a >6-log reduction of pathogenic bacteria. Total log reductions are shown in Box A1.1.

Additional virus inactivation was provided by the period between final watering and delivery of produce to market (provided through the normal operating procedures).

Box A1.1 Total log reductions

Total log reductions after treatment of sewage were:

- 5 log for enteric protozoa
- 6 log for enteric viruses
- >6 log for enteric bacteria.

Food crop testing

Crop testing showed no difference between crops irrigated with groundwater or with recycled water; both complied with the requirements of the *Australia New Zealand Food Standards Code* (FSANZ 2003)

A1.1.3 Environmental risk assessment

The environmental risk assessment of the recycled water scheme was performed in accordance with Element 2 of the framework for risk assessment and management.

Microbial quality

Microbial quality of the recycled water was not considered an environmental issue, given the high levels of treatment required to minimise risks to human health. No preventive measures were required.

Chemical quality

General environmental endpoints identified for consideration in the preliminary risk assessment were groundwater, surface water, specific soil types and plant species.

Phase 1 of the risk assessment (preliminary screening) identified the hazards chloride, sodium, salinity, nitrogen, phosphorus, hydraulic load and boron as moderate to high risks (ie not acceptable; see Figure 4.1 in Chapter 4).

Phase 2 (maximal risk assessment) confirmed that, except for boron, all key hazards identified in Phase 1 required preventive measures to reduce the risk they posed to the environment to acceptable levels. Boron was considered low risk for this system, given the soil types, plants grown, historical data and research results (additional research on boron concentrations in soil was undertaken, to provide sufficient data). However, the risk assessment identified the need for long-term monitoring as a precautionary measure, to review potential accumulation of boron in soil and chronic toxicity.

Phase 3 (residual risk assessment) identified a range of preventive measures (see below) that would reduce the risks associated with the key hazards identified above to acceptable levels (ie ‘low’ in Table 2.7, Chapter 2).

Environmental preventive measures

Salinity was identified as a key risk. A target criterion of 1450 mg/L total dissolved salts (TDS) was identified, with a critical limit of 1500 mg/L TDS. Operational corrective actions to be put in place when TDS exceeded 1450 mg/L included checking sewage water inflow, and implementing source control for industry salt loads, sewers and operation of the sewage treatment plant. If the critical limit was exceeded, the recycled water was diluted with drinking water to reduce TDS to <1500 mg/L.

On-site preventive measures were also applied (see Element 3, Table A1.1).

Food crop testing

Edible portions of crops grown with recycled water were surveyed after 2–3 years of irrigation with recycled water. The survey confirmed that the mobilisation of cadmium in soil due to the salinity of recycled water was a low risk. Further monitoring will only be required if water quality analyses exceed target criteria or critical values for salinity.

A1.1.4 Risk management plan

Table A1.1 lists the 12 elements of the framework for management of recycled water quality and use, and shows how the scheme meets the various elements.

Table A1.1 Framework elements applied to a scheme using recycled water from a major metropolitan sewage treatment plant to irrigate commercial crops

Framework element and components	Activity
Element 1: Commitment to responsible use and management of recycled water	
Components: *Responsible use of recycled water* *Regulatory and formal requirements* *Partnerships and engagment of stakeholders (including the public)* *Recycled water quality policy*	• Development of the scheme involved collaboration between the state's water utility, the state department responsible for human health (eg Health Department — HD), the state department responsible for the environment (eg Environmental Protection Authority — EPA), primary industries department, environmental protection agency (EPA) and growers. • The growers required a supply of irrigation water that could be used to water food crops without restriction on methods of application. The health, environment and primary industries agencies aimed to identify conditions that would ensure safe and sustainable use. • Regulatory requirements identified included: – *Public and Environmental Health Act* – *Environment Protection Act* – *Food Act* – *Stock Foods Act* • Other stakeholders were the: – commercial buyers of produce – local irrigators association – district horticulture centre – constructor and operator of the distribution system – consumers of produce – other users of recycled water – general public.
Element 2: Assessment of the recycled water system	
Components: *Intended uses and source of recycled water*	• The source of water is a large sewage treatment plant. • Intended uses include irrigation of – salad vegetables – lucerne for stock feed – recreational areas • Receiving environments or endpoints include groundwater, surface water, plants, soils, air. Specific soil types and plant species were identified.
Recycled water systems analysis	• A catchment survey was undertaken to identify industries attached to the collection system. • The original design of the scheme included secondary treatment and lagoons; later extended to include coagulation, dissolved air flotation and filtration (DAFF) and chlorination. • Treated effluent is distributed through 100 km of pipeline to the irrigators; users are required to have on-site storages, with air gaps between delivery pipes and the storage facility. • Irrigators use drip and overhead spray irrigation systems.
Assessment of water quality data	• Twenty years of chemical data for the treated sewage were available for assessment.

Table A1.1 (continued)

Framework element and components	Activity
Hazard identification and risk assessment	**Human health** Hazard identification and risk assessment for human health found the following: • Microbial hazards for humans included enteric bacteria, viruses and protozoa. Helminths represented a potential hazard for stock. • More than 200 priority chemicals, including potential endocrine disruptors and pharmaceutical agents, were investigated for potential impacts on human health. The risk of chemical impact was determined to be very low, based on historical results coupled with knowledge of industry inputs into the system, and the dilution and mixing impact provided by lagoons. Concentrations of most chemicals complied with values specified in the *Australian Drinking Water Guidelines* (NHMRC–NRMMC 2004). • Possible aesthetic problems associated with disinfection byproducts (eg chlorinated phenols) were identified, but these problems have not been detected. **Environmental performance** Hazard identification and risk assessment for the environment found the following: • Phase 1of the risk assessment (preliminary screening) identified chloride, sodium, salinity, nitrogen, phosphorus, hydraulic load and boron as moderate to high risks (ie not acceptable). • Phase 2 (maximal risk assessment) confirmed that all key hazards required preventive measures to lower risks to acceptable levels. • Phase 3 (residual risk assessment) identified a range of preventive measures (see Element 3 below) that should reduce the risk to an acceptable level (ie 'low' in Table 2.7, Chapter 2). **Environmental baseline monitoring requirements** Development of the irrigation management plan identified the need for a range of monitoring to establish background conditions. Monitoring was initiated before commencement of the scheme, and included: • concentrations of hazards identified above (Phase 2) in soil including, sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP), nitrate, total nitrogen and phosphorus, soluble boron, pH, chloride and electrical conductivity (EC), at three depths • the salinity (EC), SAR, phosphorus, nitrogen and boron concentration of groundwater in the district • soil types • levels of groundwater and watertables in the district.

Table A1.1 (continued)

Framework element and components	Activity
Element 3: Preventive measures for recycled water management	
Components: *Preventive measures and multiple barriers*	**Human health** Preventive measures to manage risks to human health include: • trade-waste control system to reduce likelihood of toxic chemical discharges • lagoon storage to mitigate contamination spikes and to provide pathogen reduction • coagulation, DAFF • chlorination • backflow prevention and cross-connection control at all irrigation sites • pipework (colour coded) and signage • an education program for users, families and workers on use restrictions and hygiene requirements. **Environmental performance** Preventive measures to manage risks to the environment included: • total dissolved salts (TDS) of recycled water kept below 1500 mg/L • controls on crops that could be grown • site selection — some soil types were not recommended for application of recycled water • soil amelioration using agents such as gypsum • 'shandying' (ie diluting) with borewater to reduce water salinity during germination and juvenile plant growth • irrigation tools (use of drip irrigation to water crops and an overhead spray system to leach soils between crops, if required) • education programs on irrigation practices — a user manual for irrigating with treated sewage was delivered to all licensees and users through a series of workshops. • a storage system designed and built to minimise unintended losses of recycled water • nutrient budgeting to consider the nitrogen and phosphorous in recycled water • limitation of light entering storage systems to control algae growth • filtration to remove suspended solids (eg algae) before the water entered the drip irrigation systems.
Critical control points	**Human health** Critical control points for human health were identified as: • lagoon storage (minimum 16 days) • DAFF (turbidity limits) • disinfection (chlorine residual limits). **Environmental performance** A critical control point for the environment was identified as salinity of the recycled water entering the recycled water reticulation system (TDS of 1500 mg/L).

Table A1.1 (continued)

Framework element and components	Activity
Element 4: Operational procedures and process control	
Components: *Operational procedures*	**Human health** In relation to human health: • operational procedures were identified for all processes and activities associated with the system • documented procedures must be available to all operations personnel and available for inspection at any time. **Environmental performance** In relation to the environment, irrigation procedures were established to minimise salinity impacts, maintain nutritional levels, and minimise leaching and impacts on groundwater quality and quantity (all users of recycled water are trained in best management practices for irrigation).
Operational monitoring	**Human health** Monitoring requirements in relation to human health include: • standard wastewater plant requirements, such as biochemical oxygen demand (BOD), suspended solids, etc • *Cryptosporidium* inputs into the storage lagoons • flow rates (lagoon detention) — *critical limit set* • turbidity of filtered water (continuous) — *critical limit set* • disinfection (continuous) — *critical limit set* • on-site auditing of controls (signage, backflow prevention, etc). **Environmental performance** Monitoring requirements in relation to the environment include: • recycled water electrical conductivity (continuous) — *critical limit set* • pressure sensors in the reticulation system to identify pipe bursts and automatic cessation of supply if detected • visual inspection to ensure that best management practice for irrigation is followed and leakage from the irrigation and reticulation system is minimised • moisture sensors or other monitoring tools are used to maximise irrigation efficiency • irrigation monitoring is used to minimise runoff.

Table A1.1 (continued)

Framework element and components	Activity
Corrective action	**Human health** In relation to human health, corrective actions include the following: • noncompliance with critical limits results in flow to the irrigation system being stopped automatically until remedial action is implemented; that is, flow is stopped if: – flow rates stop minimum lagoon-detention times being met – maximum turbidity (10 nephelometric turbidity units, NTU) is exceeded for more than 60 minutes – disinfection fails • users of recycled water who fail to apply on-site restrictions can be disconnected • noncompliance with other limits can result in corrective action being taken while the system remains operational • if *Cryptosporidium* numbers in the influent to the lagoons exceed 50/L, increased monitoring is activated at the DAFF plant and operators are notified. **Environmental performance** In relation to the environment, corrective actions include the following: • if the target value of 1450 mg/L TDS is exceeded, the continuous monitoring of EC of recycled water entering the reticulation system is reviewed and intensified; any corrective actions possible are taken to ensure the sewage systems and treatment plant has not malfunctioned • if the critical limit (1500 mg/L TDS) of the treated water is exceeded, then the treated water is 'shandied' with drinking water.
Equipment capability and maintenance	**Human health** In relation to human health: • online measuring devices include 24-hour monitored alarm systems for key devices including filtration and disinfection; backup power is available • the filtration plant incorporates variable dosing and variable control of flow rates. **Environmental performance** In relation to the environment: • on-site moisture sensors or other monitoring tools are used to maximise irrigation efficiency • EC is also monitored continuously as a measure of TDS and salinity entering the system.
Materials and chemicals	• Quality assurance for materials and chemicals is applied to ensure that they do not introduce contaminants into the recycled water system.

Table A1.1 (continued)

Framework element and components	Activity
Element 5: Verification of recycled water quality and environmental performance	
Components: *Recycled water quality monitoring (specifically designed for individual systems, taking into account source of water, end uses and receiving environments)*	**Human health** Parameters monitored in relation to human health include: • adenovirus, *Cryptosporidium, Escherichia coli* • pH, heavy metals • disinfection byproducts, halogenated and non-halogenated organics, benzo(a)pyrene, herbicides and pesticides, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) and volatile chlorinated hydrocarbons (VCH). **Environmental performance** Parameters monitored in relation to the enviroment include SAR, chloride, chlorine disinfection residuals, nitrate and total nitrogen, total phosphorus, boron, heavy metals and surfactants.
Application site and receiving environment monitoring	**Environmental performance** In relation to the environment, monitoring includes the following: • Environmental monitoring is undertaken on a biennial basis from application sites and which includes testing of: – soils (eg SAR, nutrients, pH, conductivity, cadmium, boron) – groundwater (eg water levels, conductivity, nutrients) (note: in this case study, no relevant surface waters require monitoring). • Environmental monitoring of marine discharge water is undertaken; this includes all parameters listed above for recycled water quality monitoring, except for adenoviruses and *Cryptosporidium*. • Crops are tested to confirm that, compared with bore water, recycled water does not adversely affect microbial or chemical content of crops (in this particular case study, crops were also specifically tested for heavy metals, particularly cadmium, to verify that any changes in salinity of recycled water compared with bore water had not increased cadmium concentrations via mobilisation of soil cadmium by salinity in the form of chloride). • Produce from the area is predominantly sold through a regional produce market, which has an active quality assurance testing program.The source of water used to irrigate crops is recorded.
Satisfaction of users of recycled water	• Satisfaction of users of recycled water is monitored by the operator of the recycled water distribution system and the local horticulture centre. • A team with relevant expertise (water quality, agronomy, environment, health) was established with a central contact through the local horticultural centre, to respond to grower concerns.
Short-term evaluation of results	• Results are provided routinely to the EPA and HD. Exceedences of set guideline values are reported immediately, in accordance with an agreed incident protocol.
Corrective responses	• Corrective responses depend on the exceedence. As a minimum, the response involves investigation of plant performance records to confirm normal operation and additional testing — first to confirm the exceedence and then to identify the source. • Environmental performance corrective actions are specific to the hazard and impact, with a focus on identifying the cause and modifying preventive measures as required.

Table A1.1 (continued)

Framework element and components	Activity
Element 6: Management of incidents and emergencies	
Components: *Communication* *Incident and emergency response protocols*	• An incident notification and communication protocol incorporates: – emergency contact lists – criteria for defining incidents – notification requirements, including timeframes – media and general communication protocols.
Element 7: Operator, contractor and end user awareness and training	
Components: *Operator, contractor and end user awareness and involvement* *Operator, contractor and end user training*	• Water treatment approval issued by the HD requires the plant to be operated by appropriately trained and skilled personnel. • All new users of recycled water are issued with an information package regarding the use of recycled water and attend a training course on best irrigation practice.
Element 8: Community involvement and awareness	
Components: *Consultation with users of recycled water and the community* *Communication and education*	• Before the scheme was commissioned, the general public, growers and buyers of produce were consulted extensively to ensure they were comfortable with the use and quality of recycled water to be supplied. The quality was based on the requirements of growers that recycled water be suitable for spray irrigation of all types of produce (from a health perspective), and that the system minimised the risk of accidental misuse of the recycled water. • Growers were informed that the salinity or chloride of the recycled water might be too high to grow some crops (eg lettuce and almonds) directly, and that dilution with low-salinity bore water might be required as an on-site preventive measure. • An information package dealing with authorised uses, restrictions, responsibilities, hygiene and occupational health and safety was provided to all users of recycled water. • After commissioning the plant, an active education program was undertaken on sustainable irrigation and land management in the area receiving recycled water; this program was combined with a growers' manual for sustainable use of recycled water.
Element 9: Validation, research and development	
Components: *Validation of processes* *Design of equipment*	• Pilot plants were constructed and operated to assist in design of treatment processes and equipment used in the recycled water scheme. • Extensive pre-commissioning testing was undertaken to validate the ability of the lagoons, the filtration plant and the disinfection station to remove pathogens and provide recycled water of the desired quality. This involved testing for adenoviruses, reoviruses, enteroviruses, hepatitis A, *Cryptosporidium, Giardia* and helminths. • Validation continued during the first year of operation, to ensure that seasonal variations were assessed.
Investigative studies and research monitoring	• Edible portions of crops grown with recycled water were surveyed after 2–3 years irrigation with recycled water, to confirm that mobilisation of cadmium in soil was a low risk. • Methods of managing soil salinity and minimising nitrate leaching have been investigated, to improve irrigation efficiencies. • Investigative studies are continuing on the impacts of irrigation on the market gardening area, including the use of recycled water. • Possible input of *Cryptosporidium* from birdlife into lagoon water and filtered water was investigated. As a result, the DAFF plant was bird-proofed.

Table A1.1 (continued)

Framework element and components	Activity
Element 10: Documentation and reporting	
Components: *Management of documentation and records* *Reporting*	• All operating procedures require documentation. All results, including printouts from continuous monitoring systems, have to be recorded and stored. • Results must be reported on a regular and agreed basis to HD and EPA.
Element 11: Evaluation and audit	
Components: *Long-term evaluation of results* *Audit of recycled water quality management*	• All monitoring results are analysed as part of an annual audit undertaken by an independent third-party auditor. The audit also involves assessment of compliance with management requirements specified by HD and EPA. Audit reports are submitted to HD and EPA. • Results of biennial monitoring programs are assessed against the results of baseline monitoring. These assessments have indicated no significant change in any environmental performance indicators monitored.
Element 12: Review and continual improvement	
Components: *Review by senior managers* *Recycled water quality management improvement plan*	• Operation of scheme reviewed by the water utility. Plans established for introduction of potential improvements identified from operating experience.

BOD = biochemical oxygen demand; DAFF = dissolved air, flotation and filtration; EC = electrical conductivity; EPA = environmental protection agency; ESP = exchangeable sodium percentage; HD = health department; NTU = nephelometric turbidity unit; PAH = polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyl; SAR = sodium absorption rate; TDS = total dissolved salts; VCH = volatile chlorinated hydrocarbons

A1.2 Dual-reticulation scheme using recycled water produced from a major metropolitan sewage treatment plant

A1.2.1 Source and proposed use

In this case study, the source was treated sewage. Recycled water from a major metropolitan treatment plant was used for a dual-reticulation scheme. Proposed uses for the recycled water included garden use, car washing, toilet flushing and urban irrigation of parks and gardens.

A1.2.2 Human-health risk assessment

Microbial quality

Microbial hazards for human health include enteric bacteria, viruses and protozoa. The total log reduction required for this scheme was 5 log protozoa, 6.5 log viruses, and 5 log bacteria (see Box A1.2).

Chemical quality

Most of the test results for individual parameters complied with the guideline values in the 2004 *Australian Drinking Water Guidelines* (NHMRC–NRMMC 2004). Exceedences were relatively minor and often restricted to individual results. Due to the exposures associated with the proposed uses, chemicals did not represent a significant health risk.

Preventive measures

A trade-waste control program was maintained to minimise release of hazardous chemicals to the sewage treatment plant. Other preventive measures included secondary treatment, coagulation, dual media filtration and chlorination (providing a minimum Ct of 90 mg/L, where Ct is the product of disinfectant concentration [C, in mg/L] and contact time [t, in minutes]).

On-site control measures were also applied (see Element 3, Table A1.2).

Validation

Performance of secondary treatment, coagulation and dual media filtration were validated by direct testing for enteric viruses (adenoviruses, reoviruses, enteroviruses and hepatitis A), *Cryptosporidium* and *Giardia*. Testing demonstrated a 5-log reduction of protozoa and a 4-log reduction of viruses.

Chlorination was validated as providing a further 3-log reduction of viruses based on published work (eg USEPA 1999). Removal of >6 logs of *Campylobacter* was validated using published data (eg USEPA 1999).

Box A1.2 Total log reductions

Total log reductions after treatment of sewage were:

- 5 log for *Cryptosporidium*
- 6.5 log for rotavirus
- >6 log for *Campylobacter*.

An alternative approach could have been to validate removal of protozoa and viruses using index organisms such as *Clostridium perfringens* and bacteriophage.

A1.2.3 Environmental risk assessment

Microbial quality

Microbial quality of the recycled water was not considered an environmental issue given the high levels of treatment required to minimise risks to human health. No preventive measures were required.

Chemical quality

The preliminary risk assessment identified groundwater, surface water, aquatic biota, landscape and garden plants, turf and lawns, and specific soil types as potential environmental endpoints for hazards.

Phase 1 of the risk assessment (preliminary screening) identified the hazards chloride, sodium, salinity, nitrogen, phosphorus and chlorine disinfection residuals, as moderate to high risks.

Phase 2 (maximal risk assessment) confirmed that only four key hazards (salinity, phosphorus, nitrogen and chlorine disinfection residuals) required preventive measures to lower the risk to acceptable levels.

Phase 3 (residual risk assessment) identified a range of preventive measures (see below) that would reduce the risks associated with the key hazards identified above to acceptable levels (ie ‘low’ in Table 2.7, Chapter 2).

Environmental preventive measures

Salinity was identified as a key parameter. A target criterion of 900 mg/L TDS was identified. Short-term spikes up to 1200 mg/L were permitted (critical limit). Where necessary, recycled water was diluted with drinking water to reduce TDS to <900 mg/L.

Secondary treatment incorporated nutrient reduction, which decreases (but does not eliminate) the potential impacts of nitrogen and phosphorus.

On-site control measures were also applied (see Element 3, Table A1.2).

A1.2.4 Risk management plan

Table A1.2 lists the 12 elements of the framework for managing recycled water quality and use, and shows how the scheme meets the various elements.

Table A1.2 Framework elements applied to the use of recycled water through a dual-reticulation system

Framework element and components	Activity
Element 1: Commitment to responsible use and management of recycled water quality	
Components: *Responsible use of recycled water* *Recycled water policy* *Regulatory and formal requirements* *Engaging stakeholders*	• Development of the dual-reticulation scheme involved collaboration between the water utility, the state department responsible for human health (eg Health Department — HD), the state department responsible for the environment (eg Environmental Protection Authority — EPA), the local council and the developers. • Regulatory requirements identified included the – *Public Health Act* – *Environment Protection Act* – *Water and Sewerage Acts* • Other stakeholders were – local community – plumbers and builders – general public.
Element 2: Assessment of the recycled water system	
Components: *Identify intended uses and source of recycled water*	• Intended uses included – toilet flushing – residential garden uses, car washing, etc – spray irrigation of parks and reserves (local council) • Source of water is a large metropolitan sewage treatment plant.
Recycled water systems analysis	• A catchment survey was undertaken to identify industries attached to the collection system. • The scheme included enhanced secondary treatment (with nutrient reduction), coagulation, dual-media filtration and chlorination. • Recycled water is distributed through a separate reticulation system, incorporating a 5 ML balancing storage before it reaches consumers. The system was installed in accord with *WSAA Sewerage Code Version 2.1* (WSAA 2002a).
Assessment of water quality data	• The treatment plant includes a marine discharge and results from chemical testing undertaken over a 10-year period, in accord with EPA licence conditions were available for assessment.

Table A1.2 (continued)

Framework element and components	Activity
Hazard identification and risk assessment	**Human health** Hazard identification and risk assessment for human health found that concentrations of most chemicals complied with values specified in the 2004 *Australian Drinking Water Guidelines* (NHMRC–NRMMC 2004). Microbial hazards for humans included enteric bacteria, viruses and protozoa. **Environmental performance** Hazard identification and risk assessment for the environment found the following: • The preliminary risk assessment identified groundwater, landscape and garden plants, turf and lawns, and specific soil types as potential environmental endpoints for hazards. • Phase 1of the risk assessment (preliminary screening) identified the hazards chloride, sodium, salinity, nitrogen, phosphorus and chlorine disinfection residuals, as moderate to high risks. • Phase 2 (maximal risk assessment) confirmed that only four key hazards (salinity, phosphorus, nitrogen and chlorine disinfection residuals) required preventive measure to lower the risk to acceptable levels. • Phase 3 (residual risk assessment) identified a range of preventive measures (see Element 3 below) available that should reduce the risk to an acceptable level (ie ‘low’ in Table 2.7, Chapter 2). **Environmental baseline monitoring requirements** A range of monitoring was identified to establish background conditions. Monitoring was initiated before commencement of the scheme, and included: • concentrations of hazards identified above (Phase 2) in soil including, sodium absorption ratio (SAR), exchangeable sodium percentage (ESP), nitrate, total nitrogen and phosphorus, pH, chloride and electrical conductivity (EC), at three depths • the salinity (EC), SAR, phosphorus, nitrogen and boron concentration of groundwater in the district • levels of groundwater and watertables in the district.

Table A1.2 (continued)

Framework element and components	Activity
Element 3: Preventive measures for recycled water management	
Components: *Preventive measures and multiple barriers*	**Human health** Preventive measures to manage risks to human health included: • trade-waste control system to reduce likelihood of toxic chemical discharges • enhanced secondary treatment to provide nutrient reduction • coagulation and filtration • chlorination • backflow prevention and cross-connection control at all irrigation sites • pipework (colour coded) and signage • an education program for householders and plumbers. **Environmental performance** Preventive measures to manage risks to the environment included: • total dissolved salts (TDS) of the recycled water entering the recycled water reticulation system kept below an average of 900 mg/L • residents advised that salinity and nutrients in water higher than in drinking water; therefore, advised to use less fertiliser, to select salt-tolerant plants and to consult with local nurseries • local council considered nutrient content when determining fertiliser requirements in parks irrigated with recycled water • educational material provided advice on how to avoid overwatering.
Critical control points	**Human health** Critical control points for human health were: • filtration (turbidity limits) • chlorination (Ct limits) **Environmental performance** A critical control point for the environment was salinity of the recycled water entering the recycled water reticulation system (TDS <900 mg/L as an average, critical limit 1200 mg/L).
Element 4: Operational procedures and process control	
Components: *Operational procedures*	**Human health** In relation to human health: • operational procedures were identified for all processes and activities associated with the system, including operation of treatment processes and auditing procedures for cross-connections • documented procedures were required to be available to all operations personnel and to be available for inspection at any time. **Environmental performance** In relation to the environment, procedures were established for irrigating parks and reserves to minimise salinity impacts, controlling nutrient application (fertiliser application), and controlling quantities of water used.

Table A1.2 (continued)

Framework element and components	Activity
Operational monitoring	**Human health** Monitoring requirements in relation to human health included: • standard wastewater plant requirements biochemical oxygen demand (BOD), suspended solids, etc • turbidity of filtered water (continuous) — *critical limit set* • disinfection (continuous) — *critical limit set* • on-site auditing of controls (signage, backflow prevention, etc). **Environmental performance** Monitoring requirements in relation to the environment included: • recycled water electrical conductivity (continuous) — *critical limit set* • pressure sensors in the reticulation system to identify pipe bursts and automatic cessation of supply if detected • visual inspection to ensure best management practice for irrigation followed and minimised leakage from the irrigation and reticulation system • visual inspection of health of plants and grassed areas • moisture sensors or other monitoring tools used to maximise irrigation efficiency • irrigation monitoring to minimise runoff.
Corrective action	**Human health** In relation to human health, corrective actions included the following: • Noncompliance with critical limits results in flow to dual-reticulation system being stopped and replaced by mains water. That is, flow stopped if: – turbidity limits (0.5 NTU average, 2 NTU maximum) not met for 60 minutes – minimum Ct (90 mg/min/L not achieved for more than 60 mins. • If cross-connections detected, flow to individual property stopped at the property boundary. **Environmental performance** In relation to the environment, corrective actions included the following: • If the target value of 900 mg/L TDS is exceeded, the continuous monitoring of EC of recycled water entering the reticulation system is reviewed and intensified. Any corrective actions possible are taken to ensure the sewage systems and treatment plant has not malfunctioned. • If the critical limit (1200 mg/L TDS) of the treated water is exceeded, then the treated water is shandied with drinking water. • If inspections reveal faults in irrigation procedures, remedial action implemented. • If inspections identify poor performance or health of plants and grass, causes should be investigated
Equipment capability and maintenance	• Online measuring devices include: – 24-hour monitored alarm systems for key devices – backup power available – variable dosing and variable control of flow rates in filtration plant.

Table A1.2 (continued)

Framework element and components	Activity
Materials and chemicals	• Quality assurance for materials and chemicals applied in the same manner as for water treatment facilities. Materials and chemicals selected to ensure that they do not introduce contaminants into the recycled water system.
Element 5: Verification of recycled water quality	
Components: *Recycled water quality monitoring (specifically designed for individual systems, taking into account source of water, end uses and receiving environments)*	**Human health** Parameters monitored in relation to human health include: • adenovirus, *Cryptosporidium*, *Escherichia coli* • pH, heavy metals • disinfection byproducts, halogenated and non-halogenated organics, benzo(a)pyrene, herbicides and pesticides, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) and volatile chlorinated hydrocarbons (VCH). **Environmental performance** Parameters monitored in relation to the enviroment include: SAR, chloride, chlorine disinfection residuals, nitrate and total nitrogen, available and total phosphorus.
Application and discharge site monitoring	**Environmental performance** In relation to the environment, monitoring includes the following: • soils (eg SAR, nutrients, pH, conductivity) • groundwater (eg water levels, conductivity, nutrients).
Satisfaction of users of recycled water	• Householder satisfaction is monitored by the operator of the recycled water distribution system. Complaints are investigated, particularly when clusters of complaints are received.
Short-term evaluation of results	• Results are provided routinely to EPA and HD. Exceedences of set guideline values are reported immediately in accord with an agreed incident protocol.
Corrective responses	**Human health** • Corrective responses depend on the exceedence. As a minimum, it involves investigation of plant performance records to confirm normal operation and additional testing to both confirm the exceedence and to identify the source. **Environmental performance** • Responses are specific to the impact, with a focus on identifying the cause and implementing preventive measures as required.
Element 6: Management of incidents and emergencies	
Components: *Communication* *Incident and emergency response protocols*	• An incident notification and communication protocol incorporates: – emergency contact lists – criteria for defining incidents – notification requirements, including timeframes – media and general communication protocols.
Element 7: Employee awareness and training	
Components: *Employee awareness and involvement* *Employee training*	• Regulatory approval includes the requirement that the plant is operated by appropriately trained and skilled personnel.

Table A1.2 (continued)

Framework element and components	Activity
Element 8: Community involvement and awareness	
Components: *Community consultation* *Communication and education*	• Before the scheme was commissioned, the residents were consulted extensively. An information package dealing with authorised uses, best practices for irrigation, restrictions and responsibilities was provided to all residents and to plumbers.
Element 9: Research and development	
Components: *Validation of processes* *Design of equipment*	• Before commissioning (2 months), testing was undertaken to validate the capacity of secondary treatment, coagulation and filtration to provide 5-log reduction of protozoa and 5-log reduction of viruses. This involved testing for adenoviruses, reoviruses, enteroviruses, hepatitis A, *Cryptosporidium, Giardia* and helminths. • Validation continued during the first year of operation to ensure that seasonal variations were assessed. • The capacity of the chlorination system to provide a minimum Ct of 60 mg.min/L was validated.
Investigative studies and research monitoring	• Resident satisfaction is being studied.
Element 10: Documentation and reporting	
Components: *Management of documentation and records* *Reporting*	• All operating procedures require documentation. All results, including printouts from continuous monitoring systems, must be recorded and stored. • Results must be reported on a regular and agreed basis to HD and EPA.
Element 11: Evaluation and audit	
Components: *Long-term evaluation of results* *Audit of recycled water quality management*	• Results are analysed as part of an annual audit by an independent third-party auditor. The audit also involves assessment of compliance with management requirements specified by HD and EPA. Audit reports are submitted to HD and EPA. • Results of biennial monitoring programs are assessed against the results of baseline monitoring.
Element 12: Review and continuous improvement	
Components: *Review by senior managers* *Recycled water quality management improvement plan*	• Operation of scheme reviewed by the water utility. Plans established for introduction of potential improvements identified from operating experience.

BOD = biochemical oxygen demand; Ct = product of disinfectant concentration (C, in mg/L) and contact time (t, in minutes); EC = electrical conductivity; EPA = environmental protection agency; ESP = exchangeable sodium percentage; HD = health department; NTU = nephelometric turbidity unit; PAH = polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyl; SAR = sodium absorption rate; TDS = total dissolved salts; VCH = volatile chlorinated hydrocarbons

A1.3 Irrigation of a golf course with recycled water produced from a small rural sewage treatment plant

A1.3.1 Source and proposed use

In this case study, the source was a communal wastewater treatment plant. Recycled water from a plant receiving septic tank waste, treated by holding in lagoons for 60 days, was used for spray irrigation of nine fairways at a local golf course.

A1.3.2 Human health risk assessment

Microbial quality

Microbial hazards for human health include enteric bacteria, viruses and protozoa. The total log reduction required for this scheme is 3.5-log reduction of protozoa, 5-log reduction of viruses, and a 4-log reduction of bacteria (see Tables 3.7 and 3.8).

Chemical quality

Exposure of chemicals in recycled water is too low to represent a health risk.

Preventive measures

Secondary treatment plus lagoons with a 60-day detention provide a 2-log reduction of protozoa and viruses, and 4-log reduction of enteric bacteria.

Spray irrigation is applied at night with 10–15 metre buffer zones and spray-drift control is applied through the use of (180°) inward-throwing sprinklers. Potential for public exposure to enteric protozoa, viruses and bacteria is reduced by 3–4 logs.

Total reductions are 5–6 log for protozoa and viruses, and 7–8 log for enteric bacteria.

Validation

Available data indicate that secondary treatment and lagoons provide the required log reductions.

A1.3.3 Environmental risk assessment

Microbial quality

Microbial quality of the recycled water is not considered an environmental issue, given the high levels of treatment required to minimise risks to human health. No preventive measures are required.

Chemical quality

The preliminary risk assessment identified groundwater, turf and grasses, and specific soil types as potential environmental endpoints for hazards. Other landscaping and screening plants were well established.

Phase 1 of the risk assessment (preliminary screening) identified the hazards sodium, salinity, nitrogen and phosphorus, as moderate to high risks.

Phase 2 (maximal risk assessment) confirmed that the four key hazards (sodium, salinity, phosphorus, and nitrogen) required preventive measures to lower the risk to acceptable levels.

Phase 3 (residual risk assessment) identified a range of preventive measures available (see Element 3 below) that should reduce the risks associated with the key hazards identified above to acceptable levels (ie 'low' in Table 2.7, Chapter 2).

Preventive measures

A range of on-site preventive measures was applied (see Element 3, Table A1.3).

A1.3.4 Risk management plan

Table A1.3 lists the 12 elements of the framework for managing recycled water quality and use, and shows how the scheme meets the various elements.

Table A1.3 Framework elements for the use of recycled water produced from a small rural sewage treatment plant to irrigate a golf course

Framework element and components	Activity
Element 1: Commitment to responsible use and management of recycled water quality	
Components: *Responsible use of recycled water* *Recycled water policy* *Regulatory and formal requirements* *Engaging stakeholders*	• The local council identified the benefits of recycling effluent rather than discharging it to sea, and included recycling in its strategic plan. • Council actively sought approval for treated effluent from the plant to be used to irrigate the local golf course, and committed to ensuring that the scheme would be managed according to approvals. • Council sought approval from the state department responsible for human health (eg Health Department — HD) and the state department responsible for the environment (eg Environmental Protection Authority — EPA), according to state legislation – *Public and Environmental Health Act* – *Environment Protection Act*. • Council owns the golf course, and consulted with users of the course and local residents before proceeding.
Element 2: Assessment of the recycled water system	
Components: *Identify intended uses and source of recycled water*	• The water will be used to spray irrigate the local golf course with secondary treated septic tank effluent.
Recycled water system analysis	• A centralised plant receives septic tank effluent from 830 residences, holiday homes and commercial properties (motels, hotels, etc). It receives no industrial discharge. • The treated effluent is to be piped to a fully lined storage on the golf course and then used for spray irrigation of nine fairways.
Assessment of water quality data	• Water quality data indicated that the effluent was typical of secondary treated domestic waste. Median numbers of *Escherichia coli* were less than 1000 organisms per 100 mL. • Average total nitrogen was 12 mg/L, total phosphorus 5 mg/L and total dissolved salts (TDS) fluctuated from 1100–1200 mg/L.

Table A1.3 (continued)

Framework element and components	Activity
Hazard identification and risk assessment	**Human health** Hazard identification and risk assessment for human health found the following: • Microbial hazards for humans include enteric bacteria, viruses and protozoa. • The golf course storage is potentially vulnerable to contamination by additional human and livestock waste. • Aesthetic problems in the storage are possible, due to cyanobacterial blooms in summer. The likelihood could be reduced by limited detention times in summer months. **Environmental performance** Hazard identification and risk assessment for the environment found the following: • The preliminary risk assessment identified groundwater, turf or grasses, and specific soil types as potential environmental endpoints for hazards. Other landscaping and screening plants were well established. • Phase 1 of the risk assessment (preliminary screening) identified the hazards sodium, salinity, bicarbonates, nitrogen and phosphorus as moderate to high risks. • Phase 2 (maximal risk assessment) confirmed that the four key hazards (sodium, bicarbonate salinity, phosphorus and nitrogen) required preventive measures to lower the risk to acceptable levels. • Phase 3 (residual risk assessment) identified a range of preventive measures (see Element 3 below) available that should reduce the risks associated with key hazards identified above to acceptable levels. • Advice from an irrigation expert indicated that the treated sewage was suitable for irrigation of trees and shrubs in the park.

Table A1.3 (continued)

Framework element and components	Activity
Element 3: Preventive measures for recycled water management	
Components: *Preventive measures and multiple barriers*	**Human health** Preventive measures to manage risks to human health were as follows: • Lagoon detention time reduced concentrations of pathogens by several logs. Median number of *E. coli* are expected to be maintained at <1000/100 mL. • Golf course storage protected from human and livestock waste. • Backflow prevention and cross-connection control at all irrigation sites. • Pipework (colour coded) and signage. • Education program for golf course employees. • Exposure reduced by: – only allowing irrigation between midnight and 5 am – buffer zones of 30 m between edge of spray irrigated area and nearest private land – outside row of sprinklers 180° inward throwing – no irrigation when windy. **Environmental performance** Preventive measures to manage risks to the environment were as follows: • Nutrient content of recycled water to be considered when determining fertiliser requirements. Greens of fine turf should not be irrigated with recycled water as excessive nutrients would be applied. • Irrigation scheduling devices and controls to monitor and/or control water application rates, soil moisture, and water movement through the soil. Use a leaching fraction to maintain acceptable soil salinity levels.
Critical control points	• Lagoon storage (minimum 60 days) • Night-time irrigation
Element 4: Operational procedures and process control	
Components: *Operational procedures*	• Operational procedures identified and documented for the treatment plant and the irrigation system.
Operational monitoring	**Human health** Monitoring requirements in relation to human health included: • standard wastewater plant requirements, such as soluble biochemical oxygen demand (BOD), etc • flow rates (lagoon detention) — *critical limit set* • on-site auditing of controls (night-time irrigation *critical limit based on approved times*, signage, backflow prevention, etc) • visual inspection of on-site storage for algal growth. **Environmental performance** Monitoring requirements in relation to the environment included: • TDS of irrigation water in storage dam • health of fairway grass • monthly inspections of irrigation system during summer.

Table A1.3 (continued)

Framework element and components	Activity
Corrective action	**Human health** In relation to human health, corrective actions include the following: • noncompliance with critical limits for lagoon detention could result in irrigation being stopped or a requirement for installation of a disinfection system • noncompliance with irrigation times rectified by maintenance and repair of timing mechanisms. **Environmental performance** In relation to the environment, corrective actions include the following: • if TDS increases above 1000 mg/L, causes should be investigated • if inspections reveal faults in irrigation procedures, remedial action is implemented • if inspections identify poor performance or health of plants and grass, causes should be investigated.
Equipment capability and maintenance	• Treatment plant of standard design. Known to be reliable.
Materials and chemicals	• Materials used in liner for golf-course storage, pipework and irrigation system suitable for required functions.
Element 5: Verification of recycled water quality	
Components: *Recycled water quality monitoring (specifically designed for individual systems, taking into account source of water, end uses and receiving environments)*	**Human health** • During first summer irrigation season, monthly sampling for: – *E. coli* (median to be <1000 organisms/100 mL) – BOD (mean of <20 mg/L soluble BOD_5) – suspended solids (mean of <30 mg/L). • In subsequent irrigation seasons, sampling reduced to once every two months. • Samples to be collected from the discharge point of the treatment plant. **Environmental performance** • sodium adsorption rate (SAR), electrical conductivity (EC) (TDS), nitrate and total nitrogen and total phosphorus.
Application and discharge site monitoring	**Environmental performance** In relation to the environment, annual environmental monitoring includes testing of: • soils, such as SAR or exchangeable sodium percentage (ESP), nitrogen, phosphorus, pH and EC • groundwater (eg water levels, conductivity, nutrients) • visual inspection of irrigation area.
Satisfaction of users of recycled water	• Checks with supervisor of golf course.
Short-term evaluation of results	• Results are provided on an annual basis to EPA and HD. Exceedences of criteria are reported immediately.
Corrective action	• Corrective action depends on the exceedence. As a minimum, it involves inspection of plant to confirm normal operation, and additional testing to confirm the exceedence and, if necessary, to investigate the source.
Element 6: Management of incidents and emergencies	
Components: *Communication* *Incident and emergency response protocols*	• Noncompliance with approval conditions to be reported immediately to HD and EPA.

Table A1.3 (continued)

Framework element and components	Activity
Element 7: Operator, contractor and end user awareness and training	
Components: *Operator, contractor and end user awareness and involvement* *Operator, contractor and end user training*	• Operator of treatment plant to be sufficiently skilled to run the plant and investigate any faults. • Operator to be aware of approval conditions and instructed on occupational health and safety requirements. • Irrigation personal are trained in requirements for irrigation with recycled water.
Element 8: Community involvement and awareness	
Components: *Community consultation communication and education*	• Council consulted with users of the golf course and advised local residents of the proposal before proceeding.
Element 9: Validation, research and development	
Components: *Validation of processes* *Design of equipment* *Investigative studies and research monitoring*	• None.
Element 10: Documentation and reporting	
Components: *Management of documentation and records* *Reporting*	• All operating procedures require documentation. All results to be recorded and stored. • Results to be reported on an annual basis to HD and EPA.
Element 11: Evaluation and audit	
Components: *Long-term evaluation of results* *Audit of recycled water quality management*	• Annual report on compliance with approval conditions, including test results, audited by HD and EPA. • Results from environmental performance monitoring assessed for changes over 5-year intervals.
Element 12: Review and continual improvement	
Components: *Review by senior managers*	• Operation of treatment plant and health of irrigated area reviewed by council.

BOD = biochemical oxygen demand; EC = electrical conductivity; EPA = environmental protection agency; ESP = exchangeable sodium percentage; HD = health department; SAR = sodium absorption rate; TDS = total dissolved salts

A1.4 Irrigation of municipal (landscape) areas with water recycled from a small community's sewage treatment plant

A1.4.1 Source and proposed use

In this case study, the source was treated sewage. Recycled water from a small community's sewage treatment plant was used for drip irrigation of trees and shrubs in municipal (landscape) areas of a local park.

A1.4.2 Human health risk assessment

Microbial quality

Microbial hazards for human health include enteric bacteria, viruses and protozoa. The total log reduction required for this scheme is 3.5-log reduction of protozoa, 5-log reduction of viruses, and 4-log reduction of bacteria (see Tables 3.7 and 3.8).

Chemical quality

Exposure of chemicals in recycled water is too low to represent a health risk.

Preventive measures

Limiting use to drip irrigation reduces the potential for public exposure to enteric protozoa, viruses and bacteria by 4 logs (see Table 3.5). A further 1-log reduction of viruses is required. This can be achieved by secondary treatment and disinfection.

Validation

Available data indicate that secondary treatment and disinfection provide the required log reduction.

A1.4.3 Environmental risk assessment

Microbial quality

Microbial quality of the recycled water is not considered an environmental issue given the high levels of treatment required to minimise risks to human health. No preventive measures are required.

Chemical quality

The preliminary risk assessment identified groundwater, landscape and garden plants, and specific soil types as potential environmental endpoints for hazards.

Phase 1 of the risk assessment (preliminary screening) identified the hazards nitrogen and phosphorus as moderate to high risks.

Phase 2 (maximal risk assessment) confirmed that phosphorus and nitrogen required preventive measures to lower the risk to acceptable levels.

Phase 3 (residual risk assessment) identified a range of preventive measures available (see Element 3 below) that should reduce the risks associated with key hazards identified above to acceptable levels (ie ‘low’ in Table 2.7, Chapter 2).

Preventive measures

A range of on-site preventive measures is applied (see Element 3, Table A1.4).

A1.4.5 Risk management plan

Table A1.4 lists the 12 elements of the framework for managing recycled water quality and use, and shows how the scheme meets the various elements.

Table A1.4 Framework elements applied to the use of recycled water for irrigation of municipal (landscape) areas

Framework element and components	Activity
Element 1: Commitment to responsible use and management of recycled water quality	
Components: *Responsible use of recycled water* *Recycled water policy* *Regulatory and formal requirements* *Engaging stakeholders*	• When designing the treatment facility, the community recognised that beneficial reuse was preferable to discharge. • The community sought approval from the regulatory authority and committed to maintaining and operating the scheme according to regulatory requirements.
Element 2: Assessment of the recycled water system	
Components: *Identify intended uses and source of recycled water*	• The use was drip irrigation of the trees and shrubs in a local park, using secondary treated and disinfected sewage.
Recycled water system	• Centralised plant receives septic tank effluent from 50 residences. Provides secondary treatment and disinfection. • The treated sewage is piped to storage and then used for drip irrigation. The storage is covered to prevent algal growth.
Assessment of water quality data	• No data were available, but the plant was expected to produce treated sewage containing a median *Escherichia coli* of fewer than 100 organisms per 100 mL. • Total dissolved salts (TDS) was expected to be <500 mg/L, average total nitrogen about 20 mg/L and average total phosphorus about 4 mg/L.
Hazard identification and risk assessment	**Human health** Hazard identification and risk assessment for human health found that microbial hazards for humans include enteric bacteria, viruses and protozoa. **Environmental performance** Hazard identification and risk assessment for the environment found the following: • The preliminary risk assessment identified groundwater, landscape and garden plants, and specific soil types as potential environmental endpoints for hazards. • Phase 1of the risk assessment (preliminary screening) identified the hazards nitrogen and phosphorus, as moderate to high risks. • Phase 2 of the risk assessment (maximal risk assessment) confirmed that phosphorus and nitrogen required a preventive measure to lower the risk to acceptable levels. • Phase 3 of the risk assessment (residual risk assessment) identified a range of preventive measures (see Element 3 below) available that should reduce the risks associated with key hazards identified above to acceptable levels (ie ‘low’ in Table 2.7, Chapter 2). • Advice from an irrigation expert indicated that the treated sewage was suitable for irrigation of trees and shrubs in the park.

Table A1.4 (continued)

Framework element and components	Activity
Element 3: Preventive measures for recycled water management	
Components: *Preventive measures and multiple barriers*	**Human health** Preventive measures to manage risks to human health include: • secondary treatment and disinfection, providing 1-log reduction of protozoa and viruses • use of drip irrigation, providing 4-log reduction in enteric protozoa, viruses and bacteria • pipework (purple) and signage at site of use indicating that recycled water is being used. **Environmental performance** Preventive measures to manage risks to the environment include: • storage covered to prevent algal growth • fertiliser application reduced to account for nutrients in water.
Critical control points	• Drip irrigation • Disinfection
Element 4: Operational procedures and process control	
Components: *Operational procedures*	In relation to human health, operational procedures were identified and documented for the treatment plant and the irrigation system.
Operational monitoring	**Human health** Monitoring requirements in relation to human health included: • inspection of drip irrigation system when in use • weekly checks of chlorine residual (critical limit of 0.5 mg/L total chlorine) • standard wastewater plant requirements (BOD_5 <20 mg/L, suspended solids <30 mg/L). **Environmental performance** Monitoring requirements in relation to the environment included visual inspection of health of plants.
Operational corrective action	• Noncompliance with chlorine residual requires rectification. • If biochemical oxygen demand (BOD) exceeds 20 mg/L or suspended solids exceed 30 mg/L, the performance of the plant is to be investigated and problems rectified. • Irrigation system to be stopped until detected faults repaired.
Equipment capability and maintenance	• Treatment plant and disinfection system of standard design; known to be reliable.
Element 5: Verification of recycled water quality	
Components: *Recycled water quality monitoring (specifically designed for individual systems, taking into account source of water, end uses and receiving environments)*	**Human health** • Quarterly testing for *E. coli*. **Environmental performance** • Nitrate and total nitrogen, total phosphorus.
Application and discharge site monitoring	**Environmental performance** In relation to the environment, annual monitoring for: • soil (sodium adsorption ratio [SAR], nitrogen, phosphorus, pH, conductivity) • groundwater (eg water levels, electrical conductivity, nitrogen, nitrate, phosphorus).
Short-term evaluation of results	• Results are provided on an annual basis to regulator.
Corrective action	• Inspection of plant to confirm normal operation and if necessary additional testing to investigate the cause leading to remediation.

Table A1.4 (continued)

Framework element and components	Activity
Element 6: Management of incidents and emergencies	
Components: *Communication* *Incident and emergency response protocols*	• Noncompliance with approval conditions to be reported immediately to the health department (HD) and environmental protection agency (EPA).
Element 7: Operator, contractor and end user awareness and training	
Components: *Operator, contractor and end user awareness and involvement* *Operator, contractor and end user training*	• Operator of treatment plant to be sufficiently skilled to run the plant and investigate any faults. • Operator to be aware of approval conditions and instructed on occupational health and safety requirements. • Irrigation personnel are trained in requirements for irrigation with recycled water.
Element 8: Community involvement and awareness	
Components: *Consultation with users of recycled water and the community* *Communication and education*	• Community made a collective decision to install the irrigation system.
Element 9: Validation, research and development	
Components: *Validation of processes* *Design of equipment*	• None.
Element 10: Documentation and reporting	
Components: *Management of documentation and records* *Reporting*	• Design of plant and irrigation system documented. • Operating procedures documented. • All results to be recorded and stored. • Results to be reported on an annual basis to the regulatory authority.
Element 11: Evaluation and audit	
Components: *Long-term evaluation of results* *Audit of recycled water quality management*	• Annual report on compliance with approval conditions, including test results audited by HD and EPA. • Results from environmental performance monitoring assessed for changes over 5-year intervals.
Element 12: Review and continual improvement	
Components: *Review by senior managers*	• Operation of treatment plant and health of irrigated area reviewed by council.

BOD = biochemical oxygen demand; EPA = environmental protection agency; HD = health department; SAR = sodium absorption rate; TDS = total dissolved salts

A1.5 Use of greywater for toilet flushing and outdoor use

A1.5.1 Source and proposed use

In this study, the source was treated greywater (laundry, bathroom, showers and handbasins) from 100 units in an apartment complex. The greywater is used for toilet flushing, drip irrigation of garden beds, and subsurface irrigation of grassed areas.

A1.5.2 Human health risk assessment

Microbial quality

Microbial hazards for human health include enteric bacteria, viruses and protozoa. The total log reduction required for this scheme was determined using the approach described in Section 3.7.2 and results from six months of greywater *Escherichia coli* monitoring at the development. The calculated targets were a 2-log reduction of protozoa, a 3.5-log reduction of viruses, and a 3-log reduction of bacteria.

Chemical quality

Exposure of chemicals in recycled water was too low to represent a health risk.

Preventive measures

Preventative measures included microfiltration, ultraviolet (UV) and chlorine disinfection. On-site control measures were also applied (see Element 3, Table A1.5).

Validation

The membranes provided a 3-log reduction of bacteriophage and *E. coli*. This was discounted to 2 log for viruses, protozoa and bacteria, because membrane integrity monitoring (turbidity and particle counting) has limited sensitivity. A minimum UV dose of 25 mJ/cm^2 was applied. Based on published data, this provided a 1.5-log reduction of *Cryptosporidium* (USEPA 2003). Chlorine disinfection was expected to produce free chlorine residuals; however, the occasional presence of ammonia could result in production of chloramines, which are weaker disinfectants but persist for longer periods. A 2-log reduction of viruses was determined based on published data for free chlorine and chloramines (USEPA 1999). The combined impact of UV disinfection and chlorination would provide greater than a 4-log reduction of enteric bacteria.

In total, the treatment processes provide a minimum 3.5-log reduction of protozoa, 4-log reduction of viruses and 6-log reduction of viruses, which exceeded the calculated targets.

A1.5.3 Environmental risk assessment

Microbial quality

Microbial quality of the recycled water is not considered an environmental issue given the high levels of treatment required to minimise risks to human health. No preventive measures are required.

Chemical quality

The preliminary risk assessment identified groundwater, landscape and garden plants, and specific soil types as potential environmental endpoints for hazards.

Phase 1 of the risk assessment (preliminary screening) used conservative literature values for greywater, and identified the hazards boron, cadmium, hydraulic load, nitrogen and phosphorus, salinity and sodium as moderate to high risks.

Phase 2 (maximal risk assessment) confirmed that all hazards identified in Phase 1 required preventive measures to lower the associated risks to acceptable levels.

Phase 3 (residual risk assessment) identified that, due to the relatively high quality of the treated greywater, minimal preventive measures (see Element 3 below) were needed to provide appropriate management of the environmental risks (ie ‘low’ in Table 2.7, Chapter 2).

Preventive measures

Preventative measures included education programs for residents, and promoted use of environmental friendly detergents in chemicals in the bathroom and laundry.

A range of on-site preventive measures was applied (see Element 3, Table A1.5).

A1.4.4 Risk management plan

Table A1.5 lists the 12 elements of the framework for managing recycled water quality and use, and shows how the scheme meets the various elements.

Table A1.5 Framework elements applied to use of greywater in an apartment complex for toilet flushing and subsurface irrigation

Framework element	Activity
Element 1: Commitment to responsible use and management of recycled water quality	
Components: *Responsible use of recycled water* *Recycled water policy* *Regulatory and formal requirements* *Engaging stakeholders*	• The body corporate managing the greywater scheme engaged the water authority to operate and maintain the treatment process and provide support. The water authority has hazard analysis critical control point (HACCP) accreditation for related activities and environmental management systems. The greywater facility was part of a range of features to improve sustainability within a new development. There was a commitment to ensure correct design, installation and management. • Approval was sought from the the state department responsible for human health (eg Health Department — HD) and the state department responsible for the environment (eg Environmental Protection Authority — EPA). • The existence of greywater recycling was a feature of advertising and promotion of the development. All new residents were provided with an education kit. Plumbers were also provided with information.
Element 2: Assessment of the recycled water system	
Components: *Identify intended uses and source of recycled water*	• Uses include toilet flushing, drip irrigation of trees and shrubs and subsurface irrigation of lawns.
Recycled water system	• Central plant receives greywater from 100 apartments. Water is subject to treatment through a membrane bioreactor, ultraviolet (UV) disinfection and chlorination. • The treated greywater is piped to an underground storage and distributed for use.
Assessment of water quality data	• Raw greywater quality was characterised through direct testing of *Escherichia coli*, nutrients and other chemicals before design and commissioning of the scheme.
Hazard identification and risk assessment	**Human health** Hazard identification and risk assessment for human health found that microbial hazards for humans include enteric bacteria, viruses and protozoa. **Environmental performance** Hazard identification and risk assessment for the environment found the following: • The preliminary risk assessment identified groundwater, landscape and garden plants, and specific soil types as potential environmental endpoints for hazards. • Phase 1 of the risk assessment (preliminary screening) used conservative literature values for greywater and identified the hazards boron, cadmium, hydraulic load, nitrogen and phosphorus, salinity and sodium, as moderate to high risks. • Phase 2 (maximal risk assessment) confirmed that all hazards identified in Phase 1 required preventive measures to lower the associated risks to acceptable levels (ie ‘low’ in Table 2.7, Chapter 2). • Phase 3 (residual risk assessment) identified that due to the relatively high quality of the treated greywater, minimal preventive measures (Element 3, below) were needed to provide appropriate management of the environmental risks.

Table A1.5 (continued)

Framework element	Activity
Element 3: Preventive measures for recycled water management	
Components: *Preventive measures and multiple barriers*	**Human health** Preventive measures to manage risks to human health include: • membrane filtration, UV disinfection and chlorine disinfection • pipework (purple and/or with text) and signage at site of use indicating that recycled water is being used • educational material to residents about avoidance of inappropriate disposal of household wastes • signage at site to alert plumbers to recycled water system and coordination of plumbers through body corporate • backflow prevention and cross-connection control • drinking water system maintained at higher pressure than recycled water supply. **Environmental performance** Preventive measures to manage risks to the environment include: • education program for residents promoting use of environmental friendly detergents in the bathroom and avoidance of disposal of household and garden chemicals • a list of detergents considered appropriate for use in the apartment building made available to all residents and updated annually • no planting of salt-sensitive plants • fertiliser application reduced to take into account nutrients in water.
Critical control points	Critical control points were identified as: • membrane filtration • UV disinfection • chlorination.
Element 4: Operational procedures and process control	
Components: *Operational procedures*	• Operational procedures were identified for all processes and activities associated with the system, including operation of treatment processes and auditing procedures for cross-connections • Documented procedures must be available to operations personnel and for inspection at any time.
Operational monitoring	Monitoring requirements include: • turbidity of filtered water (continuous) — *critical limits set* • UV lamp, power and lamp failure (continuous) — *critical limits set* • chlorination (continuous) — *critical limit set* • raw greywater monitoring for *E. coli* to assess control of disposal be residents • on-site auditing of controls (signage, backflow prevention, etc). • on-site auditing and inspection of irrigation system (weekly when in use).

Table A1.5 (continued)

<table>
<tr><th>Framework element</th><th>Activity</th></tr>
<tr><td>Corrective action</td><td>Corrective actions include the following:
• noncompliance with critical limits results in supply being stopped and replaced by mains water flow to the irrigation system; that is, flow is stopped if
– turbidity limits of 0.2 nephelometric turbidity units (NTU) average exceeded for >60 minutes or 0.5 NTU maximum exceeded
– UV light fails for >30 minutes
– free chlorine residual is interrupted for >30 minutes
• if cross-connections detected, flow to property stopped until repairs completed
• if raw greywater E. coli numbers increase over 10^5/100 mL on a consistent basis, education program to be reviewed and source investigated.</td></tr>
<tr><td>Equipment capability and maintenance</td><td>• Treatment plant and disinfection systems of standard and reliable design. Maintained by contractor associated with supplier.</td></tr>
<tr><td colspan="2">Element 5: Verification of recycled water quality</td></tr>
<tr><td>Components:
Recycled water quality monitoring (specifically designed for individual systems, taking into account source of water, end uses and receiving environments)</td><td>Human health
In relation to human health, monitoring includes:
• monitoring of
– E. coli (weekly)
– bacteriophage in membrane permeate (monthly)
– chlorine residual in distribution system
• in-system monitoring for aesthetic parameters — colour and turbidity
• householder satisfaction, monitored by the operator; complaints are investigated particularly when clusters of complaints are received.
Environmental performance
Parameters monitored in relation to the enviroment include nitrogen, phosphorus, cadmium and boron.</td></tr>
<tr><td>Application and discharge site monitoring</td><td>Environmental performance
In relation to the environment, monitoring includes:
• annual monitoring for boron, cadmium, nitrate, total nitrogen, total phosphorus, salinity (measured as electrical conductivity) and SAR (or exchangeable sodium percentage) in soil
• visual assessment of irrigation area to assess waterlogging.</td></tr>
<tr><td>Short-term evaluation of results</td><td>• Results are provided on an annual basis to regulator.</td></tr>
<tr><td>Corrective responses</td><td>• Corrective action depends on the exceedence. As a minimum, it involves investigation of plant performance records to confirm normal operation, and additional testing to confirm the exceedence and identify the source.
• If target criteria for environmental parameters are exceeded, preventive measures need to be reassessed and corrective action taken to ensure environmental performance is improved.</td></tr>
<tr><td colspan="2">Element 6: Management of incidents and emergencies</td></tr>
<tr><td>Components:
Communication
Incident and emergency response protocols</td><td>• Noncompliance with approval conditions to be reported immediately to regulator.</td></tr>
</table>

Table A1.5 (continued)

Framework element	Activity
Element 7: Operator, contractor and end user awareness and training	
Components: *Operator, contractor and end user awareness and involvement* *Operator, contractor and end user training*	• Operator of treatment plant to be sufficiently skilled to run the plant and investigate any faults. • Operator to be aware of approval conditions and instructed on occupational health and safety requirements. • Grounds keeper responsible for garden maintenance is trained in the use of recycled water and preventive measures required.
Element 8: Community involvement and awareness	
Components: *Community consultation, communication and education*	• The existence of greywater recycling was a feature of advertising and promotion of the development. All new residents were provided with an education kit.
Element 9: Validation, research and development	
Components: *Validation of processes* *Design of equipment*	• Ongoing investigations into greywater quality and treatment plant performance to refine assessments. This may enable less conservative critical control points to be adopted or treatment requirements reduced. • Studies are being undertaken into resident satisfaction.
Element 10: Documentation and reporting	
Components: *Management of documentation and records* *Reporting*	• Design of treatment plant and irrigation system documented. • Operating procedures documented. • All results to be recorded and stored. • Results to be reported on an annual basis to the regulatory authority
Element 11: Evaluation and audit	
Components: *Long-term evaluation of results* *Audit of recycled water quality management*	• Annual report on compliance with approval conditions, including test results audited by regulator. • Independent audit of compliance by a third party commissioned following the first year.
Element 12: Review and continual improvement	
Components: *Review by senior managers*	• Performance of treatment plant, customer complaints/satisfaction and condition of irrigated areas reviewed by operator.

HD = health department; EPA = environmental protection agency; HACCP = hazard analysis critical control point; NTU = nephelometric turbidity unit; SAR = sodium absorption rate; UV = ultraviolet

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Appendix 2 Calculation of microbial health-based performance targets

In a risk-based approach to managing recycled water, it is necessary to define a tolerable level of risk and set health-based targets. The targets provide the practical basis for achieving compliance with the defined tolerable level of risk. Calculation of the targets incorporates the elements of risk characterisation.

This appendix:

- provides an overview of risk characterisation (Section A2.1)
- considers the relative benefits and drawbacks of deterministic and scholastic analyses (Section A2.2)
- explains how to calculate microbial health-based targets (Section A2.3)
- provides a rapid approach for determining performance targets for treated sewage (Section A2.4).

A2.1 Risk characterisation

The standard approach to characterising risk is to determine its magnitude by integrating information from hazard identification, dose response and exposure assessment. A range of published studies employ such risk characterisations, using hazard concentrations in recycled water produced by existing facilities (ie after consideration of preventive measures) and estimates of exposure associated with specified uses of the recycled water (Rose and Gerba 1991, Asano et al 1992, Rose et al 1996, Crabtree et al 1997, Shuval et al 1997, FDEP 1998, Jolis et al 1999, Medema et al 2003). These characterisations identify risks of infection or illness associated with specific hazardous microorganisms. The calculated risks can then be compared with a tolerable level of risk, such as less than 1 infection $\times 10^{-4}$ per year (ie less than one infection per 10 000 people per year) (see Macler and Regli 1993), as cited by the United States Environmental Protection Agency (USEPA).

In these guidelines, the tolerable level of risk is defined as $<10^{-6}$ disability adjusted life years (DALYs) per person per year. Compared with the USEPA approach, this method requires the input of information on infection–illness ratios and on the impact or burden of illness.

Table A2.1 provides an example risk characterisation including these modifications. This example deals with the irrigation of lettuce by sewage subjected to secondary treatment, coagulation, filtration and disinfection. The formulae used in the calculations shown in Table A2.1 are given in Box A2.1, below.

Table A2.1 Potential risks from irrigation of lettuce using treated sewage

Sewage	*Cryptosporidium*	Rotavirus	*Campylobacter*
Organisms per litre in source water (N) (95^{th} percentile)[a]	2000	8000	7000
Log reduction provided by treatment[b]	5 log	6 log	6 log
Exposure per event (litres)	0.005	0.005	0.005
Dose per event (organisms)	1×10^{-4}	4×10^{-5}	3.5×10^{-5}
Number of events per year	70	70	70
Dose–response constants[c]	$r = 5.9 \times 10^{-2}$	$\alpha = 0.253$ $\beta = 0.426$	$\alpha = 0.145$ $\beta = 7.58$
Risk of infection (P_{infs}) (probability of infection per event)	5.9×10^{-6}	2.4×10^{-5}	6.7×10^{-7}
Ratio of illness/infection[d]	0.70	0.88	0.30
Risk of illness (P_{ills}) (per event)	4.1×10^{-6}	2.1×10^{-5}	2.0×10^{-7}
Risk of illness ($P_{ill\ year}$) (per year, ie 70 events)	2.9×10^{-4}	1.5×10^{-3}	1.4×10^{-5}
Disease burden (db) (DALY per case)[e]	1.5×10^{-3}	1.3×10^{-2}	4.6×10^{-3}
Susceptibility fraction (sfr)[f]	100%	6%	100%
DALY/year	0.4×10^{-6}	1.1×10^{-6}	0.6×10^{-7}

a Hazard concentrations in raw sewage (95^{th} percentile from Australian and international data). Numbers of adenoviruses have been used as an indication of numbers of rotaviruses, because of the lack of enumeration methods for rotaviruses. Adenoviruses were used because these were the most numerous of the viruses detected in Australian monitoring of sewage (data from Virginia Pipeline Scheme in South Australia).
b Hazard concentrations reduced by secondary treatment, coagulation, filtration and disinfection
c Constants and models used to calculate risk of infection are shown in Table 3.2. For low doses, the abbreviated formulae for P_{inf} can be used, as shown in Box A2.1.
d Havelaar and Melse (2003)
e DALYs per case based on Havelaar and Melse (2003) with a modification for rotavirus as described in WSAA (2004).
f Susceptibility fraction is the proportion of the population susceptible to developing disease following infection. A susceptibility fraction of 100% for *Cryptosporidium* and *Campylobacter* is based on the conservative assumption that everyone is susceptible to illness. The figure of 6% for rotavirus is based on that fact that infection is common in very young children; causing illness and also provides subsequent immunity. The 6% equates to the percentage of the population aged less than five years (Havelaar and Melse 2003).

Box A2.1 Formulae used in calculations

1. Dose per event = source water concentration × log reduction × exposure

2. P_{infs} =
   - $1 - \exp^{(-rd)}$ abbreviated for low doses to r.d (=0.059d)[a] — for *Cryptosporidium*
   - $1-(1+d/ß)^{-\alpha}$ abbreviated for low doses to α/ß.D (=0.59d)[a] — for rotavirus
   - $1-(1+d/ß)^{-\alpha}$ abbreviated for low doses to α/ß.D[a] (=0.19d) — for *Campylobacter*

3. $P_{infyear} = 1-(1-P_{infs})^N$

   where N = number of exposures/year.

Box A2.1	(continued)		
	For lower levels of risk, this can be approximated to:		
	$P_{infyear}$	=	$P_{infs} \times N$
4.	$P_{illnessyear}$	=	$P_{infyear} \times$ ratio of illness to infection
5.	DALY/year	=	$P_{illnessyear} \times$ DALY per case × susceptibility fraction

a FAO/WHO (2003). Low doses for *Cryptosporidium* and *Campylobacter* are less than 0.1 organisms; a low dose for rotavirus is less than 0.01 organisms.

A2.2 Deterministic versus stochastic analyses

In this context, a deterministic analysis is one that does not involve the use of estimated or random values, whereas a stochastic analysis does involve some use of such values.

The example shown in Table A2.1 applies a deterministic approach, using single-point estimates for exposure volume, numbers of exposure events and treatment effectiveness. The advantage of this approach is that it is relatively simple and can be done using desktop calculators. However, the use of single-point estimates does not address variability and uncertainty; also, the estimates are often based on conservative or even worst-case values.

The alternative is to use a stochastic approach to address the disadvantage of single point estimates by using ranges of values (Thompson et al 1992, Frey and Patil 2002). However, more information and assumptions are required, and stochastic analyses are more difficult to perform.

Due to data limitations, a deterministic approach currently provides a simpler and arguably more informative analysis. Stochastic analyses may provide a better understanding of uncertainty and variability, but research to produce better supporting information is needed before such analyses can be used routinely.

A2.3 Calculation of microbial health-based targets

Health-based performance targets are the reductions in concentrations of reference pathogens from untreated source water required to achieve compliance with the upper limit of 10^{-6} DALYs per person per day. The example in Table A2.1 showed that 5-log reductions of *Cryptosporidium* and 6-log reductions of rotaviruses and *Campylobacter* achieved a risk of 0.6×10^{-7} to 1.1×10^{-6} DALY per person per year.

The approach shown in Table A2.1 can be modified to calculate the log reductions that are required to achieve 10^{-6} DALYs per person per day for any combination of source water and end use, using the formulae shown in Box A2.2. The required inputs to the calculation are concentrations of the reference pathogens in source water and exposures associated with the end use.

Box A2.2 Calculation of log reductions required to achieve target of 10^{-6} DALYs per year in treated water

DALY per year = P_{infs} × ratio of illness to infection × DALY per case × susceptibility fraction[a]

Using this formula and those for P_{infs} shown in Box A2.1, the doses equivalent to 10^{-6} DALY can be determined

Doses equivalent to 10^{-6} DALY (dalyd) are:

Cryptosporidium:	10^{-6} ÷ r ÷ 0.7 ÷0015 ÷ 1	= 1.6×10^{-2}
Rotavirus:	10^{-6} x ß/α ÷ 0.88 ÷0.013 ÷ 0.06	= 2.5×10^{-3}
Campylobacter:	10^{-6} x ß/α ÷ 0.3 ÷0.0046 ÷ 1	= 3.8×10^{-2}

Where concentrations of organisms in source water are known, required log reductions can be determined using the formula:

Log reduction = log (concentration in source water × exposure (L) × N ÷ DALYd)

a At low doses, the abbreviated formulae for calculating P_{infs} can be used, as shown in Box A2.1

If required, maximum concentrations of organisms in recycled water can also be calculated, as shown in Box A2.3.

Box A2.3 Calculation of concentrations of organisms in recycled water

Final concentration = DALYd ÷ (exposure (L) × N)

Hence, for the example shown in Table A2.1, the maximum (95th percentile) concentrations of organisms in water used to irrigate salad vegetables are:

Cryptosporidium:	4.6×10^{-2}
Rotavirus:	7.1×10^{-3}
Campylobacter:	1.1×10^{-1}

Note: The maximum allowable concentrations in recycled water could be increased if on-site controls were used to reduce exposure.

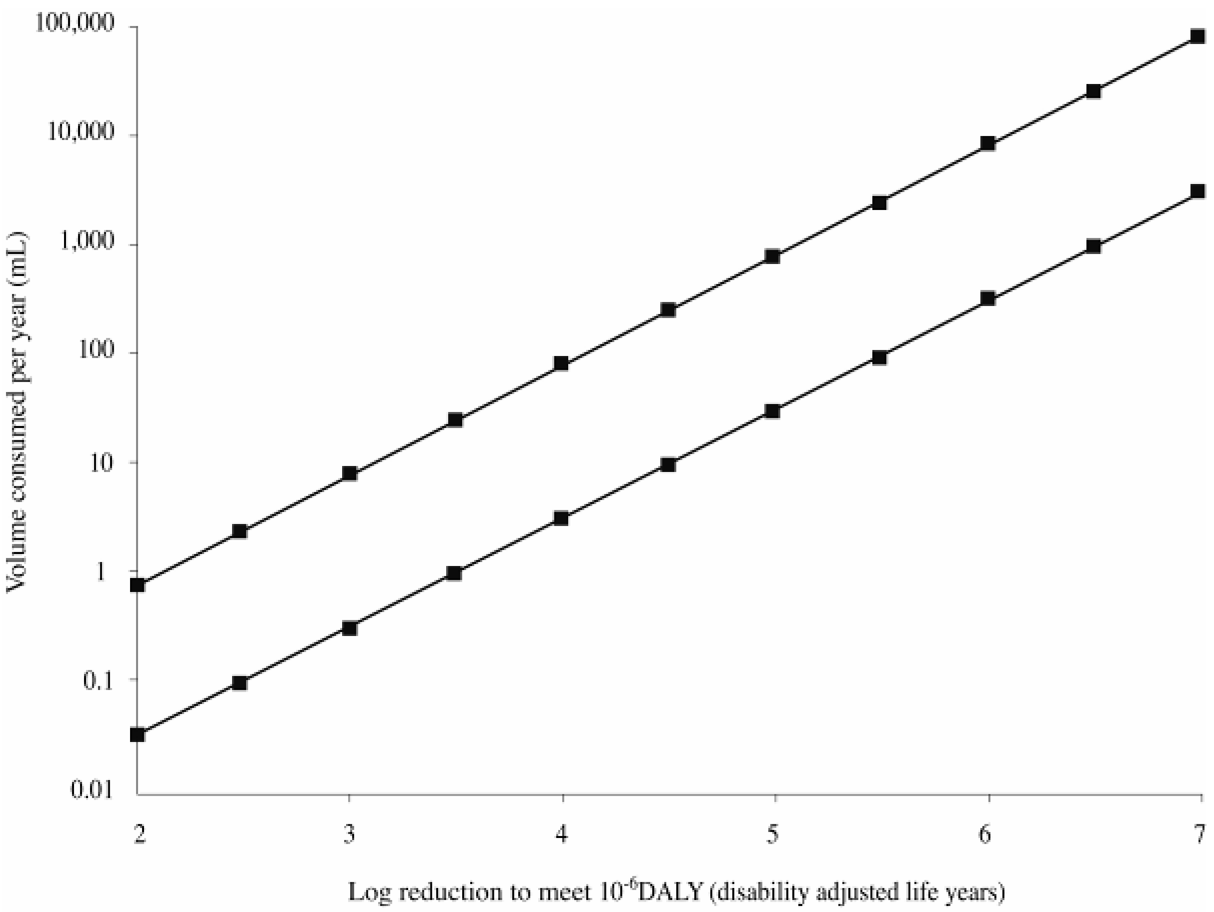
These pathogen concentrations can be used in selection of preventive measures. They can also be used in some validation monitoring; however, method sensitivities and volume restrictions generally limit suitability for this purpose. An alternative approach (discussed in Chapter 5) is to use surrogates, such as coliphage numbers.

Direct testing for pathogens is unsuitable for operational monitoring and of very limited use in verification monitoring because of the complexity and cost of tests, and the time required to complete them.

A2.4 Short-cut approach for determining performance targets for treated sewage

As an alternative to using the formulae shown in Box 3.2, health-based performance targets for recycling treated sewage can be determined from volumes of recycled water potentially consumed, using Figure A2.1. The figure was derived using the approach described above and default values of 2000 *Cryptosporidium*, 8000 rotavirus and 7000 *Campylobacter* per litre (see Section 3.5.2).

Figure A2.1 Log reductions required as a function of volumes exposed



Performance targets can be determined using the following process:

- Step 1 — List the intended uses, and anticipated inadvertent uses, of the recycled water, together with the volume of water likely to be consumed per year and the proportion of the population that could be exposed.
- Step 2 — Calculate a 'weighted total' exposure for each use (ingestion volume × frequency × proportion of population affected).
- Step 3 — Sum the weighted total for the different uses.
- Step 4 — Using Figure A2.1, determine the log reductions in microbial levels required to meet the minimum tolerable health risk (10^{-6} DALY).

Table A2.2 provides examples from applying this approach.

Table A2.2 Determining health-based targets from volumes of water consumed

Use	Ingestion volume	Frequency/ year	Proportion of population affected (%)	Weighted total	Log reduction[a]	
					Protozoa[b]	Viruses
Example 1						
Municipal, urban irrigation	0.1 mL	104	1	0.104 mL		
Residential ornamental garden watering	1 mL	26	20	5.2 mL		
Toilet flushing	0.001 mL	1825	100	1.83 mL		
Total				**7.13 mL**	**2.9**	**4.4**
Example 2						
Drinking water cross-connection	1000 mL	14	0.1	14 mL		
Residential ornamental and salad crop garden watering	10 mL	26	25	65 mL		
Toilet flushing	0.001 mL	1825	100	1.83 mL		
Total				**80.83 mL**	**4**	**5.4**

a Derived from Figure A2.1
b The bacterial log reduction is about the same as that for protozoa

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Appendix 3 Preventive measures

This appendix introduces water source protection, gives an overview of water treatments for a variety of recycled water schemes, and explains specific treatment processes. It also discusses end-use and on-site restrictions.

A3.1 Water source protection

Water source protection provides the first barrier against contamination by potential hazards. The type of water source will determine the preventive measures implemented. Examples include:

- using trade-waste programs to minimise chemical contamination of municipal sewage, and regulating industrial discharges to protect stormwater quality
- protecting against human and livestock waste, to limit the presence of human enteric pathogens in stormwater
- setting limits on the types of water used in greywater recycling (eg discarding kitchen waste or nappy-wash water), and controlling the types of detergents and other household chemicals used in water collected by greywater systems.

A3.2 Overview of treatment

There is an ever-increasing range of treatment options, examples of which are discussed below. Where alternative systems or new technologies are used, the end results and the reliability of performance should be at least equal to that achieved by conventional processes.

A3.2.1 Municipal sewage treatment plants

Municipal sewage is usually treated by combinations of primary, secondary or tertiary treatment and disinfection processes (discussed below in Section A3.3 — ‘Specific treatment processes’).

A3.2.2 On-site wastewater treatment systems

On-site treatment systems are used predominantly in non-sewered areas and are primarily designed to collect, treat and discharge effluent within the property boundaries of the premises producing the wastewater. On-site systems can be used to treat all sewage, blackwater only, or greywater only.

Traditional systems include a septic tank and a soil-adsorption field. The tank provides primary treatment, removes most settleable and floatable material, and provides partial digestion of organic material. Effluent produced by these systems is generally not recycled without further treatment, which may include collecting effluent through a linked reticulation system, and providing lagoon detention and possibly disinfection.

More advanced on-site systems produce a secondary treated and disinfected effluent, which is suitable for above-ground reuse to irrigate gardens (excluding food crops) and landscaped areas. Based on Australian and New Zealand Standards 1546 and 1547, these advanced systems should generally produce effluent with a biochemical oxygen demand (BOD) of <20 mg/L, and suspended solids (SS) <30 mg/L. The effluent should contain ≤10 *Escherichia coli* (or thermotolerant coliforms) per litre as a median. Where chlorination is used in the disinfection process, the total chlorine residual should generally be ≥0.5 mg/L. However, the quality of effluent produced by on-site systems can be variable; it depends on the level and quality of maintenance, and these systems are often poorly maintained.

The range of on-site treatment systems for sewage and greywater continues to expand. Such systems should provide effluent that is of comparable or better quality than conventional systems, and is commensurate with the end use. Manufacturers need to provide evidence of suitable performance. These systems should also address aesthetic quality, because stored greywater with minimal treatment can develop strong odours.

A3.3 Specific treatment processes

A3.3.1 Primary treatment

Primary treatment is essentially a physical treatment process, with or without chemical assistance, which removes suspended solids by settling. Primary treatment removes some organic nitrogen, phosphorus and heavy metals, but has little impact on colloidal or dissolved constituents. It has limited impact on microbial pathogens, but can provide some removal of parasites and particulate-associated microorganisms.

Primary sedimentation tanks should remove 50–70% of the suspended solids, and 25–40% of the BOD.

A3.3.2 Secondary treatment

Secondary treatment is typically a process that removes dissolved and suspended organic material by biological treatment and sedimentation. The action of biological treatment is to remove organic material by digestion. Approximately 85% of BOD and influent suspended solids are removed. Some secondary treatment designs incorporate biological nutrient reduction (BNR, see below) and aerobic and anaerobic digestion. Processes include activated sludge, trickling filters and oxidation ditches, all with secondary sedimentation, and lagoons or oxidation ponds.

The extent of the reduction of pathogen numbers depends on the nature of the secondary treatment process. Lagoon detention can be effective in removing larger organisms, such as protozoa and helminths, as well as providing several log removals of enteric bacteria. Secondary treatment is less effective in removing viruses.

Secondary effluent generally has a BOD of <20 mg/L, and SS of <30 mg/L, which may rise to >100 mg/L due to algal solids in lagoon or pond systems.

Biological nutrient reduction

BNR is used to reduce phosphorus and nitrogen concentrations present in wastewater streams. The primary aim is to reduce the environmental impact of treated wastewater. BNR is typically achieved using purpose-designed activated-sludge processes in secondary treatment. The processes involve the use of anaerobic, anoxic and aerobic zones. Typical effluents from BNR plants contain ≤10 mg/L nitrate nitrogen and 0.1–0.5 mg/L phosphorus.

Figure A3.1 shows BOD and suspended solids concentrations, and Table A3.1 shows nitrogen and phosphorus concentrations following primary and secondary treatment.

Figure A3.1 Typical biochemical oxygen demand (BOD) and suspended solid concentrations in sewage effluents

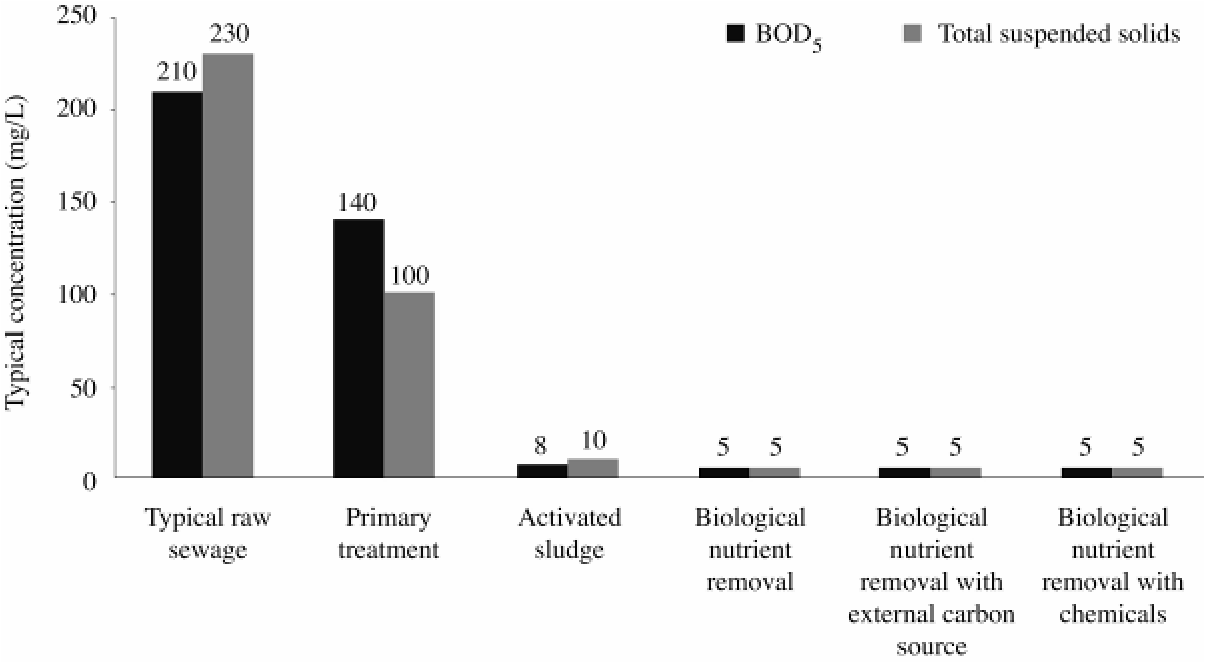

Table A3.1 Typical nitrogen and phosphorus concentrations in sewage effluents

	Typical average concentration (mg/L)				
Parameters	**Raw sewage**	**Primary treatment**	**Activated sludge**	**Biological nutrient removal**	**BNR with chemical addition**
Total phosphorus	6	5	5	1	0.1–0.5[a]
Total nitrogen	40	34	25–30	10	≤10

a Depending on chemical dose added

Chemical treatment processes

Chemical treatment is generally used in conjunction with separation or biological unit processes. The processes described below are for removing suspended solids and phosphorus.

Inorganic salts (ferric chloride, pickle liquor or alum) added to the incoming wastewater or to the effluents from solids-removal processes also precipitate. As a result, residual concentrations of these chemicals would be low in treated sewage.

Coagulation and flocculation of solids

Coagulation and flocculation is frequently used to maximise the removal of suspended solids at various stages of wastewater treatment. The performance of the sedimentation stage in primary treatment is improved by chemically assisted sedimentation, in which coagulants (eg $FeCl_3$) and polymeric flocculants are added upstream of the primary sedimentation tanks. Typically, chemically assisted sedimentation increases the removal of suspended solids to about 75%, and the removal of oil and grease to about 70%. Coagulants can also be used to remove suspended solids in secondary treated effluents, before tertiary treatment by filtration.

Typical removal from wastewater by sedimentation is 50–70% for suspended solids and 30–40% for BOD_5; coagulation and flocculation can increase these removals to 80–90% and 40–70% respectively.

Coagulation and flocculation are often followed by sedimentation or dissolved air flotation. The latter is particularly suited to treating lagoon effluent, which can contain algae. Due to the relatively high organic content and low physical quality of most sources of recycled water, higher doses of chemicals are used in wastewater treatment plants than in drinking water plants. This produces larger quantities of waste sludge.

The quality and doses of treatment chemicals must be carefully controlled to prevent unintended contamination of product water. In particular, some flocculants can be extremely toxic to aquatic life.

Chemical phosphorus removal

Phosphorus (as phosphate, PO_4^{-3}) can be removed before, during or after the biological treatment process. Common inorganic chemicals used are ferric chloride or aluminium sulphate. Addition of chemicals can reduce the phosphorus concentration in the effluent to concentrations as low as 0.1 mg/L. However, to reach such low phosphorus concentrations, relatively high chemical concentrations are needed.

In a process referred to as ‘simultaneous precipitation’, chemical phosphate precipitants are usually added to, or just before, the aeration tank. The resulting precipitate is removed with the waste-activated sludge in the final sedimentation tank.

Chemicals can also be added before primary treatment or after secondary treatment, with the resulting chemical sludges being removed either with the primary sludge or during the tertiary filtration, respectively.

A3.3.3 Tertiary treatment

Tertiary treatment refers to processes that remove suspended solids, BOD and pathogenic organisms. Processes include conventional filtration, membrane filtration and detention in polishing lagoons or wetlands. Conventional treatment is usually combined with coagulation, often in conjunction with sedimentation or flotation. These treatment processes are discussed below.

Tertiary treatment in conjunction with disinfection can provide several log removals of enteric bacteria, viruses, protozoa and helminths. Specific tertiary treatments may also be used to remove other contaminants of concern, such as toxicants and salt.

Filtration

Filtration can include processes such as dual- or single-media filtration or membrane filtration. Filtration can be preceded by coagulation, flocculation and sedimentation (or flotation) to enhance performance (see below). It is important to optimise and control operations to achieve consistent and reliable performance. The effectiveness of filtration in removing pathogenic microorganisms can be influenced by factors such as filter-media depth and hydraulic loading.

It is important to optimise and control operations to achieve consistent and reliable performance. The effectiveness of filtration in removing pathogenic microorganisms can be influenced by factors such as filter-media depth and hydraulic loading. In addition, the quality and doses of treatment chemicals must be carefully controlled to prevent unintended contamination of product water. In particular, some flocculants can be extremely toxic to aquatic life.

Membrane filtration

Membrane filtration may be used as an alternative to conventional media-based processes, because it provides a direct physical barrier and can remove more microorganisms. The use of membrane filtration is increasing, particularly in small systems and in situations where high-quality recycled water is required. Membrane technology can be used as part of an overall treatment process (eg membrane bioreactors) or as a tertiary treatment step.

Reverse osmosis

Reverse osmosis (RO) is a physical process that can be used to remove trace organics as well as inorganic chemicals, in situations where very high-quality water is required.

Saline water intrusion into sewage systems can lead to elevated concentrations of total dissolved salt (TDS), restricting the use of recycled water, and increased use of recycled water may also lead to increased TDS concentrations in collected wastewaters. RO can remove >99.5% of dissolved salt and up to 97% of most dissolved organics. RO is also effective in the removal of enteric pathogens.

One issue that needs to be addressed when considering RO is the disposal of reject water that is highly saline.

Coagulation, flocculation and sedimentation (or flotation)

The processes of coagulation, flocculation, sedimentation (or flotation) and filtration remove particles, including microorganisms (bacteria, viruses, protozoa and helminths). Coagulation and flocculation is typically achieved using alum and polyelectrolytes, and is often followed by sedimentation or dissolved air flotation. The latter is particularly suited to treating lagoon effluent, which can contain algae. Due to the relatively high organic content and low physical quality of most sources of recycled water, higher doses of chemicals are generally used in wastewater treatment plants than in drinking water plants. This produces larger quantities of waste sludge.

Advanced physicochemical processes

Physicochemical technologies for advanced treatment of wastewater can be applied to tertiary treated effluents to further improve quality. Such technologies include activated carbon adsorption and advanced oxidation. Table A3.2 shows the chemical qualities that can be achieved by advanced processes.

Table A3.2 Effect of some advanced processes on the chemical quality of sewage effluents

Treatment process	Typical effluent quality, mg/L (except turbidity, NTU)					
	TSS	BOD_5	Total N	NH_3-N	PO_4-P	Turbidity
Activated sludge/nitrification, single stage	10–25	5–15	20–30	1–5	6–10	5–15
Activated sludge + granular filtration + carbon adsorption	<5	<5	15–30	15–25	4–10	0.3–3
Activated sludge + granular filtration + carbon adsorption + reverse osmosis	≤1	≤1	≤2	≤2	≤1	0.01–1
Activated sludge/nitrification — denitrification and phosphorus removal + granular filtration + carbon adsorption + reverse osmosis	≤1	≤1	≤1	≤0.1	≤0.5	0.01–1
Activated sludge/nitrification — denitrification and phosphorus removal + microfiltration + reverse osmosis	≤1	≤1	≤0.1	≤0.1	≤0.1	0.01–1

BOD_5 = biochemical oxygen demand over 5 days; NTU = nephelometric turbidity unit; TSS = total suspended solids
Source: Tchobanoglous et al (2003)

Activated carbon adsorption

Carbon adsorption is mainly used to remove refractory organic compounds; it is also used to remove residual amounts of inorganic compounds such as nitrogen, sulphide and heavy metals. Activated carbon can be used in either granulated or powdered form. Both forms have low affinity for low molecular weight polar organic species.

Advanced oxidation processes

Advanced oxidation processes are used to oxidise complex organic constituents that are difficult to degrade biologically into simpler byproducts.

Advanced oxidation relies on the generation and use of free radicals (OH•) in solution. There are several chemical and physicochemical reactions that generate free radicals. These species are among the strongest chemical oxidants in nature.

Prolonged detention in lagoons or wetlands

Lagoon detention can substantially reduce the numbers of pathogenic bacteria, protozoa and helminths. Virus numbers will also be reduced, but not as quickly. *Giardia* is rapidly removed, and helminth eggs can be completely removed within 25 days. Detention can also lead to reductions in turbidity.

The presence of vegetation in wetlands facilitates removal of suspended solids, BOD, heavy metals and nutrients (particularly nitrogen). Care needs to be taken to ensure that lagoons and wetlands are designed to minimise short-circuiting. Lagoons, in particular, can support algal growths, leading to increases in suspended solids. In some cases, algal growths may include toxic cyanobacteria. Long-term storage can lead to increased salinity as a result of evaporation.

A3.3.4 Disinfection

Disinfection methods include chlorination, ultraviolet (UV) light irradiation, ozone and chlorine dioxide. Chlorination and UV light irradiation are the more commonly used methods for disinfecting wastewater and stormwater. These methods are very effective in killing bacteria; they can also be reasonably effective in inactivating viruses (depending on type) and some protozoa, including *Giardia*. *Cryptosporidium* is not inactivated by the concentrations of chlorine and chloramines that can be used to treat recycled water, and the effectiveness of ozone and chlorine dioxide is limited. However, there is some evidence that UV light irradiation might be effective in inactivating *Cryptosporidium*, and combinations of disinfectants can improve inactivation.

Chlorination

Chlorination of treated sewage generally results in the production of chloramines due to the presence of ammonia. Chloramines inactivate microorganisms at a rate that exceeds those predicted by laboratory experiments using preformed chloramines. However, chloramines are slower disinfectants than free chlorine. While chemical disinfectants are effective in reducing numbers of pathogenic microorganisms, they can also be toxic to aquatic life in circumstances involving discharge. Detention of treated effluent or stormwater in lagoons and wetlands can reduce substantially the numbers of pathogenic bacteria, protozoa and helminths. Virus numbers will also be reduced, but not as quickly. *Giardia* is rapidly removed by lagoon detention, and helminth eggs can be completely removed within 25 days. Detention can also reduce turbidity.

A3.3.5 Soil–aquifer systems

Soil–aquifer systems involve the movement of stormwater or treated wastewater through the soil, unsaturated zone and aquifer. Such systems can provide substantial improvements in water quality where hydrogeologic conditions permit. The process can lead to reductions in suspended solids, BOD, pathogen numbers and nutrient concentrations.

Detention of stormwater or treated wastewater following direct injection into aquifers can also reduce numbers of enteric pathogens. Higher quality wastewater is required for direct injection.

A3.3.6 Protection and maintenance of distribution systems and storages

In general, enteric pathogens do not regrow in treated effluent or stormwater. However, distribution systems and storage systems do need to be protected from microbial and chemical contamination. Entry of human and livestock waste should be prevented.

A3.4 End-use and on-site restrictions

A3.4.1 End-use controls

End-use controls can prevent or minimise public exposure to hazards and can allow use of lower quality recycled water. In regard to public health, relatively few restrictions need to be placed on non-drinking water uses of tertiary treated and disinfected effluent. However, end-use controls should increase as the quality of recycled water decreases. For example, secondary treated effluent containing up to 1000 *E. coli* per 100 mL will be restricted to applications with low levels of human exposure, such as drip irrigation of fruit trees or grape vines, or of landscaping.

End-use controls can also be used to minimise the impact on receiving environments. In some cases, this may include precluding application or discharge to highly sensitive areas. Treatments designed to reduce environmental impacts, such as BNR, can be used to reduce the number of end-use controls.

A3.4.2 On-site controls

On-site controls should be applied in association with end-use controls to reduce both human exposure to hazards and the impact on receiving environments. Such restrictions include signage; control of application methods, rates and times; use of buffer zones; control of access; and control of plumbing and distribution systems. These restrictions are discussed below.

Signage

Prominent signage indicating that the water is not suitable for drinking (eg 'Recycled water — do not drink') should be installed wherever recycled water is used. Alternative signs may be required for other uses (eg 'Recycled water being used — do not enter when irrigation in progress' or 'Recycled water storage — no swimming, wading or boating'). The incorporation of symbols should be considered, and warning signs should be designed with reference to AS 1319 (*Safety signs for the occupational environment* 2004) and AS 2416 (*Design and application of water safety signs* 2002).

Control of application methods

Methods of application (eg spray, microspray, drip or subsurface irrigation) must be controlled. Spray irrigation should be conducted using devices designed to minimise production of aerosols, and recycled water sprays should not be allowed to extend past prescribed property boundaries. On the edge of irrigation areas, 180° inward-throwing sprinklers should be used to reduce off-site exposure. Low-throw sprinklers, microsprinklers and drip irrigators will also reduce the potential for inadvertent exposure to recycled water used in landscape irrigation. The nature of food crops needs to be considered in selecting agricultural irrigation methods. For example, the issues associated with root crops such as carrots and potatoes will differ from those associated with above-ground crops such as tomatoes and lettuce.

Control of application rates

Application rates need to be controlled so that irrigation provides maximum benefit, while minimising impacts on receiving environments (including soils, groundwater and surface water). Soil characteristics, water requirements and balances, nutrient balances and mechanisms to reduce impacts from salinity and sodicity all need to be considered.

Control of application times

Potential exposure to recycled water can be reduced by limiting the time of application (eg night-time only). Effectiveness of limitation depends on location and the types of normal activities in the vicinity. For example, limiting irrigation to night-time only is more effective in outer urban or rural areas than in tourist locations that receive many visitors at night.

Use of buffer zones

Generally, spray buffer zones are not required for high-quality recycled water suitable for domestic non-drinking water use. However, buffer zones might be used as a mechanism to reduce human and environmental exposure, and to enable the use of lower quality recycled water. Default buffer zones may range from 30 metres for moderate-quality recycled water, to 100 metres for low-quality water. Buffer zones can be reduced with the use of low-throw sprinklers, 180° inward-throwing sprinklers, tree or shrub screens and anemometer switching systems. Buffer zones apply from the edge of wetted areas to the nearest point of public access, and to receiving environments of concern. Where house allotments are adjacent to irrigation areas, the buffer zone is measured to the property boundary and not to the dwelling.

Control of access

Fencing combined with warning signs can be used to restrict or control access. Fencing can range from simple railings to security mesh, depending on the quality of recycled water and site characteristics.

Ideal sites for irrigation should have a slope of no more than 10% and have permeable soil. Irrigation systems should be installed and operated to minimise surface ponding and to control surface runoff. Devices such as drinking water fountains, barbeques, playground equipment and picnic facilities need greater levels of protection from recycled water.

Control of plumbing and distribution system

All pipework associated with recycled water schemes should be installed in accordance with AS/NZS 3500 (*Plumbing and Drainage Code*; Standards Australia, published in parts from 1996 to 2003), whereas dual-reticulation systems should be installed in accordance with the relevant supplement to the *Water Supply Code* (WSAA 2002b).

A fundamental requirement in all recycled water schemes is maintaining separation from drinking water systems or from potential sources of drinking water. To protect public health, it is essential that direct connection of recycled water systems to drinking water supplies is not permitted. If drinking water is supplied as make-up water or as a supplementary source of water, an approved air gap or backflow prevention device must be installed, as specified by AS/NZS 3500 (*Plumbing and Drainage Code*; Standards Australia, published in parts from 1996 to 2003).

In dual-reticulation systems, backflow prevention devices should be installed at property boundary entry points of the drinking water supply, in order to limit potential impacts from inadvertent or unauthorised cross-connections. Operating the recycled water system at a lower pressure than drinking water systems can further reduce the risk of backflow.

All pipework should be marked as indicated in AS/NZS 3500 (*Plumbing and Drainage Code*; Standards Australia, published in parts from 1996 to 2003) and the *Water Supply Code* (WSAA 2002b).

Where possible, public access to valves and fittings should be prevented, and all such facilities should be distinctly marked and labelled (eg ‘Warning — recycled water — not for drinking’). Outlets and taps should also be clearly marked.

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Appendix 4 Detailed risk assessment for key environmental hazards

This appendix considers agricultural irrigation, municipal, residential and fire-control uses of recycled water. It must be read in conjunction with Section 4.2.2 of the guidelines, which covers the identification of key hazards, to assess risks arising from the specific site and source of wastewater.

Each hazard is explained and its risk quantified in general terms. Tables give examples of control points in environmental pathways, critical control points in processes, preventive measures and verification procedures. The list of control points and preventive measures is neither definitive nor exhaustive, but is provided to give examples that could be used in specific reuse schemes.

A4.1 Boron

Boron (B) is present in the environment in various minerals, such as borax, borate and aluminium borosilicate, and is commonly associated with saline hydrogeological conditions. Boron in a wastewater system may come from the source water, detergents, water softeners or industrial wastes. Boron in recycled waters originates principally from household water softeners and cleaners, mostly in the form of sodium perborate.

Boron is a micronutrient required by plants only in small amounts (<500 g/ha) and in a very narrow range (there is only a small difference between boron deficiency and toxicity). The trigger level for some sensitive crop plants species is 0.5 mg/L, but other crop plants can tolerate 15 mg/L (see Table A5.3). Ornamental plants vary considerably in their tolerance (see Table A5.4). Some freshwater aquatic organisms may be susceptible to concentrations as low as 0.09 mg/L (see Table A5.2). Concentrations in recycled waters in Australia average 0.3 mg/L, with a reported maximum of 0.8 mg/L.

Concentrations of boron in recycled water are unlikely to be high enough to cause direct toxicity to plants through foliar application, but excess boron from recycled water irrigation can accumulate in the root zone if it is not leached down through soil, leading to plant toxicity problems. Clay soils of marine origin have naturally elevated boron concentrations, particularly in the subsoil (Nuttall et al 2003), and relatively low concentrations of boron added to these soils can quickly lead to a toxic response in sensitive crops. Yield is likely to be reduced before symptoms of toxicity become visible.

Climatic conditions might lead to boron toxicity for aquatic biota in enclosed water bodies, where evaporation concentrates boron and there are regular additions of recycled water (eg water feature ponds or aquaculture ponds). Even in such a case, much of the boron is likely to reside in sediments and be stripped out by plants. Natural boron concentrations in marine ecosystems are 4–5 mg/L, well above the level usually found in recycled waters.

Boron in recycled waters may be a hazard to plants irrigated with recycled water if it builds up in soils. The principal preventive measures are water treatment (removal of boron), restriction of entry into the wastewater, source control, choice of plants to be grown and selection of soils with low and easily leached background boron concentrations.

A4.1.1 Environmental risks

The environmental risks considered to be low for boron in recycled water are:

- direct toxicity to plants (foliar application) (see Table A4.17)
- exposure pathways through cross-connections (because of likely dilution and the likely short duration of cross-connections)
- exposures from washing (boron accumulation in soils is more a chronic than an acute problem, and runoff from washing would be easily minimised).

Concentrations of boron in recycled waters were considered too low to pose a risk to marine biota, regardless of exposure pathway.

The environmental risks considered to be moderate to very high for boron are:

- toxicity to plants irrigated with recycled water
- concentrations in sensitive freshwater environments from environmental allocations of water, where dilution is limited.

A4.1.2 Boron toxicity

Growth and yield are likely to be reduced before toxicity symptoms can be seen. Symptoms usually appear first in older leaves, and include yellowing and a brown speckled pattern between veins near the edge of the leaf, after which the edge of the leaf gradually turns brown. Other symptoms may include small brown necrotic spots over the cupping of leaves, with a red, purple or pink band (anthocyanins) surrounding necrotic tissue.

Management options for reducing boron toxicity include choosing appropriate plants, leaching, using low-boron soils and, in some cases, reducing inputs. Leaching has limitations on some soils because toxicity is most likely where natural soil boron concentrations are high (typically on high-clay soils, which are difficult to leach). In such cases, soluble boron in the soil solution is probably in equilibrium; if it is leached, more boron may be resupplied from naturally occurring boron-containing minerals in the soil.

However, leaching remains an option for other soils if the principal source of boron is recycled water. Boron concentrations in recycled waters could be reduced if low or zero boron cleaners were used, although in Australia labelling of cleaners does not normally indicate boron content.

Table A4.1 shows a range of critical control points and preventive measures that can be used to minimise the residual risk of boron toxicity.

Table A4.1 Boron: control points, preventive measures, target criteria and verification

Control points	Preventive measures	Target criteria	Verification
Plants	*Crops or plants grown* If boron in irrigation water is >0.5 mg/L, it may build up in the soil and become toxic to some plants following repeated irrigations. Grow plants species that are tolerant to boron in soils (Tables A5.3 and A5.4).	0.5 mg/L plant-dependent (Tables A5.3 and A5.4)	No evidence of boron toxicity on foliage. Toxicity typically appears first in older leaves and includes a yellowing and brown speckling pattern found between the veins and near the edge of the leaf, followed by the edges becoming necrotic. Other symptoms include yellowing (chlorosis), tip burn, cupping of the leaves, reduced size, premature leaf drop and the development of a red, pink, purple or bluish band on the edge of chlorotic leaves.
Irrigation or watering	*Irrigation or watering tools* If soil monitoring indicates boron accumulated in soils from recycled waters. Leaching fraction should be modified to leach boron through the soil profile away from plant root zone. Leaching should be done according to standard protocols (see eg Ayres and Westcot 1985, Anon 1997).	0.5 mg/L plant-dependent (Tables A5.3 and A5.4)	Soil boron concentrations are below critical limit for plants to be grown.
Source water	*Hazard source control* If concentrations of boron in water are above acceptable limits for crops to be grown, determine whether the sources of boron entering the wastewater can be decreased, and if so, decrease boron added to the wastewater.	0.5 mg/L plant-dependent (Tables A5.3 and A5.4)	Boron concentration in recycled water is below critical value for plants grown (Tables A5.3 and A5.4).
Distribution system	*Shandy with fresh water* If concentration of boron is above acceptable limits for plants to be grown, dilute recycled water with fresh water to decrease boron concentrations to acceptable levels.	0.5 mg/L plant-dependent (Tables A5.3 and A5.4)	Boron concentration in recycled water is below critical value for plants grown (Tables A5.3 and A5.4).
Soils	*Site selection* Where soils are to be irrigated, select soils that do not contain clays of marine origin. Plant toxicity is likely if there is >15 mg/kg total soil boron.	0.5 mg/L plant-dependent (Tables A5.3 and A5.4)	Soil boron concentrations are below critical limit for plants to be grown (Tables A5.3 and A5.4).
Treatment process	*Decrease concentrations* If boron concentrations in recycled water are too high for the intended use, change treatment process to remove more boron when reclaiming the water.	0.5 mg/L plant-dependent (Tables A5.3 and A5.4)	Boron concentration in recycled water is below critical value for plants grown (Tables A5.3 and A5.4).

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

A4.2 Chlorine disinfection residual

Most sewage treatment plants in Australia disinfect effluent before discharge. Disinfection involves the addition of chlorine or ozone, or exposure to UV light. UV light disinfection is unlikely to produce hazardous compounds in the recycled water. Like chlorine, ozone produces disinfection byproducts because it is an oxidising agent. These byproducts have been less extensively studied, but they appear to be generally less toxic than chlorine byproducts, although they still have some toxicity. However, chlorine 'residuals' (chlorine remaining in the water after treatment) are often required to protect human health.

Chlorine is commonly used either as a disinfectant to kill pathogenic microorganisms or to control biofilm growth in distribution systems. However, if chlorine residuals are not managed appropriately, they may harm terrestrial and aquatic organisms.

A4.2.1 Environmental risks

The environmental risk considered to be low for chlorine disinfection residuals in recycled water is:

- cross-connections, where recycled water is used for irrigation.

The environmental risks considered to be moderate to very high for chlorine disinfection residuals are:

- irrigation of sensitive crops or plants
- unintentional or intentional direct discharge into surface water bodies.

A4.2.2 Terrestrial impacts

The risk posed to plants by chlorine residuals in recycled water (chlorine phytotoxicity) has been studied by several researchers (eg Bisessar and McIlveen 1992, citing Brennan et al 1965).

Irrigation water with a residual chlorine concentration of <1 mg/L did not adversely affect the growth or appearance of most potted plants and vegetable seedlings grown in a medium of peat, perlite and vermiculite (Frink and Bugbee 1987). Sensitivity to the chlorine depended on the plant species. Plants found to have reduced weights and leaf chlorosis were:

- geranium and begonia, with chlorine at 2 mg/L
- peppers and tomatoes, with chlorine at 8 mg/L
- lettuce, with chlorine at 18 mg/L
- broccoli, marigold and petunia, with chlorine at 37 mg/L.

The germination of vegetable seedlings was unaffected.

Free chlorine is probably one of the most reactive and phytotoxic chlorine residuals and is expected to be a relatively conservative measure of chloramine phytotoxicity (chloramines are formed by the reaction of hypochlorous acid or aqueous chlorine with ammonia).

The studies reviewed suggest that 1 mg/L of chloramine or free chlorine should represent a low risk for irrigation, while 1–5 mg/L would be expected to pose a low risk to most crops. It would be advisable to undertake some trials where chlorine residuals approaching 5 mg/L are proposed for irrigation, and when relatively sensitive crops are involved. Concentrations higher than 5 mg/L may be readily tolerated by many crops, but a more detailed assessment would be required.

Table A4.2 gives a range of critical control points and preventive measures to minimise the risk from chlorine disinfection residuals in the terrestrial environment.

Table A4.2 Chlorine disinfection residual — terrestrial: control points, preventive measures, target criteria and verification

Control points	Preventive measures	Target criteria	Verification
Treatment process	*Design or decrease concentrations* If chlorine disinfection residuals are above levels, which may affect plant growth, install a dechlorination system or lower chlorination doses to decrease concentrations in recycled water to acceptable levels.	1.5 mg/L **Critical limit** 2 mg/L of chloramine or free chlorine **Critical control point** Water treatment facility	Plants health not affected by high chlorine disinfection residuals.
Irrigation	*Irrigation tools* If chlorine disinfection residuals are above levels, which may affect plant growth, do not apply recycled water to the leaves of the plant.	1–5 mg/L of chloramine or free chlorine depending on plants grown	Plants health not affected by high chlorine disinfection residuals.

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

A4.2.3 Aquatic impacts

Chlorine residuals in recycled water may typically pose a low risk to terrestrial organisms from irrigation; however, these levels could cause significant impacts on aquatic systems. The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC and ARMCANZ 2000a) discusses the aquatic impacts of chlorinated water, describing the ecotoxicity data based on total chlorine as:

- freshwater fish — eight species tested, with acute LC_{50}s[11] of 14–840 µg/L
- freshwater crustaceans — seven species tested, with acute LC_{50}s of 5–1010 µg/L
- freshwater molluscs, annelids and insects — toxicity occurring at >500 µg/L (relatively low hazard)
- marine fish — two species had acute LC_{50}s of 128–250 µg/L, with similar values being reported for chronic data
- marine crustaceans — one species had acute LC_{50}s of 73–268 µg/L, depending on exposure duration; a 7-day no observed effect concentration (NOEC) for reproduction was 20–87 µg/L;

[11] LC_{50} is the lethal concentration of the chemical in air that kills 50% of the test animals in a given time

Manning et al (1996) were cited as reporting a 24-hour LC_{50} value of 180 µg/L for the Australian marine prawn.

Based on these data, the guidelines established a total residual chlorine trigger value of 3 µg/L as affording 95% protection for freshwater systems (ANZECC and ARMCANZ 2000a). This value was also established as a low-reliability trigger value for the marine environment.

In using this information to assess risks from discharge, key features of the data are as follows:

- Most of the dataset shows acute toxicity values (eg 24-hour exposures) greater than 50 µg/L; only limited freshwater species had values less than 50 µg/L.
- Increased exposure increased the toxicity, but the changes were not as marked as with many chemicals. For a freshwater crustacean, a 1-hour exposure resulted in an LC_{50} of 280 µg/L, a 24-hour exposure resulted in 260 µg/L, and a 10-day exposure resulted in a lowest observed effect level (LOEC) of 66 µg/L.

A number of other readily available documents provide relevant information. The Department of Environment and Heritage Report Qld (DEH Qld 1991) references chlorine threshold limits for aquatic species as 0.002 mg/L in fresh water and 0.01 mg/L in saline water. Scholz (2000) references 0.05 mg/L of free chlorine in water as lethal for the majority of fish, while 0.3–0.6 mg/L causes reduction in plant and animal biomass.

An important series of studies explored the effects of chlorine and chloramines on algal growth (UWRAA 1990). A range of species were used, with representatives of the chlorophytes (4 species), the euglenophytes (1 species) and the cyanobacteria (1 species). The results indicated a wide range of algal sensitivities to both chlorine and chloramine, with the *Microcystis aeruginosa* t99 time at 2 mg/L being 3 and 5 minutes respectively, and the t99 time for *Chlorella minutissima* being greater than 240 minutes for both forms of chlorine. Importantly, the various species had the same sensitivity ranking patterns for chlorine and chloramine. The species were 1.5—3 times more sensitive to chlorine than to chloramine, depending on the species.

Preventive measures to minimise the risk from chlorine disinfection residuals in the aquatic environment are shown in Table A4.3.

Table A4.3 Chlorine disinfection residual — aquatic: control points, preventive measures, target criteria and their verification

Control points	Preventive measures	Target criteria	Verification
Treatment process	*Design or decease concentrations* If chlorine disinfection residuals are above levels that may affect aquatic biota, install a dechlorination system or lower chlorination doses to decrease concentrations in recycled water to acceptable levels.	80% of critical limit or value considered suitable for specific system **Critical limit** 3 µg/L **Critical control point** Post chlorination and chlorine contact system	Aquatic biota health not affected by high chlorine disinfection residuals.
Water storage	*Management plan* If storages use fish for algae control, check sensitivity of aquatic biota that may be sensitive to chlorine disinfection residuals (Table A5.2).	< 3µg/L or adequate dilution	Fish and other aquatic biota healthy and breeding successfully.
Water distribution	*Shandy with fresh water* Fresh water can be used to reduce concentration of chlorine disinfection residuals.	**Critical limit** Final mix <3 µg/L before release to the environment **Critical control point** Point of release to environment	Fish and other aquatic biota healthy.
Storage and distribution system	*Maintenance* Main lines and large storages should not be located adjacent to sensitive waterways. Environmental management plan should consider effects of unintentional discharges to sensitive waterways.	Maintenance schedule kept and program has maintained storage and distribution system minimising burst and leakages.	Unintentional discharges minimised and no environmental impacts.
Storage and distribution system	*Incident management* An assessment of the likely outcome of unplanned mains discharges on surface and marine waters should be conducted. Management plan should include local contacts and processes for dealing with unplanned discharges to sensitive waterways.	Incident management plan in place (documented)	Response time to incident acceptable (ie risk to environment minimised).
Surface water	*Decrease concentration* If direct discharge to the environment is intended (environmental allocation), then check that concentrations of chlorine disinfection residuals are below critical values for the specific water body.	(Table A5.2 or as outlined above). **Critical limit** <3 µg/L **Critical control point** Point of release to environment	Concentrations of chlorine disinfection residuals in recycled water meeting critical values.
Surface water	*Shandy with fresh water* If direct discharge to the environment is intended (environmental allocation), and concentrations of chlorine disinfection residuals are above appropriate values for protection of the specific water body (Table A4.15), then shandy with a water source that has low concentrations.	Rapid dilution to appropriate levels in relatively large volume of water	Large volume of receiving water and no effect on aquatic biota.

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

A4.2.4 Major considerations for recycled water

The following are important considerations for recycled water:

- 1 mg/L of chloramine or free chlorine is a low risk to terrestrial plants
- 1–5 mg/L of chloramine or free chlorine poses a low risk to crops unless highly sensitive crops are grown
- concentrations of chloramine or free chlorine greater than 5 mg/l may be readily tolerated by many crops; however, specific assessment is required
- for discharges from sewage treatment plants directly to waterways, the chronic effects of chlorine residual should be considered; dechlorination is likely to be necessary before discharge (Victoria EPA 2003)
- for indirect and occasional discharges associated with land-based water recycling, impacts should be considered based on the acute values, factoring in the timescales of release and the effects of discharge mixing
- sewage that has been disinfected using chlorine and has not been dechlorinated is likely to contain levels of total residual chlorine significantly in excess of the water quality guideline and likely to cause acute toxicity to aquatic organisms
- recycled water released directly to surface waters or runoff that reaches surface waters almost immediately after application is likely to cause environmental impacts, particularly if such discharges are continuous or persist over an extended period
- no special precautions are needed for outdoor uses (eg garden watering or car washing) that do not result in recycled water reaching surface waters
- any uses that involve direct and ongoing release to surface waters may need to involve a dechlorination step, such as storage in sunlight for a few hours or the addition of sodium metabisulfite.

A4.3 Hydraulic loading

Irrigation of crops often requires a leaching fraction to manage salts in the water that accumulate in soils. However, excess application of water to surface soils can result in various on-site and off-site environmental consequences that need to be carefully managed. Where such water percolates down through the soil (leaching), it can cause ‘hydraulic loading’ to the extent that local or regional watertables rise. Leaching requirements must be balanced with regional hydrology. If they are unbalanced, the watertable can rise to within 2–3 metres of the surface (the plant root zone) and soils can 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, such as phreatophytic plant communities (eg some Banksia woodlands; Dawson and Pate 2001), and wetlands that depend on surficial aquifers. Such systems may be susceptible to changes in water levels, increased salinity or nutrient enrichment.

Waterlogging makes oxygen less available to plant roots and to other organisms (hypoxia), and causes runoff. Waterlogged plants usually grow very slowly, and roots become very susceptible to infections from disease-causing organisms. Runoff can be a threat to the quality of surface waters if it contains high nutrient loads (see the sections on phosphorus and nitrogen in this appendix). Excess hydraulic loading can also transfer pollutants to groundwater and surface water runoff (Stevens 2006).

Hydraulic loading usually results from multiple water users rather than a single irrigator; that is, it is more likely to arise from diffuse, rather than specific, water sources. However, leakage or seepage from one or a number of large storage reservoirs can also contribute significantly to hydraulic load.

Excess water can also result in direct waterlogging at the surface, if irrigation water is applied at a rate greater than evaporative demand plus the rate of downward movement of soil water. This often occurs where there are impermeable or poorly permeable subsurface layers in the soil, and is best controlled by good management and control of water application, or by subsoil drainage systems, if required.

In Australia, watertable rise and secondary salinity are principally associated with increased groundwater recharge after clearing of perennial native vegetation (Allison et al 1990). However, accessions from irrigation are also important in some areas (Bethune 2004). Management options aim to reduce total water use by more closely matching supply with current evaporative demand and ensuring tight control of leaching requirements. Attention is focused on:

- using irrigation methods (Christen et al 2006) that give a rate of application that does not induce preferential flow (does not saturate the topsoil)
- considering the potential for groundwater levels to mound at the points of high hydraulic loading in environmental assessment
- taking into account irrigation over the whole aquifer system (not just property by property)
- monitoring soil moisture and using sensors to control the amount and timing of irrigation
- monitoring local and regional groundwater levels and quality in the centre or on the down-gradient edge of an irrigation area.

A4.3.1 Environmental risks

The environmental risks considered to be low for hydraulic loading using recycled water are:

- washing, because the volume of water involved would be low relative to that required to substantially affect local or regional hydrology
- cross-connection, because the recycled water would otherwise be used in other environmental pathways and uses, and should be considered in the risk assessment.

The environmental risks considered to be moderate to very high for hydraulic loading are:

- waterlogging of soils during irrigation
- secondary salinity from groundwater rise
- hydraulic load from leaky storage reservoirs
- movements of nutrients and salts to groundwater from irrigation.

A4.3.2 Waterlogging

The main effect of waterlogging is hypoxia of plants and other organisms, with salinity (discussed below) being a lesser problem. Plants suffering from hypoxia usually have greatly reduced growth rates and become susceptible to root pests and diseases. Some plants that can thrive under waterlogged conditions can provide oxygen to the roots through aerenchyma or similar specialised roots (Barrett-Lennard 2003). However, management focuses on prevention, rather than on selection of plants adapted to such conditions. Selecting the appropriate site to be irrigated is crucial. Other preventive measures include irrigation tools to minimise over watering, and subsoil drainage where subsoils are only semipermeable.

Symptoms of waterlogging in plants typically include yellowing or decay between leaf veins, softening of leaf tissue at the base or in the centre, wilting due to root decay, and/or blackened, damaged roots.

Table A4.4 shows preventive measures that can be used to minimise the risk of waterlogging.

Table A4.4 Hydraulic load — waterlogging: control points, preventive measures, target criteria and verification

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.	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.
Irrigation	*Irrigation tools* Ensure irrigation scheduling methods follow best practice. Water applied is carefully calculated to match current demand, according to standard protocols (eg see Allen et al 1998; Christen et al 2006).	Delivery of correct water volumes	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 becomes soft at the base or in the centre. Wilting may occur due to root decay and damaged roots 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.	Drainage capacity of specific site appropriate	Hydraulic conductivity of the soil profiles will cope with the required leaching fraction and irrigation volume required for the plants to be grown (saturated hydraulic conductivity (K_{sat}) at least >5 mm/hour).
Soils	*Site selection* Verify watertable is >2 m from soil surface or the lateral hydraulic conductivity of the watertable will handle required leaching fractions and irrigation rates.	Groundwater below 2 m	Groundwater remains below 2 m during irrigation and rain events throughout the year.
Groundwater	*Monitoring* Ensure watertable remains >2 m from soil surface.	Groundwater below 2 m	Verify watertable in piezometer is >2 m from surface.
Soils	*Drainage* Subsoil drainage can be installed to increase infiltration rate and remove excess water.	Drainage greater than 5 mm/hour	Soil water content less than field capacity, drainage at least >5 mm/hour.

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.

A4.3.3 Watertable rise and secondary salinity

Secondary salinity is normally accompanied by waterlogging, and the relative impacts of the two are difficult to untangle (Barrett-Lennard 2003). Since the problem is usually caused on a regional scale, both cause and cure have long lag times. Management efforts are focused on prevention, although other measures are also likely to contribute to a partial cure in many cases.

Irrigation water scheduling should take into account rainfall, evaporation, plant water use, the hydraulic conductivity of the soil and the water required for leaching salt from the root zone (Christen et al 2006). Irrigation demands calculated using weekly, monthly or annual water balances will always leach more water than those that consider rainfall and irrigation as discrete events. This is because irrigation is often scheduled for areas of the paddock that drain most quickly and, in some soils, because preferential flow allows water to bypass most of the soil profile. When the salinity of irrigation water increases, such as with recycled water, the proportion of water required for leaching increases; this may lead to higher rates of groundwater recharge, even though the total area under irrigation is unchanged. Soil water should be carefully monitored so that water applied in irrigation does not lead to excessive leaching or surface waterlogging. Groundwater levels should be monitored through piezometers appropriate for local and regional hydrology.

Preventive measures to minimise the residual risks of watertable rise and secondary salinity are shown in Table A4.5.

Table A4.5 Hydraulic load — watertable rise and secondary salinity: control points, preventive measures, target criteria and their verification

Control points	Preventive measures	Target criteria	Verification
Irrigation	*Irrigation tools* Ensure irrigation scheduling methods follow best practice. Water applied is carefully calculated to match current demand, according to standard protocols (eg see Allen et al 1998; Christen et al 2006).	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 becomes soft at the base or in the centre. Wilting may occur due to root decay and damaged roots blackened.
Groundwater	*Monitoring* Ensure watertable remains >2 m from soil surface.	Groundwater not rising and <2 m	Groundwater levels in installed observation wells <2 m and not rising.
Plants	*Monitoring* Monitor vegetation in the irrigation area and nearby for changes.	No detrimental changes in vegetation nearby	No changes in biodiversity indices for local ecosystems which may interact with groundwaters.
Plants	*Crops and plants grown* Grow salt and waterlogging tolerant plants where saline watertables are present and close to the soil surface (<2 m).	Plants species grown are not affected by salinity	Salinity is less than the threshold for plants to be grown.
Storage system	*Design* Storage dams and reservoirs must be designed to not leak water to local or regional watertable.	Technically sound design of storage system	Storage system design includes thorough assessment of soil profile properties and base is sealed. Water loss from storage is no more than sum of use and evaporation.
Storage and distribution system	*Monitoring* Conduct monthly water budgets to check water losses.	No water losses of unintentional leakages	Water budget for storage and distribution systems indicates no losses from the system.

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.

A4.4 Nitrogen

Most plants require nitrogen (N) in greater quantity than any other soil nutrient. Nitrogen is generally found in high concentrations in recycled waters originating from human and domestic wastes. In general, the higher the level of treatment, the lower the concentration of nitrogen. Much nitrogen can also be lost through denitrification during storage of recycled water. Average concentrations in recycled water are around 12 mg/L but can be as high as 50 mg/L. The principal forms of nitrogen in recycled water are organic nitrogen, ammonium (NH_4^+) and nitrate (NO_3^-).

Organic nitrogen contributes to ongoing soil fertility, and ammonium and nitrate to current plant nutrition. Organic nitrogen and ammonium can be easily converted to nitrate by soil microorganisms. Large amounts of nitrogen are usually added to gardens, crops and lawns as fertiliser. These additions can be reduced by the nitrogen in recycled water. As with all nutrients, inputs of nitrogen must be matched to plant demand, and neither too much nor too little should be provided. However, balancing plant nitrogen needs with plant water needs makes the management of recycled water irrigation more complex.

In addition to being a useful plant nutrient, nitrogen from runoff or direct discharge can enter water bodies and cause excessive growth of algae (eutrophication) in storage dams, lakes, rivers or estuaries. Nitrate nitrogen is mobile in the soil and can be leached to groundwaters, contaminating them. Such ‘off-site’ effects of nitrogen are hard to rectify and need careful management. Prevention is the main management aim.

Risks that need to be considered when using recycled water are:

- plant nutrient imbalance during irrigation
- increased plant pest and disease incidence
- eutrophication of surface waters
- contamination of groundwater.

A4.4.1 Environmental risks

The environmental risks considered to be low for nitrogen in recycled water are:

- risks from cross-connections (because of dilution)
- direct toxicity to plants
- unintentional discharges resulting in nutrient imbalances and groundwater contamination with nitrate
- washing and cleaning in domestic, agricultural and general municipal applications, excluding road washing, because of infrequency and small volumes — other, large-volume washing systems are industrial uses, which would be covered under state-specific site licensing regulations.

The environmental risks considered to be moderate to very high are:

- nutrient imbalance in plants
- increased pest and disease incidence in plants
- contamination of groundwater
- eutrophication of storage dams
- eutrophication of surface waters from runoff of irrigation waters
- road washing.

A4.4.2 Plant nutrient imbalance

Plants vary enormously in their nutritional requirements. Nutrient management strategies usually attempt to provide nutrients in similar ratios to those found in plant tissues, and in quantities approximating total plant demand, taking into account nutrients already available in the soil. Recycled water can contain much higher concentrations of nitrogen than traditional water sources, but irrigation rates generally match water requirements, rather than nutrient demands. Therefore, there is a risk of oversupplying nitrogen when irrigating with recycled water.

Oversupply of nitrogen (over fertilisation) may result in excessive vegetative growth and reduced fruit set for crops, or delays in maturation. Some fruits can become pulpy or grainy; leafy vegetable crops can suffer from pests and diseases if canopies become shaded and retain high humidity, providing an ideal moist, nutritive environment for pests and diseases to thrive, especially fungi (Baier and Fryer 1973). Such problems may be exacerbated by sprinkler irrigation. This is usually a combination of excessive fertiliser application and high nitrogen concentrations in recycled water.

Where too much nitrogen is supplied, plants may encounter deficiencies of other nutrients, such as phosphorus or potassium, if they are not provided in appropriate ratios.

The key to managing nitrogen is in matching the inputs to the on-site sinks. For example, the amount of nitrogen added should not exceed the capacity of the soil to store it in forms that maintain plant health, or result in a high risk of transport off-site. Nitrogen loads applied in irrigation water should be calculated, and compared with likely uptake by the plants or crops to be watered. If too much nitrogen is being added, watering should be reduced, recycled water should be diluted with other water sources, or more suitable crops, with a high nitrogen requirement, should be grown. Plant demand for other nutrients should also be considered, to ensure that it matches the growth governed by the nitrogen input.

Preventive measures to minimise the risk of nutrient imbalances are shown in Table A4.6.

Table A4.6 Nitrogen — nutrient imbalance: control points, preventive measures, target criteria and their verification

Control points	Preventive measures	Target criteria	Verification
Irrigation and fertilisation	*Nutrient balancing* Nitrogen available for plant uptake should not exceed anticipated plant demand. Ensure nutrient budget for irrigation period includes all nitrogen sources (irrigation water, fertiliser, soil nitrogen).	Nutrients supplied do not exceed plant requirements.	Nutrient management plan in place and documented. No excessive vegetative growth of plants, disease or delayed maturity of fruits.
Treatment process	*Decrease concentrations* If nitrogen concentrations in recycled water are too high for the intended crop, modify the treatment process to remove more nitrogen.	Nutrient levels decrease to levels that do not exceed site-specific requirements.	Nitrogen levels in soils are not excessive with respect to plant requirements.
Irrigation and fertilisation	*Nutrient balancing* Non-nitrogen nutrients balanced with anticipated plant demand (growth) and N input.	Fertilisation program considers nutrients in recycled water.	Nutrient management plan in place and documented, no plant nutrient deficiency symptoms observed.
Irrigation	*Irrigation tools* Do not sprinkler irrigate crops if excessive vegetative growth may lead to pest and disease issues from humid microclimates around plants.	Drip or furrow irrigation used.	Nutrient and water management plan in place and documented. No excessive vegetative growth of plants, disease or delayed maturity of fruits.

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.

A4.4.3 Terrestrial eutrophication

Some Australian bushland ecosystems are adapted to scarce nutrients and relatively low rainfall. Such bushland may be sensitive to increased nutrient and water inputs if it is adjacent to urban developments (Thomson and Leishman 2004) and broadacre agriculture (Grigg et al 2000). This 'terrestrial eutrophication' typically results in a loss of biodiversity and an increase in weed invasion. Many native plants are much less competitive in nutrient and water enriched environments, and have shorter lives, produce less seeds or grow less than other species, especially weeds, which are able to respond rapidly to these conditions. Terrestrial eutrophication should be prevented to maintain the integrity of native vegetation assemblages and the fauna that depend on them. Water and nutrients in recycled water can move into bushland through surface runoff, stormwater drains and diversions, shallow watertables (Grigg et al 2000) and unintentional discharges.

Protection of bushland from such incursions can be achieved by restricting inputs of recycled water to no more than required. Using buffers between recycled water uses and bushland, and ensuring that unintentional discharges from main lines and storages are unlikely to threaten valuable bushland communities, reduces the likelihood of runoff or transfer via shallow groundwaters. Buffers can be both physical (distance, bunds and drains) and biological (vegetation). One of the most effective means of protection is strategically planted buffer strips that extract nutrients and water before they can enter sensitive bushland (see Appendix 6).

Table A4.7 lists measures to minimise the risk of terrestrial eutrophication from nitrogen.

Table A4.7 Nitrogen — terrestrial eutrophication: control points, preventive measures, target criteria and their verification

Control points	Preventive measures	Target criteria	Verification
Irrigation	*Buffer distances and strips* Appropriate buffer distances need to be observed and buffer plantings used to strip nutrients from runoff. Buffer distances and extent of nutrient stripping devices will depend on slope and the importance and sensitivity of the vegetation system (Appendix 6).	Minimisation of any discharges on to locally significant natural ecosystems as nutrient enrichment may be detrimental to them.	Runoff from irrigated areas captured in bunds or drains, and/or stripped of nutrients before moving off-site.
Irrigation and fertilisation	*Nutrient balancing* Ensure crop nutrient budget includes inputs from all sources (water, fertilisers, soils, etc) so excess nutrients moving off-site are limited.	Nutrient supplied = plant demands.	Crop nutrient management plan in place and documented, and soil nitrogen levels kept within plant requirements.
Storage and distribution system	*Buffer distances and strips* Discharges on to locally significant natural ecosystems need to be minimised because nutrient enrichment may affect values. Appropriate buffer distances need to be observed and buffer plantings used to strip nutrients from runoff. Buffer distances and extent of nutrient-stripping devices will depend on slope, and the importance and sensitivity of the vegetation system (Appendix 6).	Discharges to locally significant ecosystems minimised to appropriate site-specific criteria.	Verify that management plan includes consideration of incidental runoff to local vegetation systems, including consultation with local relevant natural resource management authority.
Storage and distribution system	*Incident management* Appropriate authorities should be notified of unintentional discharges and suitable plans put in to place, including diversions and dilutions where necessary.	Quick responses to incidents minimising related impacts.	Have a plan in place to deal with large leaks or discharges near sensitive waterways. Appropriate local authorities to be consulted in plan preparation and plan to include local contacts in case of emergency.
Storage and distribution system	*Site selection* Sites for storage and reticulation systems can be located in areas where intentional or unintentional discharge will not drain into sensitive ecosystems.	Drainage for intentional or unintentional discharges do not drain into sensitive ecosystems.	Site for storage of reticulation not within drainage area of sensitive ecosystems, consultation with local relevant natural resource management authority advised.
Storage and distribution system	*Interception and drainage* If storage or reticulation systems are near sensitive ecosystems, bunds and interception systems can be put in place for large storages near sensitive waterways.	Drainage for intentional or unintentional discharges do not drain into sensitive ecosystems.	Site plan includes assessment of drainage system and includes preventive measures to prevent water moving off-site, consultation with local relevant natural resource management authority advised.

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

A4.4.4 Contamination of groundwater with nitrate

Nitrate (NO_3^-) is the most mobile form of nitrogen in the soil. Being poorly bound to soil particles, it leaches freely and is the most commonly reported pollutant in drinking waters around the world (Spalding 1993). High concentrations of nitrate nitrogen in drinking waters have long been linked to methemoglobinaemia in humans, although this finding has recently been challenged (Addiscott and Benjamin 2004). Standards for nitrates in drinking water in Australia are 100 mg NO_3/L (22.6 mg N/L), and half of this level for infants (ANZECC and ARMCANZ 2000a).

Leaching of nitrate is normally associated with crop and garden fertiliser use and management. Ammonium (NH_4^+) is normally found in greater concentrations than nitrate in recycled waters, because it binds to soil particles and therefore is not usually leached. However, ammonium is readily converted to nitrate by soil bacteria, and thus the risk of nitrate leaching is related to both ammonium and nitrate nitrogen in soil. Nitrate and ammonium can be rapidly taken up by plants, but where they are provided in excess of plant needs there is a high risk of leaching. In addition to potential human health problems, nitrates in groundwaters may cause eutrophication or toxicities for groundwater dependent ecosystems, such as phreatophytic plant communities (eg some Banksia woodlands) and wetlands dependent on surficial aquifers.

Nitrogen will be leached if water and nitrate are provided in excess of plant needs. The risk of leaching is not confined to agricultural uses of recycled water — leaching from residential lawns on sandy soils is also likely to be high (Barton and Colmer 2004). Water application needs to be managed in conjunction with soil nitrate. Under waterlogged (anaerobic) conditions, nitrate may be converted to nitrogen gas (N_2) via denitrification; this process has been used to reduce nitrate concentrations in wastewaters (Schmidt et al 2003) and in groundwater (Wilson et al 1995).

Preventive measures include careful nutrient budgeting taking into account all nitrogen inputs, using hay crops to phytomine nitrogen, and leaching soils to manage other hazards only when available nitrogen concentrations in the soil are low. In southern Australia, leaching is most likely during autumn and winter, when plant growth (evaporative demand) is slow and rainfall higher, or during intense summer rainstorms on soils with high hydraulic conductivity (eg sands).

Management of crop irrigation with recycled water should attempt to balance nutrient and water inputs with crop demand, and restrict leaching to periods of low nitrate availability. Problems of nitrate leaching are not restricted to recycled water use; the same preventive measures are required to prevent nitrate leaching in all irrigation systems (see Thorburn et al 2003; Stevens 2006).

Measures to minimise the risk of nitrogen contamination of groundwater are shown in Table A4.8.

Table A4.8 Nitrogen — contamination of groundwater: control points, preventive measures, target criteria and their verification

Control points	Preventive measures	Target criteria	Verification
Treatment process	*Decrease concentrations* If nitrogen concentrations in recycled water are too high for the intended crop and soils sandy (Appendix 6), modify the treatment process to remove more nitrogen.	Nutrient levels decrease to levels that do not exceed site-specific requirements	Nitrogen levels in soils are not excessive with respect to plant requirements.
Soil	*Site selection* Avoid sandy soils where nitrate can be readily leached from the surface soil to aquifers. Avoid locating reuse sites above aquifers where current or future uses of the aquifer are identified as drinking.	Soils types will minimise water leaching to site-specific aquifers	Verify that irrigation scheduling plan includes consideration of hydraulic properties of local soils, that soils are not prone to leaching or do not overlay freshwater aquifer. Consult with local catchment management authority.
Irrigation	*Irrigation tools* Identify and implement irrigation methods or scheduling that will minimise leaching of nitrate to groundwater.	Leaching of nitrogen down the soil profile minimised or groundwater nitrogen levels acceptable	Confirm that appropriate irrigation methods and scheduling are in place. Confirm groundwater nitrate concentrations have not increased. Benchmark groundwater nitrate concentrations and document. Consult with local catchment management authority.
Irrigating	*Irrigation tools* When controlling salinity by leaching, leach soils when their nitrate concentration is low. Soil nitrate may be high after addition of manures and fertilisers, and shortly after tillage. Delay leaching until after nitrate availability has been decreased through plant uptake and harvesting.	As above	Soil water content less than field capacity in plant root zone until nutrient removal (eg harvest) or as above
Irrigation and fertilisation	*Nutrient balancing* Ensure crop nutrient budget includes inputs from all sources (water, fertilisers, soils, etc), so excess nutrient moving off-site is limited.	Nutrients supply balance with demand from plants grown	Crop nutrient management plan in place, approved and documented. Soil nitrogen levels do not exceed plant requirements.
Plants	*Crops and plants grown* Grow grass or hay crops that can be grown quickly to immobilise available nitrogen or remove it from the soil through crop removal from the site.	Nutrient applied is not in excess of plant demands	Nitrogen removal in crop is estimated to be equal to inputs, or soil nitrate analysis shows low risk of leaching.
Fertilisation	*Soil ameliorants* If possible, use low-nitrate fertilisers, especially on sandy soils.	Ensure nutrients applied do not exceed plant requirements	Fertiliser has no nitrate or nitrate is only a minor component, and soil nitrogen levels do not exceed plant requirements.

Table A4.8 (continued)

Control points	Preventive measures	Target criteria	Verification
Fertilisation	*Nutrient balancing* Apply nitrogen fertilisers in split dressings rather than as a single application.	Fertiliser program meets plants growth requirements	Quantity of fertiliser nitrogen applied meets plant demand through growing season.

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

A4.4.5 Eutrophication of surface waters

Nitrogen enrichment can lead to increased growth and productivity in ecosystems. In aquatic ecosystems this often results in algal blooms, which can release toxins, deplete oxygen levels, cause substantial mortality of biota and create health risks to humans and wildlife. Many natural water bodies are normally dominated by macrophyte plant communities, but become dominated by algae when nutrients are enriched. In some cases they become dominated by cyanobacteria, which may produce toxins. Phosphorus has been considered the principal cause of eutrophication in Australian surface waters (Davis 1998); however, nitrogen can also play a role, especially in estuarine systems (Peters and Donohue 2001).

Nitrogen from recycled water use could reach surface waterways via a number of pathways, including runoff, leaching, stormwater and seepage. Management strategies aim to reduce inputs and prevent movement off-site. If recycled water is directly discharged to stormwater systems (eg by road washing), the nitrogen concentration of the recycled water relative to that of the receiving water body must be assessed.

Recycled water storages (reservoirs, dams and tanks) could also suffer from excessive algal growth and eutrophication. In addition to producing toxins, algae in recycled waters may clog irrigation systems. Management strategies include source control, hazard reduction through nutrient stripping, turbidity management, and restriction of light sources (Thomas and Martinelli 1999, CRCWQT 2002).

Table A4.9 lists measures to minimise the risk of eutrophication of surface waters from nitrogen.

Table A4.9 Nitrogen — eutrophication of surface water: control points, preventive measures, target criteria and their verification

Control points	Preventive measures	Target criteria	Verification
Soil	*Site selection* In conjunction with appropriate experts, identify threats to surface waters though recycled water use on site-specific soils.	Diffuse and point discharge of nitrogen to sensitive environments minimised	Verify that site management plan includes consideration of diffuse and point discharges to local and regional surface waters, including consultation with relevant catchment management authority. Nitrogen concentrations in nearby surface waters have not increased from baseline levels taken before development of the reuse scheme.
Soils	*Buffer distances and strips* Irrigation with recycled water should not be conducted directly adjacent to surface waters. Appropriate buffer distances need to be observed and buffer plantings used to strip nitrogen from runoff (Appendix 6).	Discharges to surface waters minimised	Local waterways down slope of recycled water infrastructure and irrigation systems are buffered from discharges, and runoff to local waterways does not carry substantive nitrogen load.
Irrigation and fertilisation	*Nutrient balancing* Ensure crop nutrient budget includes inputs from all sources (water, fertilisers, soils, etc), so excess nutrients moving off-site are limited.	Nutrients supply balance with demand from plants grown	Crop nutrient management plan in place and documented. Soil nitrogen levels do not exceed plant requirements.
Storage system	*Crops and plants grown* Incorporate plants that grow in the stored water, which strip nutrients from the recycled water.	Plants grow well in storage; nitrogen concentrations decreased	Nitrogen concentrations in storage water decreased relative to inlet water and algal growth minimised.
Storage system	*Shandy with fresh water* If nitrogen concentrations in stored water govern algae growth, shandy with alternative water source to decrease them.	Nitrogen concentrations decreased to acceptable levels	Nitrogen concentrations in storage water decreased relative to inlet water and algal growth minimised.
Storage system	*Light reduction* Restriction of recycled water to light sources will minimise algal growth (eg a sealed tank compared with an open tank).	Algae number low enough to prevent environmental issues	No algae blooms.
Storage and distribution system	*Management plan* Site management plan should include consideration of off-site impacts of nitrogen from intentional or unintentional discharges of recycled water on local and regional surface water quality.	Off-site impact from intentional or unintentional discharges minimised	Impacts of nitrogen on surface waters recognised in the management plan and strategies for dealing with intentional or unintentional discharges developed in conjunction with local catchment management authority.

Table A4.9 (continued)

Control points	Preventive measures	Target criteria	Verification
Storage and distribution system	*Incident management* Runoff from overflowing dams, burst pipes, pressure release and road washing (intentional or unintentional discharge) could result in nutrient enrichment of waterways. Site management plan should include local contacts and processes for dealing with unplanned discharges to sensitive waterways.	Quick responses to incidents minimising related impacts	Incident management plan documented and in place, developed in conjunction with local catchment management authority and including local contacts in case of emergency.
Storage and distribution system	*Training and education* Operators are aware of nitrogen-sensitive waterway in the area of the recycled water use.	Operators trained in location of nitrogen-sensitive water bodies	Operators trained in location of nitrogen-sensitive water bodies.
Storage and distribution system	*Maintenance* Large storages and recycled water mains near sensitive waterways should be routinely checked and maintained regularly.	Maintenance schedule kept and program has maintained storage and distribution system minimising bursts and leakages	Thorough, scheduled maintenance checks undertaken and documented.
Treatment process	*Shandy with fresh water or treatment process* If using recycled water for washing (eg roads), assess where the drainage from road washing will be received in the environment. Will the nitrogen concentrations in recycled water cause eutrophication at this receiving point? If so, use low nitrogen water sources, dilute with fresh water to lower nitrogen concentration and/or treat water sufficiently so that nitrogen concentrations do not affect receiving environments.	Nitrogen concentration in recycled water less than site-specific maximum considered appropriate for this use	Nitrogen entering ecosystems or water body though street cleaning is insignificant, relative to the receiving water bodies or ecosystem nitrogen concentrations.

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

A4.5 Phosphorus

Phosphorus (P) is an important plant nutrient that limits productivity in many agricultural systems, and in natural aquatic and terrestrial ecosystems. Phosphorus in recycled water is usually in the range of 5–10 mg/L total phosphorus, most of which is organic phosphorus, usually with ≤3 mg/L as soluble phosphorus. The soluble fraction is readily ‘bioavailable’. When phosphorus is added to the soil in recycled water, most of the soluble fraction becomes adsorbed onto soil particles, is retained in the surface soils and is sparingly available to plants. Phosphorus is stripped from recycled water as it moves through the soil, because the phosphorus concentration in the soil solution is usually lower than in the water (Ryden and Pratt 1980). The slower the water moves through the soil, the more phosphorus is stripped out. Usually, in contrast to nitrogen, little phosphorus is leached from agricultural soils, except on sandy soils where much less of the phosphorus becomes adsorbed and a greater fraction remains soluble; some phosphorus may then leach into drainage water. Generally, the phosphorus in recycled water greatly benefits the productivity of crops and landscape plants. However, many native Australian plants that have adapted to low nutrient sandy soils can suffer phosphorus toxicity under high available phosphorus concentrations (Robinson 1996).

The principal pathway by which phosphorus in recycled water becomes an environmental hazard is through runoff, either from overland flow or in stormwater drains, or via unintentional discharges to aquatic ecosystems. In aquatic ecosystems, productivity is often limited (0.01 mg/L) by available phosphorus (Davis 1998), and plant communities normally dominated by macrophytes can switch to being dominated by phytoplankton (usually algae) if phosphorus is enriched (>0.02 mg/L). Further increase in nutrient levels culminates in the eventual dominance of algae (including cyanobacteria, which may produce toxins), depleting oxygen, producing substantial mortality of biota and creating health risks to humans and wildlife. However, the supply of nutrients alone is insufficient to predict the occurrence of an algal bloom, since other factors may also play critical roles — for example, warm, still water bodies with low flow, good light penetration, an abundant energy source (carbon), nitrogen, iron and molybdenum for nitrogen-fixing blue-green algae, and an absence of zooplankton grazers (Donnelly et al 1997). In some cases, the addition of nutrients may actually prevent an algal bloom (McAuliffe et al 1998).

Because of the many factors that can constrain or promote algal blooms, it is difficult to set practical preventive trigger values for irrigation waters. Regardless of whether land is irrigated with recycled water or not, phosphorus loads in runoff from agricultural (and urban) land frequently exceed quality parameters for the protection of waterways (Davis et al 2001). The key elements to successfully keeping phosphorus on-site are matching fertiliser applications to periods of peak crop demand, preventing runoff wherever possible, not applying phosphorus immediately before intense rain, applying phosphorus and water sparingly on sandy soils to prevent leaching, and providing perennial buffer strips around irrigation areas and storage dams (Appendix 6). Initial irrigations after fertiliser application are particularly important control points for phosphorus in runoff. Direct discharges of recycled water to stormwater systems, such as from road washing, must assess the phosphorus concentration of the recycled water relative to that of the receiving water body. Will this recycled water use increase the phosphorus concentration significantly in site-specific water bodies?

A4.5.1 Environmental risks

The environmental risks considered to be low for phosphorus in recycled water are:

- hazards from cross-connections in pipework (because of dilution and short duration)
- direct toxicity to plants (at observed concentrations in recycled water), when applied directly to plant foliage
- washing (other than road washing).

The environmental risks considered to be moderate to very high are:

- eutrophication of surface waters from irrigation and intentional or unintentional discharges (moderate to high risk)
- terrestrial eutrophication of bushland from irrigation (moderate risk)
- eutrophication of storage reservoirs (moderate risk)

- toxicity to sensitive native plants from irrigation (moderate to high risk)
- road washing (moderate).

A4.5.2 Plant nutrient imbalance or phosphorus toxicity

The principal force driving significant changes in soil chemistry is soil pH. Phosphorus interacts strongly with iron, calcium and aluminium in the soil at different pH levels. In acid soils (pH <7 in a $CaCl_2$ extract), phosphorus and iron combine in a form that makes both unavailable for plant uptake (Glendinning 1999). This interaction is the key to understanding potential iron deficiency (which may be a form of phosphorus toxicity) in plants irrigated with recycled water. Remedial actions include increasing soil pH to nearly neutral (not beyond, as iron immobilisation can also occur under alkaline conditions), using iron chelating agents as foliar sprays, adding fertilisers to the soil, ceasing phosphorus inputs and growing plants less susceptible to the problem.

Preventive measures to minimise the risk of nutrient imbalance or phosphorus toxicity are shown in Table A4.10.

Table A4.10 Phosphorus — nutrient imbalance or toxicity: control points, preventive measures, target criteria and verification

Control points	Preventive measures	Target criteria	Verification
Plants	*Soil ameliorant* When growing sensitive plants and soil pH is <7 ($CaCl_2$), excess P may precipitate Fe, resulting in Fe deficiency. Many plants native to sandy soils in Australia and South Africa are sensitive to P-enriched environments. This may cause problems where recycled water is used in nurseries and landscape irrigation of native vegetation. Iron chelates and foliar sprays can be applied for small areas. Add lime to increase soil pH to neutral (7 $CaCl_2$), add iron fertiliser, do not use phosphorus fertiliser.	Sufficient iron levels in plants	No symptoms of iron deficiency, which include young, light green leaves with dark green net-like pattern. Youngest leaves may become yellow or white in severe cases.
Plants	*Crops and plants grown* Do not grow native Australian plants that are more sensitive to phosphorus-induced iron deficiency (Tables A5.24–A5.27).	Plants grown are not sensitive to phosphorus-induced iron deficiency	No symptoms of iron deficiency, which include young, light green leaves with a dark green net-like pattern. Youngest leaves may become yellow or white in severe cases.
Irrigation and fertilisation	*Nutrient balancing* Phosphorus loads can be reduced through reductions in irrigation water applied and through reductions in fertilisers applied. Ensure crop nutrient budget includes inputs from all sources (water, fertilisers, soils, etc).	Nutrients supplied equal plant demands	Crop nutrient management plan in place and documented, and soil nitrogen levels do not exceed plant requirements.
Fertilisation	*Soil ameliorant* Sandy soils have very little capacity to immobilise phosphorus. Use sparingly soluble, slow-release or organic phosphatic fertilisers. Do not apply soluble phosphorus to sensitive native plants on sandy soils.	No visual symptoms of phosphorus deficiencies or toxicity in plant grown	Verify form and solubility of phosphorus in fertiliser is low for sensitive plant species on sandy soils. No visual symptoms of phosphorus deficiencies or toxicity in plant grown.

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

A4.5.3 Terrestrial eutrophication

Terrestrial eutrophication is discussed above (see Section 4.4.3). Various preventive measures can be used to reduce the residual risk of terrestrial eutrophication from phosphorus to acceptable levels (see Table A4.11).

Table A4.11 Phosphorus — terrestrial eutrophication: control points, preventive measures, target criteria and verification

Control points	Preventive measures	Target criteria	Verification
Soils	*Site selection* In conjunction with appropriate experts, identify high-value natural heritage bushland adjacent to planned recycled water development. Determine if thorough assessment of likely impacts is warranted with resource management authority.	No detrimental impacts on natural heritage bushland adjacent to recycled water use	Impacts on natural heritage bushland adjacent to recycled water use reduced to acceptable levels.
Soils and storage and distribution systems	*Buffer distances and strips* Prevent discharges on to locally significant natural ecosystems, because nutrient enrichment may impact on this ecosystem. Appropriate buffer distances need to be observed and buffer plantings used to strip nutrients from potential runoff. Buffer distances and extent of nutrient stripping devices will depend on slope and the importance and sensitivity of the vegetation system (Appendix 6).	As above	Discharge of nutrient risk water to sensitive ecosystems prevented. Runoff from irrigated areas captured in bunds, drains and/or buffer planting, to capture phosphorus before moving off-site.
Storage and distribution system	*Incident management* An assessment of the likely outcome of unplanned discharges should be conducted, with particular attention to off-site effects of nutrients and water on local bushlands.	Quick responses to incidents minimising related impacts	Ensure site management plan includes local contacts and process for dealing with unplanned discharge to sensitive natural ecosystems, and P levels in regional waterways meet criteria specified in local natural resource management plans.
Soils	*Site selection* Where bushland of very high natural heritage value or phosphorus sensitive environments are adjacent to planned recycled water development, a thorough assessment of the likely impacts is warranted.	No detrimental impacts on natural heritage bushland adjacent to recycled water use	Local advice provided regard presence of high-value natural heritage (eg threatened species) and requirements documented and actioned. No detrimental impact recorded.

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

A4.5.4 Eutrophication of surface waters

Irrigating crops and landscapes with recyled water creates a high risk of a significant amount of phosphorus moving off-site into surface waterways, as does unintentional discharge. Small changes in the phosphorus concentration in surface waters can have significant environmental consequences by causing algal blooms, the consequences of which are discussed above (see Section 4.4.5). Principal pathways for phosphorus transport to waterways are anticipated to be runoff, leaching, stormwater flows and seepage. These pathways carry phosphorus regardless of whether land is irrigated with recycled water or not. Phosphorus loads in runoff from agricultural and urban land can exceed quality parameters for protecting waterways. Intentional discharges of recycled water to stormwater systems, such as from road washing, must assess the nitrogen concentration of the recycled water relative to the receiving water bodies of that stormwater. Management strategies are aimed at reducing loads and preventing movement off-site.

Recycled water storages (reservoirs, dams and tanks) can also suffer from excessive algal growth from eutrophication. In addition to production of toxins, algae in recycled waters may clog irrigation systems. Preventive measures include source control, hazard reduction, irrigation tools and light reduction.

Various measures can be used to reduce the residual risk of eutrophication of waterways from phosphorus to acceptable levels (see Table A4.12).

Table A4.12 Phosphorus — eutrophication of waterways: control points, preventive measures, target criteria and verification

Critical control points	Preventive measures	Target criteria	Verification
Soil	*Buffer distances and strips* Irrigation with recycled water should not be conducted directly adjacent to surface waters. Appropriate buffer distances need to be observed and buffer plantings used to strip nutrients from runoff. Buffer distances and extent of nutrient stripping devices will depend on slope and the importance and sensitivity of the waterway (Appendix 6).	Discharges to surface waters minimised	Local waterways down slope of recycled irrigation systems are buffered from runoff to local waterways. Phosphorus concentrations in nearby surface waters have not increased from baseline levels taken before development of the reuse scheme.
Irrigating and fertilisation	*Nutrient balance* Some runoff to surface waters is inevitable. Minimise phosphorus loads by not applying excess. Also, minimise phosphorus loads by reducing recycled water applied or fertilisers applied. Ensure crop nutrient budget includes inputs from all sources (water, fertilisers, soils, manures, etc).	Nutrients supply balance with demand from plants grown	Phosphorus loads in crops, pastures, parks and gardens are no more than required for target productivity.
Storage systems	*Water treatment* Fish and other animals can strip nutrients from the water column.	Phosphorus concentration limits algae growth	Phosphorus concentration low enough to limit algal growth. No algal blooms observed.
Irrigation	*Irrigation tools* Reduce residence time of water in storage, increasing the turnover rate in storages, reducing the time available for algal growth and producing conditions unsuitable for algal growth.	Algae number low enough to prevent irrigation issues	Algal growth controlled. No irrigation emitters and filters blocked.

Table A4.12 (continued)

Critical control points	Preventive measures	Target criteria	Verification
Storage system	*Shandy with fresh water* Mix water with very low concentrations of phosphorus with recycled water to decrease total phosphorus concentration.	Phosphorus concentrations decreased to acceptable levels	Phosphorus concentration below what is required for algae to bloom.
Storage system	*Light reduction* Restricting recycled water to exposure to light will minimise algal growth (eg a sealed tank compared with an open tank).	Algae numbers low enough to prevent environmental issues	Algal growth controlled.
Storage and distribution system	*Incident management* Runoff from overflowing dams or burst pipes could result in nutrient enrichment of water bodies. An incident management plan should include local contacts and processes for dealing with unplanned discharges to sensitive waterways.	Off-site impact from intentional or unintentional discharges minimised	Incident management plan documented and in place, developed in conjunction with local catchment management authority and should include local contacts in case of emergency.
Irrigation	*Site selection* Where very high-value surface waters are adjacent to planned recycled water development, a thorough assessment of the likely impacts is warranted.	No sensitive surface water bodies nearby to irrigation	Storage and distribution systems are located in areas where recycled water leakage will not enter high-value, phosphorus-sensitive waterways.
Storage and distribution systems	*Maintenance* Large storages and recycled water mains near sensitive waterways should be routinely checked and maintained to prevent pipe bursts and leakages from storage systems.	Maintenance schedule kept and program has maintained storage and distribution system, minimising bursts and leakages	Inspections and repairs carried out according to written schedule and documented. Record all leakages. Balance water entering and leaving the storage and reticulation systems.
Washing	*Treatment process* If using recycled water for washing (eg roads), assess where the drainage from road washing will be received in the environment. Will the phosphorus concentrations in recycled water cause eutrophication at this receiving point? If yes, remove more phosphorus from recycled water during reclamation so phosphorus concentrations do not affect receiving environments.	Appropriate phosphorus concentrations from street washing entering water bodies	Phosphorus entering ecosystems or water bodies through street cleaning is insignificant relative to the receiving water bodies or ecosystem, ie the baseline phosphorus concentrations in that water body are not significantly increased.

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

A4.6 Salinity

Salinity is the concentration of soluble salts in water that are measured as total dissolved salts (TDS) or electrical conductivity (EC). The principal salts in recycled water are sodium (Na), potassium (K), calcium (Ca), chloride (Cl), magnesium (Mg), sulphate (SO_4) and bicarbonate (HCO_3). These salts come from a range of sources, including drinking water (or source water entering the wastewater stream), detergents and water softeners, and kitchen and industrial wastes.

From an environmental perspective, sodium and chloride are the most important salts, because they are more likely to remain as ions in solution and contribute to the effects of salinity. The environmental risk from salinity is high, due to its effect on plants via soil salinity. As water evaporates from soils or is used by plants, salts are left behind. This increases the concentration of salts in the soil with time, until it influences the amount of water a plant can take up from the soil due to the osmotic effect it creates.

Many soils are naturally saline, particularly in semiarid areas where high evaporation rates and low rainfall concentrates salts near the soil surface. Some soils of marine origin also have high natural salinity. Irrigation, regardless of the water source, adds salts to the soil; therefore, salinity management remains an ongoing priority for all irrigation systems. When considering salinity, the salinity of both the irrigation water and soil must be considered.

A common measure of salinity is EC, with a preferred unit of deci-Siemens/metre (dS/m). However, a variety of other units are used across Australia (see Table A5.11 for conversion factors). EC is an indirect measurement of the TDS in the irrigation water or soil extract. The preferred unit for TDS is milligrams per litre (mg/L). Electrical conductivity of soil extracts can be based on a 1:5 soil:water extract (EC1:5) or a saturation paste extract (ECe). ECe is commonly used as an indicator of what plants experience, and plant tolerances are usually reported as ECe. However, because EC1:5 is much easier to obtain, conversion factors are often used to convert soil EC1:5 to ECe (see Figure A4.2). Conversion factors should be verified for specific soils, since they can vary significantly between soil types.

Plants vary considerably in their susceptibility to the osmotic and toxicity effects from salinity (see Tables A5.12–A5.16). As soils dry out, the salinity of the remaining soil water tends to increase, and so the effects become more severe. Plants affected by salinity have a reduced growth rate and show signs of water stress (eg wilting). Leaves may suffer burning along the margins due to the combined effects of salinity, chloride and sodium toxicity (discussed below). Perennial plants tend to be more sensitive than annuals, possibly because they accumulate salts over a much longer period of time than do short-lived annual plants.

Increases in salinity in freshwater environments may also cause problems for biota, especially plants and invertebrates, both of which can suffer from osmotic shock when their low-salinity environment rapidly becomes more saline. Another form of salinity, secondary salinity, occurs when salts move upward with regional watertables and rise by capillary action through the soil profile. The management or prevention of this type of salinity differs from that used for primary salinity, because it is a result of increases in ‘hydraulic load’; it is therefore discussed under that key hazard.

A4.6.1 Environmental risks

The environmental risks considered to be low for salinity when using recycled water are:

- unintentional discharges on to land due to the ‘one-off’ nature, or dilution of receiving waters
- quantities of water used in fire fighting that provide insufficient salt loads to be of concern
- low quantities of water used for dust suppression or road building, and salinity that is relevant only to the road itself (effects on the structure of the road itself should be considered separately).

The environmental risks considered to be moderate to very high for salinity when using recycled water are:

- soil salinity from irrigation
- cadmium released from soils due to increased chloride salts
- intentional and unintentional discharges into freshwater aquatic systems
- salt damp or rusting of infrastructure (eg buildings and fences)
- salinisation of groundwater that could affect ecosystems dependent upon this groundwater.

A4.6.2 Soil salinity

Salinisation of soils is one of the most difficult environmental consequences of irrigation with recycled water (or any water source) to manage. Soil salinity increases slowly and should be monitored annually to assess trends.

Various preventive measures can be used to reduce the residual risk of soil salinity to acceptable levels (see Table A4.13). However, in some cases, the residual risk for salinity management may not be decreased to acceptable levels with cost-effective preventive measures; in such situations, other reuse sites may need to be located.

Table A4.13 Soil salinity: control points, preventive measures, target criteria and verification

Control points	Preventive measures	Target criteria	Verification
Treatment plant	*Decrease concentration* Desalination of the recycled water may be required if the salinity is too high for the plant grown.	ECe and ECi that give 100% yield of crops and plants grown **Critical limit** 75% yield **Critical control point** Yes at point of desalination in the treatment plant	Salinity of the water meets target criteria and critical limits.
Plants	*Crops and plants grown* If irrigation water salinity is greater than an EC of 0.7 dS/m (or >450 mg/L TDS) some plants may suffer from salinity (Jones 1998). Most plants are sensitive to some level of salinity. Choose plant varieties tolerant to the level of salinity in the irrigation water (Tables A5.12–A5.16).	Salt tolerance of the plants grown are greater than the ECi and estimated ECe	Check plants do not show symptoms of salinity stress. This includes reduced growth rate and tendency to wilt in hot weather. Severe stress is indicated by yellowing (burning) of leaf tips and scorching of leaf margins, usually seen on older leaves first.

Table A4.13 (continued)

Control points	Preventive measures	Target criteria	Verification
Irrigation	*Irrigation tools* Do not apply more water (salt load) than necessary to meet the plant water requirements and estimated leaching requirements.	Watering rate meets crop demand and required leach fractions	Plant and crop water requirements calculated according to evaporative demand, local climate and plants grown (Allen et al 1998). Irrigation and watering records kept.
	Salinity should be managed by leaching. Leaching fraction to be calculated for specific conditions according to standard protocols (Anon 1997).	Watering rate meets crop demand and required leach fractions	Soil salinity remains below critical level for plants grown (see Figure A4.1, Tables A5.12–A5.16).
	Wet, salty soil adjacent to buildings may cause salt damp (salt deposition on buildings due to capillary rise/evaporation). High water content saline soils should not be created adjacent to infrastructure that may be subject to salt damp.	No excessive irrigation near buildings	Ensure reuse scheme management plan has considered effects of salinity on infrastructure. No salt damp on buildings in vicinity of reuse scheme.
Soils	*Site selection* Assess salinity of soils and key soil properties before irrigation to ensure that soil can be leached and/or increases in soils salinity will not be detrimental to crops or plants being irrigated.	Soil type is satisfactory for the soil type, water quality and plant grown	Soil salinity is less than the threshold for plants to be grown (Tables A5.12–A5.16)
Treatment process	*Decrease concentration* There is an increased risk of cadmium contaminating produce if irrigation water salinity is >1150 mg/L TDS. Soils must contain sufficient potential phytoavailable cadmium and have a soil pH <8.0 (in $CaCl_2$) or <7.3 (in H_2O). In these cases, reduction in recycled water salinity will decrease the risk of contamination of sensitive food crops.	ECi is below trigger-level values for increasing cadmium uptake	Recycled water salinity below trigger-level values (Table A5.6).
Plants	*Crops and plants grown* If irrigation water salinity is >1100 mg/L TDS (Table A5.6), select crops to grow that are at a lower risk of cadmium accumulations (Table A5.7).	1100 mg/L TDS depends on the crop grown	Cadmium concentrations in produce below critical values given in FSANZ (2003).

Table A4.13 (continued)

Control points	Preventive measures	Target criteria	Verification
Fertilisation	*Hazard source control* If recycled water salinity is >1100 mg/L TDS (Table A5.6), select phosphatic and other fertilisers with low cadmium; do not add more phosphorus fertiliser than necessary.	Fertilisers used are low in cadmium	Fertilisers used are low in cadmium. Cadmium concentration in topsoil not increased significantly from baseline values.
Soils	*Soil amendment* If mobilisation of cadmium already found in the soil is a concern from high salinity, as per the three preventive measures above, low pH can also increase the risk of cadmium uptake by plants. If soil pH <5.5 (H_2O) or <4.8 ($CaCl_2$), soil pH should be increased by the addition of lime to increase soil pH to 6.2–6.7 (H_2O) or 5.5–6.0 ($CaCl_2$).	Soil pH is 6.2–6.7 (H_2O) or 5.5–6.0 ($CaCl_2$)	Soil pH should be pH 6.2–6.7 (H_2O) or 5.5–6.0 ($CaCl_2$).
Washing	*Monitoring* Wet, salty soil adjacent to buildings may cause salt damp (salt deposition on buildings due to capillary rise/evaporation). High water content saline soils should not be created adjacent to significant buildings subject to salt damp. Check for splash on to sensitive materials, wash off with drinking water (low salinity) where necessary, check heritage value of buildings.	Infrastructure near washing areas is protected from spray, splash and drainage water	No runoff or splashing from washing damages salt-sensitive infrastructure adjacent to washdown areas.
Storage and reticulation systems	*Maintenance* Intentional or unintentional discharge of recycled water to sensitive fresh waters may affect plants and invertebrates sensitive to rapid changes in salinity levels. Large storages and recycled water mains near sensitive waterways should be routinely checked and maintained to prevent pipe bursts and leakages from storage systems.	Maintenance schedule kept and program has maintained storage and distribution system minimising bursts and leakages	Check health of aquatic organisms if water salinity is >1000 mg/L TDS (>1.56 dS/m EC).

EC = electrical conductivity; ECe = electrical conductivity of a soil paste extract; ECi = electrical conductivity of irrigation water; TDS = total dissolved salts

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

A4.6.3 Groundwater salinity

Fresh groundwater can become salinised due to excessive leaching during irrigation, or use of aquifers for storage and recovery of recycled water. This can degrade the quality of the water for other environmental uses or adversely affect groundwater dependent ecosystems.

Various preventive measures can be used to reduce the residual risk of groundwater salinity to acceptable levels (see Table A4.14). However, the residual risk for salinity management may remain above low, and it may be an ongoing hazard requiring continued monitoring, as with all irrigation systems, regardless of the water source. It may also indicate that the environmental risk of the site being assessed is not acceptable, in which case other reuse sites should be assessed.

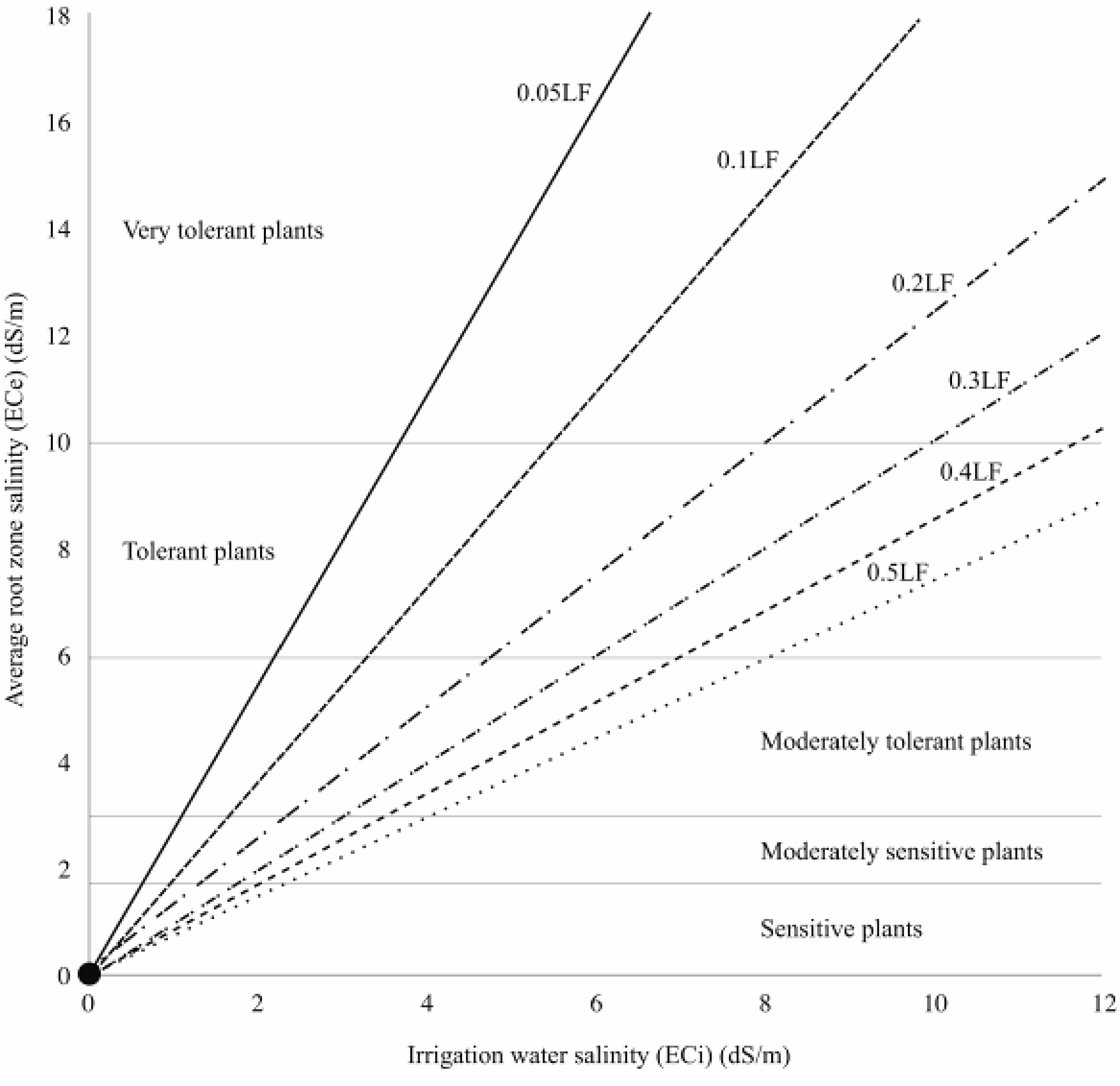
Table A4.14 Groundwater salinity: control points, preventive measures, target criteria and verification

Control points	Preventive measures	Target criteria	Verification
Irrigation	*Irrigation tools* Leach only what is required to manage soil salinity. If possible, rely on rainfall for leaching. Allen et al (1998) gives details on how to accurately calculate water requirements.	Irrigation and rainfall apply sufficient water to meet leaching requirements	Irrigation scheduling plan includes consideration of hydraulic properties of local soils, evapotranspiration and precipitation. Salinity of groundwater is not increasing to concentrations that will affect other environmental uses, such as groundwater dependent ecosystems.
Soils	*Site selection* Chose site where groundwater and aquifers are already saline, or where leaching from irrigation will not impact on relevant groundwater systems.	Changes in groundwater salinity cause no impact on the environment	Aquifers under area where recycled water will be used are already saline or not used (now or in the future) for purposes where increases in salinity will impact on these uses.
Storage systems	*Buffer distances and strips* If using aquifer storage and recovery (ASR), ensure changes to groundwater salinity will be minimised by incorporating buffer distances between injection area in aquifer and groundwater dependent ecosystems.	Changes in groundwater salinity cause no impact on the environment	Groundwater dependent ecosystems are healthy and not affected by salinity.
Storage systems	*Shandying with fresh water* If the salinity of recycled water is too high relative to the salinity of the water in the storage aquifer, dilute the recycled water with a freshwater source before injecting it into the aquifer.	Recycled water salinity meets aquifer quality standards	Increases in groundwater salinity are not detectable near sensitive groundwater dependent ecosystems.
Storage systems	*Site selection* When selecting an aquifer for storage and recovery, choose a site where groundwater and aquifers are already saline.	Changes in groundwater salinity have no impact on the environment	Aquifer for storage and recovery saline and not used for other purposes.
Storage systems	*Design* Unintentional discharge can occur from storage facilities (eg tanks and dams) that can leak into groundwater. Design storages to prevent leakages.	Leakages from storages minimised	Storage system design includes thorough assessment of soil profile properties and base is sealed.

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

The soil salinity risk to plants is a combination of the soil salinity itself, the irrigation water salinity, the amount of salt leached with each irrigation, and the salinity tolerance of the plants being grown. Therefore, Rhoades et al (1992) developed a scheme for predicting the salinity risk to crops by integrating these three factors into a single diagram (see Figure A4.1). This scheme may be useful in selecting suitable plants for a given irrigation scheme, or in matching water quality and irrigation management (leaching requirement) to the plants to be irrigated.

Figure A4.1 Relationship between average root zone salinity (ECe) and electrical conductivity of irrigation water (ECi), as a function of leaching fraction (LF) and plant salt tolerance (source: adapted from Rhoades et al 1992)



A4.7 Chloride and sodium (toxicity)

Chloride and sodium are the principal elements contributing to salinity (see Section A4.6). In addition to their role in salinity, chloride and sodium may be toxic to plants at high concentrations. However, for both elements, the toxicity generally occurs at concentrations higher than those that cause salinity and associated osmotic effects; consequently, the toxicity effects are usually secondary to the osmotic effects from salinity. Chloride and sodium in recycled waters come from a variety of sources or products, including detergents. These salts are readily soluble.

Other environmental sources of chloride include soil reserves, fertilisers, rain, chemicals and air pollution.

Crops grown in soil environments high in chloride or sodium can suffer from toxicity and associated nutrient imbalances. Chloride and sodium can also be toxic to some sensitive plant species if applied direct to foliage (see Table A5.17). Chloride and sodium toxicity is more widespread in arid and semiarid environments, partly due to greater evaporative concentration. Many soils, particularly those with a finer texture (clay soil), have naturally elevated chloride and sodium levels that may exacerbate toxicities from direct leaf exposure or from recycled water irrigation. These soils typically have a clay content greater than 25%. Sandier soils (<25% clay) have a much lower risk of primary salinity and chloride or sodium toxicity.

Chloride and sodium ions are considered together here, because the effects are generally similar, and in the case of plant toxicity, it is very difficult to determine which ion is the causative agent. This difficulty is increased by the fact that when one ion is in high concentration, the other ion usually accompanies it, because their sources are similar. Chloride also plays a critical role in increasing the phytoavailability of the heavy metal cadmium, and this risk is considered in detail under the salinity section above.

Chloride and sodium may enter the plant through the root, or directly through the leaf from rainfall or overhead irrigation. The limited data available suggest that woody plants (trees and vines) are generally the most susceptible to chloride and sodium toxicities (see Tables A5.18 and A5.19). Sodium is usually more toxic to plants and other biota than chloride, but direct plant toxicity due to high soil sodium concentrations is partially regulated by plants that have more control over sodium than chloride uptake at the root surface. However, these exclusion mechanisms are not effective if salt is applied directly to foliage through sprinkler irrigation. Symptoms of both chloride and sodium toxicity are leaf burn, scorch and dead tissue along the margins of leaves. The symptoms occur first in the oldest leaves. As the severity increases, the symptoms move inwards between the leaf veins, toward the centre of the leaf. Plants vary in their tolerance to chloride in the environment. For citrus, which are probably the most sensitive group, the major pathway to alleviate chloride toxicity is through the use of rootstocks that are able to reduce the uptake of chloride. Table A5.17 shows the relative tolerance of some fruit crops to chloride and sodium in sprinkling water, and Table A5.18 shows the relative tolerance of a range of fruit crops to chloride in soils. Foliar toxicity is easily seen in sensitive species if water containing high chloride or sodium concentrations is applied directly to foliage. Concentrations in soils of both chloride and sodium are greater than concentrations in recycled waters, due to evaporative concentration in the soil from repeated applications.

In addition to being toxic, high concentrations of either chloride or sodium in the soil can interfere with acquisition of other nutrients (ions) by plants. Chloride may interfere with the uptake of other anions such as nitrate, phosphate and sulphate, and sodium may intefere with the uptake of potassium and calcium ions. Such problems are usually only manifest when the availability of these other ions is suboptimal. However, because of this, plant tolerance to sodium is sometimes ranked in terms of relative sodium availability (eg SAR, see Table A5.21) compared with other cations. The ratio of sodium to other cations is more critical to soil structure than to plant nutrition (Sumner et al 1998). Interestingly, deciduous fruit crops appear to be the most sensitive to high amounts of sodium, relative to other cations. The best management option is to maintain good plant nutrition at all times and to avoid foliar applications for sensitive species (Unkovich et al 2005). Some plants that live in saline environments have a higher sodium requirement.

Data on the toxicity of chloride and sodium to aquatic biota are limited. In one Canadian province, a guideline of 150 mg/L chloride is used for chronic exposure and 600 mg/L for acute exposure, for freshwater aquatic organisms (Nagpal et al 2005). This same guideline suggests that any marine system should be maintained within 10% of existing or natural levels. Chloride toxicity to aquatic organisms has not received attention in Australia. There is no indication of possible sodium toxicity in freshwater environments, and for both chloride and sodium, their role in salinity is probably more important than possible ion toxicity.

A4.7.1 Environmental risks

The environmental risk considered to be low for chloride and sodium toxicity when using recycled water is:

- chloride in marine environments.

The environmental risks considered to be moderate to very high for chloride and sodium toxicity when using recycled water are:

- sodium and chloride toxicity to plant from irrigation and cross-connections
- chloride toxicity to aquatic biota from irrigation and intentional or unintentional discharge.

Various preventive measures can be used to reduce the residual risk of chloride and sodium toxicity to acceptable levels (see Table A4.15).

Table A4.15 Chloride and sodium toxicity: control points, preventive measures, target criteria and verification

Control points	Preventive measures	Target criteria	Verification
Irrigation	*Irrigation tools* Chloride concentrations in water of >175 mg/L or sodium of >115 mg/L may be directly toxic to the foliage of some plants. Do not sprinkle high chloride or sodium water directly on to leaves (Table A5.17).	Plants not irrigated with overhead sprinkler systems	No signs of chloride or sodium toxicity on leaves of plants irrigated with recycled water. Symptoms are scorching and bleaching of leaves. Symptoms may be confused with salinity.
Irrigation	*Plants grown* Grow plant species tolerant to direct application of chloride and sodium in irrigation water and in soils.	Plant sensitivity to chloride is below recycled water chloride concentrations (Table A5.17)	No signs of chloride or sodium toxicity on leaves of plant irrigated with recycled water. Symptoms are scorching and bleaching of leaves. Symptoms may be confused with salinity.
Irrigation	*Irrigation tools* Do not apply more water (chloride and sodium load) than necessary to meet the plant water requirements and estimated leaching requirements. Chloride and sodium concentrations in soils can build up to phytotoxic concentrations.	Irrigation and rainfall apply sufficient water to meet leaching requirements but not overirrigate	Plant/crop water requirement calculated according to evaporative demand, local climate and plants grown (see Allen et al 1998). Irrigation records kept.
Soils	*Site selection* Select soils with sufficient drainage to manage chloride and sodium build-up in soils and maintain favourable conditions for the plants grown.	Soil drainage capacity meets requirements (Table A5.20)	Soil structure permits drainage and leaching of salts, Ksat >5 mm/hour.

Table A4.15 (continued)

Control points	Preventive measures	Target criteria	Verification
Soils	*Buffer distances and strips* If recycled water use is near chloride-sensitive aquatic systems, ensure irrigation areas have buffer distances between them and these systems.	Appropriate buffers in place (Appendix 6)	Check that appropriate buffer systems are in place to minimise direct overflow into waterways.
Distribution system	*Training and education* Quality assurance systems for designers and plumbers must be in place to prevent cross-connection of high chloride and sodium recycled water with drinking water systems.	Plumbers training in recycled water system or plumbing audited before commissioning	All plumbing carried out by plumbers trained in recycled water reticulation issues. No signs of chloride and sodium toxicity on leaves (ie scorching and bleaching of leaves).
Storage and distribution system	*Buffer distances and strips* Main lines and storage to be kept away from sensitive water bodies.	Buffer distance appropriate distance from sensitive water bodies	Buffer distances from sensitive water bodies checked and recorded.
Storage and distribution system	*Maintenance* Have a system in place to regularly check storage and distribution system.	Appropriate maintenance program in place	Maintenance checks for leaks recorded regularly near sensitive water bodies.

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

A4.8 Soil sodicity (sodium)

Sodicity is a complex interaction between physical and chemical properties of soil that can be difficult to manage. It is caused by an excess of sodium ions (Na^{+}) in the soil compared with the abundance of the divalent cations calcium (Ca^{2+}) and magnesium (Mg^{2+}). This results in a relatively higher portion of the clay exchange sites in the soil being occupied by sodium ions. If other soluble salts are leached from such soils, the clay particles repel each other when the soil is wet. This disperses the soil particles, causing the soil to swell and preventing the movement of water and air through the soil. Sodic surface soils can be identified by the turbidity (cloudiness) they create in water. The problem occurs naturally in many soils in Australia, often in subsoil layers where it is not always apparent.

Sodicity can also be induced by applying irrigation water with a high ratio of sodium to calcium and magnesium, and low salinity, or by precipitating calcium with bicarbonate (HCO_3^{-}) to form calcium carbonate ($CaCO_3$). The latter is uncommon, but could occur if waters very high in bicarbonate were used for irrigation. If carbonates are present in high concentrations, the residual sodium carbonate (RSC) of recycled water can be calculated, to assess the risk of sodium accumulating on soil-exchange sites. The RSC is much easier to calculate than an adjusted SAR (Carrow and Duncan 1998), which can overestimate the SAR risk (ANZECC and ARMCANZ 2000a). The ultimate verification of the effect of sodium in recycled water on the soil is measuring the exchangeable sodium percentage (ESP) or SAR of the soil, where the impacts of any carbonates will be reflected in the soil sodicity measurement.

The risk (and occurrence) of soil sodicity in sandy soils is much lower than for clay soils. Sandy soils usually have only small amounts of clay and readily leach sodium ions, due to greater hydraulic conductivity and a low capacity to hold on to ions in the soil (low cation exchange capacity). Conversely, clay soils tend to hold on to sodium ions on clay particles and do not readily leach excess ions if permeability is low. Consequently, clay soils are much more likely to display sodic properties.

Plants have difficulty extending their roots through sodic soils, and may also suffer from waterlogging and anoxia. Sodic soils are prone to run-off of irrigation and rain waters due to surface sealing and low hydraulic conductivities (permeability). Such run-off is invariably turbid because of the high load of dispersed clay particles. Some publications list the relative SAR tolerance of plants (see Table A5.21), but these are more likely to reflect sodium toxicity than tolerance to soil sodicity per se.

For soils, sodicity is normally expressed as the ESP occupying the soil cation exchange capacity, or the SAR, the ratio of sodium to calcium and magnesium in the soil solution. The latter is also used to assess the sodicity of irrigation waters.

The SAR of a soil extract or water can be calculated by using either of the following equations (ANZECC and ARMCANZ 2000a):

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

Where concentrations of cations are expressed in meq/L.

To convert from mg/L to meq/L

Na^{+} (mg/L)/23 = meq/L
Ca^{2+} (mg/L)/20 = meq/L
Mg^{2+} (mg/L)/12.2 = meq/L

or

$$SAR = \frac{\frac{Na^{+}}{23}}{\sqrt{\frac{\frac{Ca^{2+}}{20} + \frac{Mg^{2+}}{12.2}}{2}}}$$

Where concentrations of cations are expressed in mg/L.

The RSC of recycled water can be calculated by the equation:

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$$

Where concentrations of cations and anions are expressed in meq/L.

To convert from mg/L to meq/L:

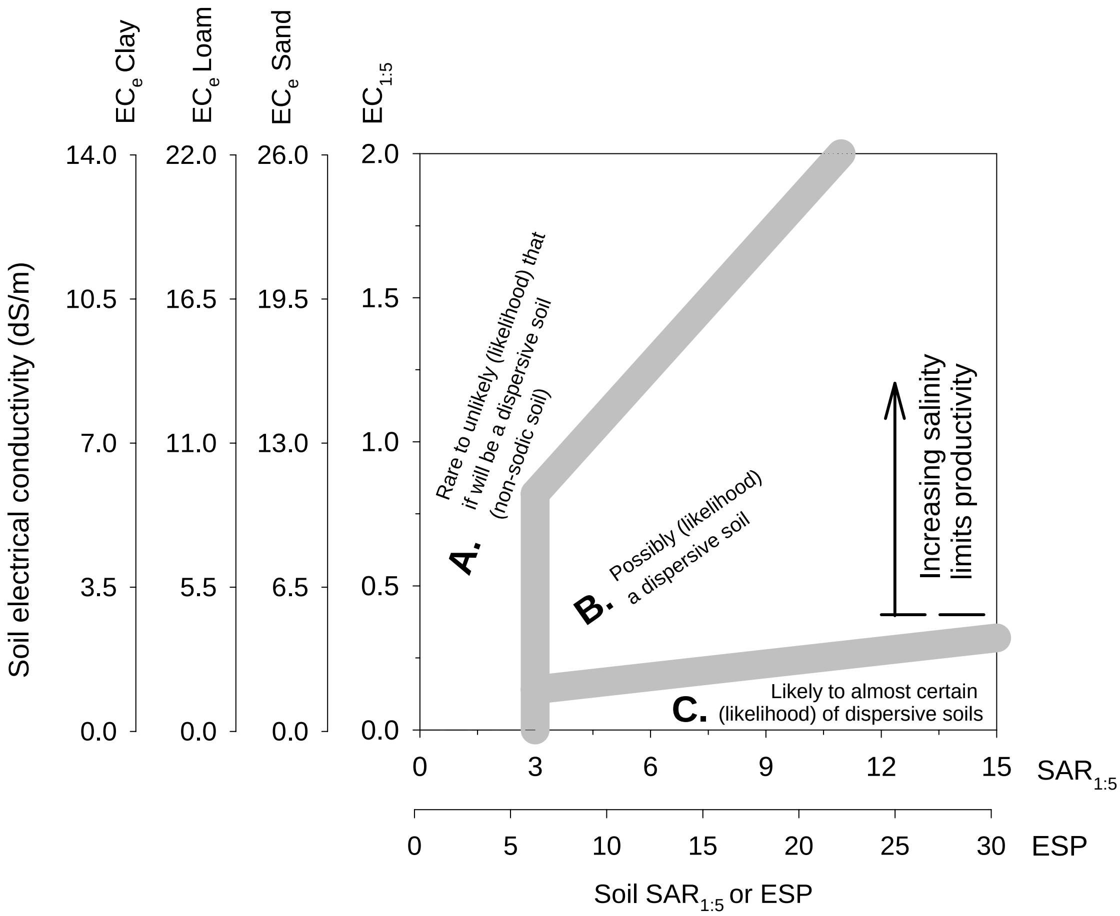
Ca^{2+} (mg/L)/20 = meq/L
Mg^{2+} (mg/L)/12.2 = meq/L
CO_3^{2-} (mg/L)/30 = meq/L
HCO_3^{-} (mg/L)/61 = meq/L

If the RSC is less than zero, the likelihood of sodium accumulation on soil cation exchange sites is low. If RSC is 0–1.25 meq/L, the likelihood is moderate; if RSC is 1.25–2.5 meq/L, the likelihood is high; and if RSC is greater then 2.5 meq/L, the likelihood is very high (Carrow and Duncan 1998).

Since SAR is easier to measure in soils than ESP, many researchers have developed relationships between SAR and ESP (Sumner et al 1998, Stevens et al 2003), but these tend to be specific to the soils in which they were derived. In Australia, soils with an ESP ≥6 may be sodic (Rengasamy 2002). Such soils tend to have a relatively high pH (approximately 7–10), as sodium carbonate is much more soluble than calcium or magnesium carbonates; thus, higher concentrations of carbonate and bicarbonate are maintained in sodic soil solutions (Rengasamy and Olsson 1991, Brady and Weil 2002). However, although uncommon in Australia, some acidic (approximately pH 5) sodic soils can be found (Rengasamy and Olsson 1991).

If the soil solution (or irrigation water) contains a high level of total salts, their electro-osmotic effects tend to counteract the repulsive forces that result from hydration of sodium on the exchange complex (Rengasamy and Olsson 1993), and therefore soils with a high ESP can still maintain permeability if they have high salinity (see Figure A4.2). If these salts are leached out by fresh water, this effect is lost and soil structure breakdown (dispersion) may occur. Salinity needs to be assessed along with sodicity to predict whether problems will develop. This interaction between sodicity and soil solution salt concentration means that while irrigation with higher salinity water continues, there is unlikely to be deterioration in soil structure because the salinity of the water should counteract the high soil SAR or ESP. However, if fresh water is used, the soils would disperse and sodic effects would appear. One complexity of this scenario is that rainfall can dilute surface soil salinity and cause sodic soilt to disperse or form a crust, making it difficult for seedlings to grow through the soil surface. As the rainfall leaches through the soil, it mixes with soil salinity to decrease this effect.

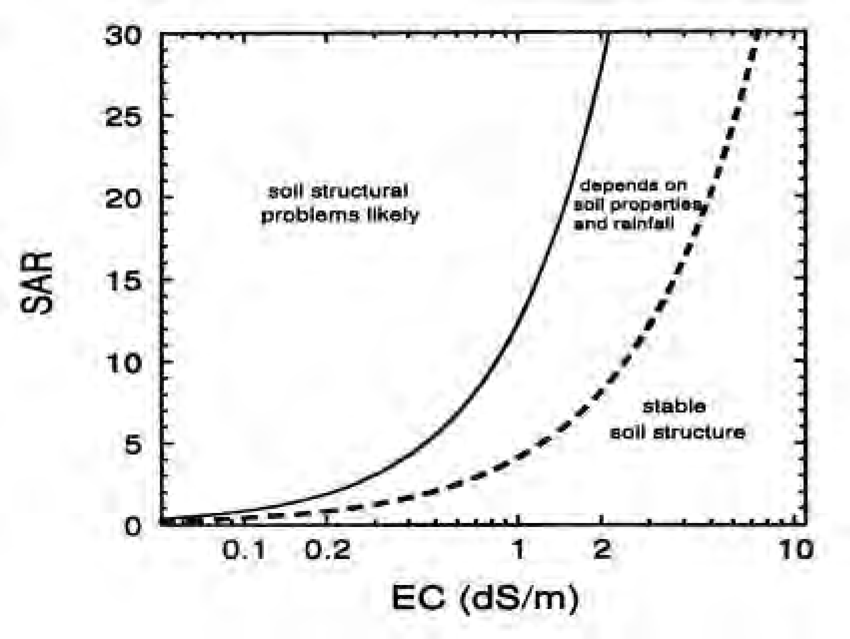
Figure A4.2 Relationship between sodium adsorption ratio (SAR) and electrical conductivity (EC) of soils and likelihood of soil structure breakdown



Note: This figure can also be used as a guide to sodicity risk from irrigation with recycled water, assuming an irrigation leaching fraction of 0.25 and an EC of the irrigation water equivalent to the ECe of the surface soil (not $EC_{1:5}$).
Source: adapted from Rengasamy et al (1984), Cass et al (1995), Peverill et al (1999), Stevens et al (2003)

The SAR of recycled water in Australia is in the range 2.6–20, averaging 6, with salinity averaging 1.2 dS/m. Applying these data to Figure A4.3 shows that irrigating with recycled water has associated sodium problems, which need to be managed.

Figure A4.3 Relationship between sodium adsorption ratio (SAR) and electrical conductivity (EC) of irrigation water and likelihood of soil structure breakdown (source: ANZECC and ARMCANZ 2000a)



Remediation of sodic soils requires the displacement of sodium (Na^+) in the soil with a divalent cation, usually calcium (Ca^{2+}). This may be provided through amendments such as gypsum ($CaSO_4$) or calcium carbonate ($CaCO_3$) or, where the soil contains calcium carbonate, through the addition of acids or acid forming compounds (aluminium or ferrous sulfates), which release calcium from the soil as calcium sulfate (Rhoades 1982). Phosphogypsum is particularly efficacious since it provides calcium both directly and through the acid dissolution reactions. The amount of amendment added is very difficult to predict (Rengasamy and Churchman 1999), although Rhoades (1982) suggested that the use of approximately 75% of the excess sodium in the upper part of the root zone (0–30 cm), ideally mixed in the soil would be a useful starting point. Certainly, for the amendment to be effective at any depth, it needs to be leached through the soil. Compared with fresh water, the higher EC of recycled water would help to reduce dispersion, thus facilitating better downward water movement, displacement of sodium with calcium, and leaching of the sodium.

A4.8.1 Environmental risks

The environmental risks considered to be low for sodicity when using recycled water are:

- intentional discharges (testing fire control systems) and unintentional discharges (pipe burst), because sodicity is more a chronic than an acute problem, and these are generally short term in nature
- municipal use for dust suppression on roads or road building (note that these guidelines do not assess the affects of recycled water use on the structural integrity of roads and their foundation).

The environmental risks considered to be moderate to very high for sodicity when using recycled water are:

- irrigation with recycled water
- cross-connections associated with recycled water (leads to shandying of water and associated impacts outlined in the distribution system; see Table A4.16).

A range of critical control points and preventive measures can be used to reduce the residual risk of sodicity to acceptable levels (see Table A4.16).

Table A4.16 Sodicity: control points, preventive measures, target criteria and verification

Control points	Preventive measures	Target criteria	Verification
Soils	*Site selection* Choose sandy soils that are free draining. The lower the clay content, the less chance of sodic effects. Check interaction between salinity and sodicity (Figures A4.2 and A4.3) to determine if the salinity and sodicity of recycled water is appropriate for a specific soil type.	SAR of recycled water is appropriate for soil type to be irrigated (Table A5.22, Figures A4.2 and A4.3)	Soils do not crust, disperse or set hard after irrigation with recycled water. Water infiltration rates are acceptable for specific uses identified.
Soils	*Soil ameliorant* If it is possible to likely that the soil will be sodic, (B) in Figure A4.2, add appropriate calcium amendments for your soils (eg gypsum). Other practices that may be beneficial include reducing or eliminating tillage where surface soils are sodic. (Note: may be sodic in subsoil.) Using irrigation water of a sufficiently high ECi to counter the dispersive effects of excess sodium is sometimes promoted as beneficial, but carries the significant environmental cost of increasing salinity. See Ayers and Westcot (1985) for full discussion of above.	Appropriate levels of a calcium amendment are added	Verify soil does not disperse and the soil ESP or soil extract SAR are within appropriate limits (Table A5.22, Figures A4.2 and A4.3). Soil permeability has not decreased from baseline values.
Distribution systems	*Shandying with fresh water* If other water sources that are high in calcium and magnesium, but lower in sodium, are available, it may be possible to shandy the two water sources and decrease the overall SAR.	SAR of water is acceptable for specified site and uses	Verify soil does not disperse and the soil ESP or soil extract SAR are within appropriate limits (Table A5.22, Figures A4.2 and A4.3).
Distribution systems	*Shandying with saline water* Very low salinity water can increase the detrimental effects of sodicity (ie if water is desalinated using reverse osmosis). If water is too low in salinity, increasing salinity may overcome sodicity. However, this needs to be done with caution, because salinity may become an issue.	SAR of water is acceptable for specified site and uses	Verify soil does not disperse and the soil ESP or soil extract SAR are within appropriate limits (Table A5.22, Figures A4.2 and A4.3).

Table A4.16 (continued)

Control points	Preventive measures	Target criteria	Verification
Treatment process	*Decrease concentrations* Selectively remove sodium from recycled water.	SAR of water is acceptable for specified site and uses	Verify soil does not disperse and the soil ESP or soil extract SAR are within appropriate limits (Table A5.22, Figures A4.2 and A4.3).
Source water	*Source control* Sewage treatment plant — restrict high sodium loads from entering sewerage system (eg saline seepage into leaky sewers). Greywater — use detergents low in sodium, or when using high sodium products, divert greywater to the sewerage system.	SAR of water is acceptable for specified site and uses	Verify soil does not disperse and the soil ESP or soil extract SAR are within appropriate limits (Table A5.22, Figures A4.2 and A4.3).

ECi = electrical conductivity of irrigation water; ESP = exchangeable sodium percentage; SAR = sodium adsorption rate
Note: All control points, preventive measures, target criteria, critical limits, critical control points and their verification are site and scheme specific. The examples given here should be validated and verified for specific schemes.

A4.9 Detailed risk assessment for different uses of water recycled from treated sewage

Tables A4.17–A4.20, below, are a guide to some of the hazards and risks commonly associated with various uses of recycled water. They give examples of preventive measures required for key hazards and the exposure pathways, environmental endpoints, effects on the environment, control points, preventive measures, maximum risk and residual risk. The lists are not definitive, and should not be treated as such. All environmental risk assessments should begin with an initial screening risk assessment (see Section 4.2.2) followed by a maximum risk assessment and then a residual risk assessment.

Tables A4.17–A4.20 show only the risks determined to be moderate to very high for various uses of recycled water. Low-risk pathways have been excluded for demonstration purposes, and to highlight the risks that will generally require preventive measures. Specific environmental endpoints have not been identified in these tables because of the generic nature of the risk assessment. If the full risk assessment table were shown (ie including risks determined to be low), there would be many cases where the pathways identified lead to no effect on the environment. Every risk assessment needs to take into account:

- the site-specific nature of the source water and treatment methods
- the final quality of the recycled water
- the most sensitive specific environmental endpoints.

Table A4.17 Environmental risk assessment for agricultural, municipal and residential use of water recycled from treated sewage

Hazard, exposure pathway, endpoint and effect				Maximum risk — no preventive measure (ie uncontrolled)			Control points (CP) and preventive measures		Residual risk — with preventive measures		
Use or exposure entry	Receiving environment or receptor	Environ-mental endpoint	Effect	Likelihood	Impact	Level of risk[a]	Critical CP or CP in environmental pathway	Preventive measure/s	Likelihood	Impact	Level of risk
Boron											
Irrigation	Soils	Plants	Toxicity	Possible	Moderate	High	Plants	Crops and plants grown	Unlikely	Minor	Low
				Possible	Moderate	High	Soils	Site selection	Unlikely	Minor	Low
				Possible	Moderate	High	Treatment process	Decrease concentration	Rare	Minor	Low
				Possible	Moderate	High	Distribution system	Shandying with fresh water	Unlikely	Minor	Low
				Possible	Moderate	High	Irrigation	Irrigation tools	Unlikely	Minor	Low
Chlorine residuals											
Irrigation	Plants	Plants	Toxicity	Possible	Moderate	High	Treatment process	Design	Unlikely	Minor	Low
				Possible	Moderate	High	Plants	Crops and plants grown	Unlikely	Minor	Low
Storage system	Water bodies	Biota — aquatic	Toxicity	Possible	Minor	Moderate	Treatment process	Design	Unlikely	Minor	Low
Discharge (unintentional and intentional)	Water bodies	Biota — aquatic	Toxicity	Possible	Moderate	High	Distribution system	Pipeline infrastructure	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Buffer distances and strips	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Incident management	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Interception/drainage	Unlikely	Minor	Low
Hydraulic loading											
Irrigation	Soils	Plants	Waterlogging	Possible	Minor	Moderate	Irrigation	Irrigation tools	Rare	Minor	Low
				Possible	Minor	Moderate	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Possible	Minor	Moderate	Soils	Site selection	Rare	Minor	Low
				Possible	Minor	Moderate	Soils	Site selection	Unlikely	Minor	Low
	Soils	Soils	Waterlogging	Possible	Minor	Moderate	Soils	Drainage	Rare	Minor	Low
				Possible	Minor	Moderate	Groundwater	Monitoring	Unlikely	Minor	Low
	Soils	Water — ground	Waterlogging	Possible	Moderate	High	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Possible	Moderate	High	Irrigation	Monitoring	Unlikely	Minor	Low
				Possible	Moderate	High	Soils	Site selection	Unlikely	Minor	Low
				Possible	Moderate	High	Soils	Drainage	Unlikely	Minor	Low
			Salinity	Possible	Minor	Moderate	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Possible	Minor	Moderate	Groundwater	Monitoring	Unlikely	Minor	Low
				Possible	Minor	Moderate	Plants	Monitoring	Unlikely	Minor	Low
				Possible	Minor	Moderate	Plants	Crops and plants grown	Unlikely	Minor	Low
Discharge (unintentional and intentional)	Water bodies	Water — ground	Waterlogging	Possible	Moderate	High	Storage system	Storage design	Unlikely	Minor	Low
				Possible	Moderate	High	Groundwater	Monitoring	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Monitoring	Unlikely	Minor	Low
			Salinity	Possible	Moderate	High	Storage system	Storage design	Unlikely	Minor	Low
				Possible	Moderate	High	Groundwater	Monitoring	Unlikely	Minor	Low
Nitrogen											
Irrigation	Soils	Plants	Nutrient Imbalance	Possible	Minor	Moderate	Irrigation and fertilisation	Nutrient balancing	Unlikely	Minor	Low
			Pest and disease	Possible	Minor	Moderate	Irrigation and fertilisation	Nutrient balancing	Unlikely	Minor	Low
				Possible	Minor	Moderate	Irrigation	Irrigation tools	Unlikely	Minor	Low
			Eutrophication	Possible	Minor	Moderate	Soils	Buffer distances and strips	Unlikely	Minor	Low
				Possible	Minor	Moderate	Soils	Management plan	Unlikely	Minor	Low
		Water — ground	Contamination	Possible	Moderate	High	Irrigation and fertilisation	Nutrient balancing	Rare	Moderate	Low
				Possible	Moderate	High	Irrigation	Irrigation tools	Rare	Moderate	Low
				Possible	Moderate	High	Soils	Site selection	Rare	Moderate	Low
				Possible	Moderate	High	Groundwater	Monitoring	Possible	Moderate	High
				Possible	Moderate	High	Plants	Crops and plants grown	Unlikely	Minor	Low
				Possible	Moderate	High	Fertilisation	Soil ameliorant	Unlikely	Minor	Low
		Water — surface	Eutrophication	Unlikely	Moderate	Moderate	Irrigation and fertilisation	Nutrient balancing	Rare	Moderate	Low
				Unlikely	Moderate	Moderate	Soils	Management plan	Unlikely	Moderate	Moderate
Table A4.17 (continued)				Unlikely	Moderate	Moderate	Soils	Buffer distances and strips	Unlikely	Moderate	Moderate
				Unlikely	Moderate	Moderate	Surface water	Monitoring	Rare	Moderate	Low
Storage system	Water bodies	Biota — aquatic	Eutrophication	Possible	Moderate	High	Storage system	Crops and plants grown	Unlikely	Minor	Low
				Possible	Moderate	High	Storage system	Shandying with fresh water	Unlikely	Minor	Low
				Possible	Moderate	High	Storage system	Irrigation tools	Unlikely	Minor	Low
				Possible	Moderate	High	Storage system	Irrigation tools			–
				Possible	Moderate	High	Storage system	Light reduction			–
Discharge (unintention	Soils	Plants	Eutrophication	Possible	Minor	Moderate	Storage and distribution system	Buffer distances and strips	Unlikely	Minor	Low

Hazard, exposure pathway, endpoint and effect				Maximum risk — no preventive measure (ie uncontrolled)			Control points (CP) and preventive measures		Residual risk — with preventive measures		
Use or exposure entry	Receiving environment or receptor	Environ-mental endpoint	Effect	Likelihood	Impact	Level of risk[a]	Critical CP or CP in environmental pathway	Preventive measure/s	Likelihood	Impact	Level of risk
al and intentional)				Possible	Minor	Moderate	Storage and distribution system	Training and education	Unlikely	Minor	Low
				Possible	Minor	Moderate	Storage and distribution system	Incident management	Unlikely	Minor	Low
				Possible	Minor	Moderate	Storage and distribution system	Site selection	Unlikely	Minor	Low
				Possible	Minor	Moderate	Storage and distribution system	Interception/drainage	Unlikely	Minor	Low
Discharge (unintentional and intentional)	Water bodies	Water — surface	Eutrophication	Unlikely	Moderate	Moderate	Storage and distribution system	Management plan	Unlikely	Minor	Low
				Unlikely	Moderate	Moderate	Storage and distribution system	Buffer distances and strips	Unlikely	Minor	Low
				Unlikely	Moderate	Moderate	Storage and distribution system	Incident management	Unlikely	Minor	Low
Washing	Water bodies	Water — surface	Eutrophication	Possible	Minor	Moderate	Distribution system	Shandying with fresh water	Unlikely	Minor	Low
				Possible	Minor	Moderate	Treatment process	Decrease concentration	Unlikely	Minor	Low
Phosphorus											
Irrigation	Soils	Plants	Eutrophication	Possible	Moderate	High	Irrigation	Buffer distances and strips	Unlikely	Minor	Low
				Possible	Moderate	High	Irrigation	Management plan	Unlikely	Minor	Low
			Nutrient imbalance	Possible	Minor	Moderate	Irrigation and fertilisation	Soil ameliorant	Unlikely	Minor	Low
			Toxicity	Possible	Moderate	High	Plants	Crops and plants grown	Unlikely	Minor	Low
				Possible	Moderate	High	Irrigation and fertilisation	Nutrient balancing	Unlikely	Minor	Low
	Soils	Water — surface	Eutrophication	Possible	Moderate	High	Irrigation	Management plan	Unlikely	Moderate	Moderate
				Possible	Moderate	High	Soils	Buffer distances and strips	Unlikely	Moderate	Moderate
				Possible	Moderate	High	Surface water	Monitoring	Unlikely	Moderate	Moderate
Storage system	Water bodies	Biota — aquatic	Eutrophication	Possible	Moderate	High	Storage system	Crops and plants grown	Unlikely	Minor	Low
				Possible	Moderate	High	Storage system	Shandying with fresh water	Unlikely	Minor	Low
				Possible	Moderate	High	Storage system	Irrigation tools	Unlikely	Minor	Low
				Possible	Moderate	High	Storage system	Irrigation tools	Unlikely	Minor	Low
				Possible	Moderate	High	Storage system	Light reduction	Unlikely	Minor	Low
Discharge (unintentional and intentional)	Soils	Plants	Toxicity	Possible	Moderate	High	Storage and distribution system	Buffer distances and strips	Rare	Moderate	Low
				Possible	Moderate	High	Storage and distribution system	Incident management	Rare	Moderate	Low
				Possible	Moderate	High	Storage and distribution system	Site selection	Rare	Moderate	Low
	Water bodies	Water — surface	Eutrophication	Possible	Moderate	High	Storage and distribution system	Buffer distances and strips	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Management plan	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Incident management	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Site selection	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Maintenance	Unlikely	Minor	Low
Washing	Water bodies	Water — surface	Eutrophication	Possible	Minor	Moderate	Distribution system	Shandying with fresh water	Unlikely	Minor	Low
				Possible	Minor	Moderate	Treatment process	Decrease concentration	Unlikely	Minor	Low
Salinity (measured as electrical conductivity (EC) or total dissolved salts (TDS))											
Irrigation	Infrastructure	Infrastructure	Salinity	Possible	Minor	Moderate	Soils	Site selection	Unlikely	Minor	Low
	Soils	Plants	Salinity	Likely	Minor	Moderate	Plants	Crops and plants grown	Possible	Moderate	High
				Likely	Minor	Moderate	Irrigation	Irrigation tools	Possible	Moderate	High
				Likely	Minor	Moderate	Soils	Site selection	Unlikely	Minor	Low
				Likely	Minor	Moderate	Influent to sewage treatment plant	Hazard source control	Unlikely	Minor	Low
			Contamination	Possible	Moderate	High	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Possible	Moderate	High	Treatment process	Decrease concentration	Unlikely	Minor	Low
				Possible	Moderate	High	Soils	Soil ameliorant	Unlikely	Minor	Low
			Sodicity	Possible	Moderate	High	Soils	Soil ameliorant	Unlikely	Minor	Low
				Possible	Moderate	High	Distribution system	Shandying with saline water	Unlikely	Minor	Low
				Possible	Moderate	High	Treatment process	Water treatment	Unlikely	Minor	Low
		Water — ground	Salinity	Possible	Moderate	High	Irrigation	Irrigation tools	Possible	Moderate	High
				Possible	Moderate	High	Soils	Site selection	Possible	Moderate	High
		Water — surface	Salinity	Unlikely	Moderate	Moderate	Irrigation	Irrigation tools	Rare	Moderate	Low
				Unlikely	Moderate	Moderate	Soils	Site selection	Rare	Moderate	Low

Table A4.17 (continued)

Hazard, exposure pathway, endpoint and effect				Maximum risk — no preventive measure (ie uncontrolled)			Control points (CP) and preventive measures		Residual risk — with preventive measures		
Use or exposure entry	Receiving environment or receptor	Environ-mental endpoint	Effect	Likelihood	Impact	Level of risk[a]	Critical CP or CP in environmental pathway	Preventive measure/s	Likelihood	Impact	Level of risk
Storage system	Water bodies	Water — ground	Salinity	Unlikely	Moderate	Moderate	Storage system	Buffer distances and strips	Unlikely	Minor	Low
				Unlikely	Moderate	Moderate	Treatment process	Decrease concentration	Unlikely	Minor	Low
				Unlikely	Moderate	Moderate	Soils	Site selection	Unlikely	Minor	Low
Discharge (unintentional and intentional)	Water bodies	Water — ground	Salinity	Possible	Moderate	High	Storage and distribution system	Storage design	Unlikely	Minor	Low
				Possible	Moderate	High	Groundwater	Monitoring	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Monitoring	Unlikely	Minor	Low
Washing	Infrastructure		Salinity	Possible	Minor	Moderate	Infrastructure	Monitoring	Rare	Minor	Low
Chloride											
Cross-connection	Plants	Plants	Toxicity	Possible	Minor	Moderate	Distribution system	Training and education	Rare	Minor	Low
Irrigation	Plants	Plants	Toxicity	Possible	Minor	Moderate	Irrigation	Incident management	Rare	Minor	Low
				Likely	Moderate	High	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Likely	Moderate	High	Plants	Crops and plants grown	Unlikely	Minor	Low
	Soils	Plants	Toxicity	Possible	Moderate	High	Soils	Crops and plants grown	Possible	Minor	Moderate
				Possible	Moderate	High	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Possible	Moderate	High	Soils	Site selection	Unlikely	Minor	Low
	Soils	Water — surface	Toxicity	Possible	Moderate	High	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Possible	Moderate	High	Soils	Buffer distances and strips	Unlikely	Minor	Low
Discharge (unintentional and intentional)	Water bodies	Biota — aquatic	Toxicity	Possible	Minor	Moderate	Storage and distribution system	Buffer distances and strips	Unlikely	Minor	Low
				Possible	Minor	Moderate	Storage and distribution system	Incident management	Unlikely	Minor	Low
				Possible	Minor	Moderate	Storage and distribution system	Interception/drainage	Unlikely	Minor	Low
				Possible	Minor	Moderate	Storage and distribution system	Maintenance	Unlikely	Minor	Low
Sodium											
Cross-connection	Plants	Plants	Toxicity	Possible	Minor	Moderate	Distribution system	Training and education	Unlikely	Insignificant	Low
	Soils	Soils	Sodicity	Possible	Minor	Moderate	Distribution system	Training and education	Unlikely	Minor	Low
Irrigation	Plants	Plants	Toxicity	Possible	Minor	Moderate	Plants	Crops and plants grown	Rare	Moderate	Low
				Possible	Minor	Moderate	Irrigation	Irrigation tools	Rare	Moderate	Low
	Soils	Plants	Toxicity	Possible	Moderate	High	Plants	Crops and plants grown	Unlikely	Minor	Low
				Possible	Moderate	High	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Possible	Moderate	High	Soils	Site selection	Unlikely	Minor	Low
	Soils	Soils	Sodicity	Possible	Moderate	High	Soils	Soil ameliorant	Unlikely	Minor	Low
				Possible	Moderate	High	Soils	Site selection	Unlikely	Minor	Low
				Possible	Moderate	High	Treatment process	Decrease concentration	Rare	Moderate	Low

a Maximum risk is highlighted to identify risk requiring preventive measures

Note: All risks determined to be low have been removed to highlight the higher risk pathways identified through a general initial-screening risk assessment undertaken in developing these guidelines. No specific end points have been identified because this was a general risk assessment.

Table A4.18 Environmental risk assessment for fire control use of water recycled from treated sewage

Hazard, exposure pathway, endpoint and effect				Maximum risk — no preventive measure (ie uncontrolled)			Control points (CP) and preventive measures		Residual risk — with preventive measures		
Use or exposure entry	Receiving environment or receptor	Environmental endpoint	Effect	Likelihood	Impact	Level of risk[a]	Critical CP or CP in environmental pathway	Preventive measure/s	Likelihood	Impact	Level of risk
Boron — all risks considered low											
Chlorine residuals — all risks considered low											
Storage system	Water bodies	Biota — aquatic	Toxicity	Possible	Minor	Moderate	Treatment process	Monitoring	Unlikely	Minor	Low
Discharge (unintentional and intentional)	Water bodies	Biota — aquatic	Toxicity	Likely	Minor	Moderate	Storage and distribution system	Education and training	Unlikely	Minor	Low
				Likely	Minor	Moderate	Storage and distribution system	Interception/drainage	Unlikely	Minor	Low
Washing		Biota — aquatic	Toxicity	Possible	Minor	Moderate	Washing	Education and training	Unlikely	Minor	Low
Hydraulic loading — all risks considered low											
Nitrogen											
Fire control	Soils	Water — surface	Eutrophication	Unlikely	Moderate	Moderate	Fire control	Interception/drainage	Rare	Minor	Low
				Unlikely	Moderate	Moderate	Fire control	Shandying with fresh water	Rare	Minor	Low
Storage system	Water bodies	Biota — aquatic	Eutrophication	Possible	Minor	Moderate	Storage system	Crops and plants grown	Rare	Minor	Low
				Possible	Minor	Moderate	Storage system	Shandying with fresh water	Rare	Minor	Low
				Possible	Minor	Moderate	Treatment process	Decrease concentration	Rare	Minor	Low
Discharge (unintentional and intentional)	Water bodies	Biota — aquatic	Eutrophication	Possible	Moderate	High	Storage and distribution system	Management plan	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Buffer distances and strips	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Incident management plan	Unlikely	Minor	Low
Phosphorus											
Fire control	Soils	Water — surface	Eutrophication	Unlikely	Moderate	Moderate	Fire control	Interception/drainage	Rare	Minor	Low
				Unlikely	Moderate	Moderate	Fire control	Shandying with fresh water	Rare	Minor	Low
Storage system	Water bodies	Biota — aquatic	Eutrophication	Possible	Minor	Moderate	Storage system	Crops and plants grown	Rare	Minor	Low
				Possible	Minor	Moderate	Storage system	Shandying with fresh water	Rare	Minor	Low
				Possible	Minor	Moderate	Treatment process	Decrease concentration	Unlikely	Minor	Low
Discharge (unintentional and intentional)	Water bodies	Biota — aquatic	Eutrophication	Possible	Moderate	High	Storage and distribution system	Management plan	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Buffer distances and strips	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Incident management plan	Unlikely	Minor	Low
Salinity (EC and TDS) — all risks considered low											
Chloride — all risks considered low											
Sodium — all risks considered low											

EC = electrical conductivity; TDS = total dissolved salts

a Maximum risk is highlighted to identify risk requiring preventive measures

Note: All risks determined to be low have been removed to highlight the higher risk pathways identified through a general initial-screening risk assessment undertaken in developing these guidelines. No specific end points have been identified because this was a general risk assessment.

Table A4.19 Environmental risk assessment for environmental allocation of water recycled from treated sewage

Hazard, exposure pathway, endpoint and effect				Maximum risk — no preventive measure (ie uncontrolled)			Control points (CP) and preventive measures		Residual risk — with preventive measures		
Use or exposure entry	Receiving environment or receptor	Environmental endpoint	Effect	Likelihood	Impact	Level of risk[a]	Critical CP or CP in environmental pathway	Preventive measure/s	Likelihood	Impact	Level of risk
Boron											
Storage system	Water bodies	Water — surface	Toxicity	Possible	Minor	Moderate	Surface water	Shandying with fresh water	Unlikely	Minor	Low
Chlorine residuals											
Storage system	Water bodies	Water — surface	Toxicity	Possible	Minor	Moderate	Treatment process	Design	Unlikely	Minor	Low
Discharge (unintentional and intentional)	Water bodies	Water — surface	Toxicity	Possible	Moderate	High	Distribution system	Pipeline infrastructure	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Buffer distances and strips	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Incident management	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Interception/drainage	Unlikely	Minor	Low
Hydraulic loading											
Discharge (unintentional and intentional)	Water bodies	Water — ground	Waterlogging	Possible	Moderate	High	Storage system	Storage design	Unlikely	Minor	Low
				Possible	Moderate	High	Groundwater	Monitoring	Unlikely	Minor	Low
			Salinity	Possible	Moderate	High	Storage system	Storage design	Unlikely	Minor	Low
				Possible	Moderate	High	Groundwater	Monitoring	Unlikely	Minor	Low
Nitrogen											
Storage system	Water bodies	Water — surface	Eutrophication	Possible	Moderate	High	Storage system	Crops and plants grown	Unlikely	Minor	Low
				Possible	Moderate	High	Storage system	Shandying with fresh water	Unlikely	Minor	Low
				Possible	Moderate	High	Storage system	Irrigation tools	Unlikely	Minor	Low
				Possible	Moderate	High	Storage system	Irrigation tools	Unlikely	Minor	Low
				Possible	Moderate	High	Storage system	Light reduction	Unlikely	Minor	Low
Discharge (unintentional and intentional)	Soils	Plants	Eutrophication	Possible	Minor	Moderate	Storage and distribution system	Buffer distances and strips	Unlikely	Minor	Low
				Possible	Minor	Moderate	Storage and distribution system	Education and training	Unlikely	Minor	Low
				Possible	Minor	Moderate	Storage and distribution system	Incident management	Unlikely	Minor	Low
				Possible	Minor	Moderate	Storage and distribution system	Site selection	Unlikely	Minor	Low
				Possible	Minor	Moderate	Storage and distribution system	Interception/drainage	Unlikely	Minor	Low
Discharge (unintentional and intentional)	Water bodies	Water — surface	Eutrophication	Unlikely	Moderate	Moderate	Storage and distribution system	Management plan	Unlikely	Minor	Low
				Unlikely	Moderate	Moderate	Storage and distribution system	Buffer distances and strips	Unlikely	Minor	Low
				Unlikely	Moderate	Moderate	Storage and distribution system	Incident management	Unlikely	Minor	Low
Phosphorus											
Storage system	Water bodies	Water — surface	Eutrophication	Possible	Moderate	High	Storage system	Crops and plants grown	Unlikely	Minor	Low
				Possible	Moderate	High	Storage system	Shandying with fresh water	Unlikely	Minor	Low
				Possible	Moderate	High	Storage system	Irrigation tools	Unlikely	Minor	Low
				Possible	Moderate	High	Storage system	Irrigation tools	Unlikely	Minor	Low
				Possible	Moderate	High	Storage system	Light reduction	Unlikely	Minor	Low
Discharge (unintentional and intentional)	Soils	Plants	Toxicity	Possible	Moderate	High	Storage and distribution system	Buffer distances and strips	Rare	Moderate	Low
				Possible	Moderate	High	Storage and distribution system	Incident management	Rare	Moderate	Low
				Possible	Moderate	High	Storage and distribution system	Site selection	Rare	Moderate	Low
Discharge (unintentional and intentional)	Water bodies	Water — surface	Eutrophication	Possible	Moderate	High	Storage and distribution system	Buffer distances and strips	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Management plan	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Incident management	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Site selection	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Maintenance	Unlikely	Minor	Low
Salinity (EC TDS)											
Storage system	Water bodies	Water — ground	Salinity	Unlikely	Moderate	Moderate	Storage system	Buffer distances and strips	Unlikely	Minor	Low
				Unlikely	Moderate	Moderate	Treatment Process	Decrease concentration	Unlikely	Minor	Low

Table A4.19 (continued)

Hazard, exposure pathway, endpoint and effect				Maximum risk — no preventive measure (ie uncontrolled)			Control points (CP) and preventive measures		Residual risk — with preventive measures		
Use or exposure entry	Receiving environment or receptor	Environ-mental endpoint	Effect	Likelihood	Impact	Level of risk[a]	Critical CP or CP in environmental pathway	Preventive measure/s	Likelihood	Impact	Level of risk
				Unlikely	Moderate	Moderate	Soils	Site selection	Unlikely	Minor	Low
Discharge (unintentional and intentional)	Water bodies	Water — ground	Salinity	Possible	Moderate	High	Storage and distribution system	Storage design	Unlikely	Minor	Low
				Possible	Moderate	High	Groundwater	Monitoring	Unlikely	Minor	Low
				Possible	Moderate	High	Storage and distribution system	Monitoring	Unlikely	Minor	Low
Chloride											
Discharge (unintentional and intentional)	Water bodies	Biota — aquatic	Toxicity	Possible	Minor	Moderate	Storage and distribution system	Buffer distances and strips	Unlikely	Minor	Low
				Possible	Minor	Moderate	Storage and distribution system	Incident management	Unlikely	Minor	Low
				Possible	Minor	Moderate	Storage and distribution system	Interception/drainage	Unlikely	Minor	Low
				Possible	Minor	Moderate	Storage and distribution system	Maintenance	Unlikely	Minor	Low
Sodium – all risks considered low											
Surfactants											
Discharge (unintentional and intentional)	Water bodies	Water — surface	Toxicity	Unlikely	Moderate	Moderate	Storage and distribution system	Buffer distances and strips	Rare	Minor	Low
				Unlikely	Moderate	Moderate	Treatment process	Decrease concentration	Unlikely	Minor	Low

EC = electrical conductivity; TDS = total dissolved salts.

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

Note: All risks determined to be low have been removed to highlight the higher risk pathways identified through a general initial-screening risk assessment undertaken in developing these guidelines. No specific end points have been identified because this was a general risk assessment.

Table A4.20 Environmental risk assessment for untreated greywater from a single household used on site

Hazard, exposure pathway, endpoint and effect				Maximum risk — no preventive measure (ie uncontrolled)			Control points (CP) and preventive measures		Residual risk — with preventive measures		
Use or exposure entry	Receiving environment or receptor	Environ-mental endpoint	Effect	Likelihood	Impact	Level of risk[a]	Critical CP or CP in environmental pathway	Preventive measure/s	Likelihood	Impact	Level of risk
Boron											
Irrigation	Soils	Plants	Toxicity	Possible	Minor	Moderate	Treatment process	Hazard source control	Unlikely	Minor	Low
				Possible	Minor	Moderate	Irrigation	Crops and plants grown	Unlikely	Minor	Low
				Possible	Minor	Moderate	Soils	Site selection	Unlikely	Minor	Low
				Possible	Minor	Moderate	Distribution system	Shandying with fresh water	Unlikely	Minor	Low
Cadmium											
Irrigation	Soils	Soils	Contamination	Possible	Minor	Moderate	Source water	Hazard source control	Unlikely	Minor	Low
				Possible	Minor	Moderate	Irrigation	Crops and plants grown	Unlikely	Minor	Low
Chlorine residuals											
Storage system	Water bodies	Biota — aquatic	Toxicity	Possible	Minor	Moderate	Storage system	Health risk — not recommended	Unlikely	Minor	Low
Discharge (unintentional and intentional)	Water bodies	Biota — aquatic	Toxicity	Possible	Moderate	High	Storage and distribution system	Buffer distances and strips	Rare	Moderate	Low
				Possible	Moderate	High	Storage and distribution system	Incident management	Rare	Moderate	Low
				Possible	Moderate	High	Storage and distribution system	Site selection	Rare	Moderate	Low

Table A4.20 (continued)

Hazard, exposure pathway, endpoint and effect				Maximum risk — no preventive measure (ie uncontrolled)			Control points (CP) and preventive measures		Residual risk — with preventive measures		
Use or exposure entry	Receiving environment or receptor	Environ-mental endpoint	Effect	Likelihood	Impact	Level of risk[a]	Critical CP or CP in environmental pathway	Preventive measure/s	Likelihood	Impact	Level of risk
Hydraulic loading											
Irrigation	Soils	Plants	Waterlogging	Possible	Minor	Moderate	Irrigation	Irrigation tools	Rare	Minor	Low
			Waterlogging	Possible	Minor	Moderate	Soils	Site selection	Rare	Minor	Low
Irrigation	Soils	Soils	Waterlogging	Possible	Minor	Moderate	Soils	Drainage	Rare	Minor	Low
Nitrogen											
Irrigation	Soils	Plants	Pest and disease	Possible	Minor	Moderate	Irrigation	Nutrient balancing	Unlikely	Minor	Low
				Possible	Minor	Moderate	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Possible	Minor	Moderate	Source water	Hazard source control	Unlikely	Minor	Low
	Water bodies	Water — ground	Contamination	Possible	Minor	Moderate	Irrigation	Nutrient balancing	Unlikely	Minor	Low
				Possible	Minor	Moderate	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Possible	Minor	Moderate	Soils	Site selection	Unlikely	Minor	Low
Storage system	Water bodies	Biota — aquatic	Eutrophication	Possible	Minor	Moderate	Storage system	Health risk — not recommended	Unlikely	Minor	Low
Phosphorus											
Irrigation	Soils	Plants	Toxicity	Possible	Minor	Moderate	Source water	Hazard source control	Unlikely	Insig-nificant	Low
				Possible	Minor	Moderate	Plants	Crops and plants grown	Unlikely	Insig-nificant	Low
			Nutrient Imbalance	Possible	Minor	Moderate	Irrigation and fertilisation	Nutrient balancing	Unlikely	Insig-nificant	Low
Irrigation	Water bodies	Water — surface	Eutrophication	Possible	Minor	Moderate	Irrigation	Irrigation tools	Unlikely	Minor	Low
Intentional or unintentional discharge	Water bodies	Water — surface	Eutrophication	Possible	Minor	Moderate	Distribution system	Incident management	Unlikely	Minor	Low
Salinity (EC TDS)											
In-house	Sewage treatment plant/septic tank		Concentration	Possible	Minor	Moderate	Source water	Hazard source control	Unlikely	Minor	Low
Irrigation	Infrastructure	Infra-structure	Salinity	Possible	Minor	Moderate	Irrigation	Irrigation tools	Unlikely	Insignific ant	Low
	Soils	Plants	Salinity	Likely	Minor	Moderate	Plants	Crops and plants grown	Possible	Minor	Moder ate
				Likely	Minor	Moderate	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Likely	Minor	Moderate	Soils	Site selection	Unlikely	Minor	Low
			Contamination	Possible	Minor	Moderate	Irrigation	Irrigation tools	Unlikely	Minor	Low
				Possible	Minor	Moderate	Source water	Hazard source control	Unlikely	Minor	Low
		Infra-structure	Salinity	Possible	Minor	Moderate	Irrigation	Monitoring	Possible	Insig-nificant	Low
Washing	Soils	Plants	Salinity	Possible	Minor	Moderate	Washing	Health risk — not recommended	Rare	Insig-nificant	Low
Chloride											
Cross-connection	Plants	Plants	Toxicity	Possible	Minor	Moderate	Irrigation	Health risk — not recommended	Rare	Minor	Low
In-house	Sewage treatment plant/septic tank		Concentration	Possible	Minor	Moderate	Source water	Hazard source control	Unlikely	Minor	Low
Irrigation	Plant	Plant	Toxicity	Likely	Minor	Moderate	Irrigation	Health risk — not recommended	Unlikely	Insignific ant	Low
				Likely	Minor	Moderate	Plants	Crops and plants grown	Unlikely	Insignific ant	Low
Sodium											
In-house	Sewage treatment plant/septic tank		Concentration	Possible	Minor	Moderate	Source water	Hazard source control	Unlikely	Minor	Low
Irrigation	Plants	Plants	Toxicity	Possible	Minor	Moderate	Irrigation	Health risk — not recommended	Rare	Minor	Low
	Soils	Soils	Sodicity	Possible	Minor	Moderate	Irrigation	Soil ameliorant	Rare	Minor	Low
			Sodicity	Possible	Minor	Moderate	Soils	Site selection	Rare	Minor	Low
			Sodicity	Possible	Minor	Moderate	Source water	Hazard source control	Rare	Minor	Low

EC = electrical conductivity; TDS = total dissolved salts

a Maximum risk is highlighted to identify risk requiring preventive measures

Note: All risks determined to be low have been removed to highlight the higher risk pathways identified through a general initial-screening risk assessment undertaken in developing these guidelines. No specific end points have been identified because this was a general risk assessment.

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Appendix 5 Reference tables for environmental risk assessment

This appendix provides reference tables for potential contaminants of recycled water, including metalloids and heavy metals, boron, cadmium, nutrients, salinity, sodium and phosphate.

A5.1 Metalloids and heavy metals

Table A5.1 Guideline values for contaminant concentrations of heavy metal and metalloids in (a) soil and biosolids, (b) drinking water and irrigation water

(a)		Soil						
		Health-based investigation levels (HILs)[a]				EIL[b] interim urban	Background ranges	RSCL and biosolids upper limit
		A	D	E	F			
Heavy metal or metalloid	Symbol	(mg/kg)						
Aluminium	Al	–	–	–	–	–	–	–
Arsenic (total)	As	100	400	200	500	20	1–50	20
Barium	Ba				300	300	100–300	–
Beryllium	Be	20	80	40	100	–	–	–
Boron	B	3000	12 000	6000	15 000	–	–	–
Cadmium	Cd	20	80	40	100	3	1	1
Chromium (III)	Cr (III)	12%	48%	24%	60%	400	–	400
Chromium (VI)	Cr (VI)	100	400	200	500	1	–	–
Chromium (total)[c]	Cr	–	–	–	–	–	5–1000	
Cobalt	Co	100	400	200	500		1–40	
Copper	Cu	1000	4000	2000	5000	100	2–100	100
Fluoride	F	–	–	–	–	–	–	–
Iron	Fe	–	–	–	–	–	–	–
Lead	Pb	300	1200	600	1500	600	2–200	300
Lithium	Li	–	–	–	–	–	–	–
Manganese	Mn	1500	6000	3000	7500	500	850	–
Methylmercury	CH_3Hg^+	–	10	40	20	–	–	–
Mercury (inorganic)	Hg		15	60	30	1	0.03	1
Molybdenum	Mo	–	–	–	–	–	–	–
Nickel	Ni	600	2400	600	3000	60	5–500	60
Selenium	Se	–	–	–	–	–	–	3
Uranium	U	–	–	–	–	–	–	–
Vanadium	V	50	20		500	50	20–500	–
Zinc	Zn	7000	28 000	14 000	35 000	200	10–300	200

Table A5.1 (continued)

(b)		Water			
Heavy metal or metalloid	Symbol	ADWG Health (mg/L)	LTV (mg/L)	STV (mg/L)	CCL (kg/ha)
Aluminium	Al	0.2	5.0	20	–
Arsenic (total)	As	0.007	0.1	2.0	20
Barium	Ba	0.7	–	–	–
Beryllium	Be		0.1	0.5	–
Boron	B	0.3	0.5	0.5–15	–
Cadmium	Cd	0.002	0.01	0.05	2.0
Chromium (III)	Cr (III)	–	–	–	–
Chromium (VI)	Cr (VI)	0.05	0.1	1.0	–
Chromium (total)[c]	Cr	–	–	–	–
Cobalt	Co	–	0.05	0.1	–
Copper	Cu	2.0	0.2	5.0	140
Fluoride	F	1.5	1.0	2.0	–
Iron	Fe	–	0.2	10	–
Lead	Pb	0.01	2.0	5.0	260
Lithium	Li	–	2.5	2.5	–
Manganese	Mn	0.5	0.2	10	–
Methylmercury	CH_3Hg^+	–	–	–	–
Mercury (inorganic)	Hg	0.001	0.002	0.002	2.0
Molybdenum	Mo	0.05	0.01	0.05	
Nickel	Ni	0.02	0.2	2.0	85
Selenium	Se	0.01	0.02	0.05	10
Uranium	U	–	0.01	0.1	–
Vanadium	V	–	0.1	0.5	–
Zinc	Zn	–	2.0	5.0	300

– = no data available; ADWG = *Australian Drinking Water Guidelines* (NHMRC and ARMCANZ 1996); CCL = cumulative contaminant loading limit (see Section 8.1 for full description) (ANZECC and ARMCANZ 2000a); EIL = ecological investigation level; HIL = health-based investigation level; LTV = long-term trigger value; RSCL = receiving soil contaminant limit (EPAV 2004); STV = short-term trigger value

a Human exposure settings based on land use have been established for HILs (see Taylor and Langley 1998). These are:
A — 'Standard' residential with garden/accessible soil (home-grown produce contributing less than 10% of vegetable and fruit intake; no poultry): this category includes children's day-care centres, kindergartens, preschools and primary schools
D — Residential with minimal opportunities for soil access: includes dwellings with fully and permanently paved yard space, such as high-rise apartments and flats
E — Parks, recreational open space and playing fields: includes secondary schools
F— Commercial/industrial: includes premises such as shops and offices, as well as factories and industrial sites (for details on derivation of HIL for human exposure settings based on land use, see Schedule B(7A)

b Interim EILs for the urban setting are based on considerations of phytotoxicity, ANZECC B levels, and soil survey data from urban residential properties in four Australian capital cities

c Valence state not distinguished — expected as Cr (III)

Sources: NHMRC and ARMCANZ (1996), NEPC (1999), ANZECC and ARMCANZ (2000a), EPAV (2004)

A5.2 Water quality — fresh and marine

Table A5.2 Guidelines for fresh and marine water quality

Chemical	Table-note	Trigger values for fresh water (µg/L)				Trigger values for marine water (µg/L)			
		Level of protection (% species)				Level of protection (% species)			
		99	95	90	80	99	95	90	80
Metals and metalloids									
Aluminium	pH >6.5	27	55	80	150	ID	ID	ID	ID
Aluminium	pH <6.5	ID	ID	ID	ID	ID	ID	ID	ID
Antimony		ID	ID	ID	ID	ID	ID	ID	ID
Arsenic (AsIII)		1	24	94C	360C	ID	ID	ID	ID
Arsenic (AsV)		0.8	13	42	140C	ID	ID	ID	ID
Beryllium		ID	ID	ID	ID	ID	ID	ID	ID
Bismuth		ID	ID	ID	ID	ID	ID	ID	ID
Boron		90	370C	680C	1300C	ID	ID	ID	ID
Cadmium	H	0.06	0.2	0.4	0.8C	0.7B	5.5B, C	14B, C	36B, A
Chromium (CrIII)	H	ID	ID	ID	ID	7.7	27.4	48.6	90.6
Chromium (CrVI)		0.01	1.0C	6A	40A	0.14	4.4	20C	85C
Cobalt		ID	ID	ID	ID	0.005	1	14	150C
Copper	H	1	1.4	1.8C	2.5C	0.3	1.3	3C	8A
Gallium		ID	ID	ID	ID	ID	ID	ID	ID
Iron		ID	ID	ID	ID	ID	ID	ID	ID
Lanthanum		ID	ID	ID	ID	ID	ID	ID	ID
Lead	H	1	3.4	5.6	9.4C	2.2	4.4	6.6C	12C
Manganese		1200	1900C	2500C	3600C	ID	ID	ID	ID
Mercury (inorganic)	B	0.06	0.6	1.9C	5.4A	0.1	0.4C	0.7C	1.4C
Mercury (methyl)		ID	ID	ID	ID	ID	ID	ID	ID
Molybdenum		ID	ID	ID	ID	ID	ID	ID	ID
Nickel	H	8	11	13	17C	7	70C	200A	560A
Selenium (total)	B	5	11	18	34	ID	ID	ID	ID
Selenium (SeIV)	B	ID	ID	ID	ID	ID	ID	ID	ID
Silver		0.02	0.05	0.1	0.2C	0.8	1.4	1.8	2.6C
Thallium		ID	ID	ID	ID	ID	ID	ID	ID
Tin (inorganic, SnIV)		ID	ID	ID	ID	ID	ID	ID	ID
Tributyltin (as µg/L Sn)		ID	ID	ID	ID	0.0004	0.006C	0.02C	0.05C
Uranium		ID	ID	ID	ID	ID	ID	ID	ID
Vanadium		ID	ID	ID	ID	50	100	160	280
Zinc	H	2.4	8.0C	15C	31C	7	15C	23C	43C
Non-metallic inorganics									
Ammonia	D	320	900C	1430C	2300A	500	910	1200	1700
Chlorine	E	0.4	3	6A	13A	ID	ID	ID	ID
Cyanide	F	4	7	11	18	2	4	7	14
Nitrate	J	17	700	3400C	17000A	ID	ID	ID	ID
Hydrogen sulfide	G	0.5	1	1.5	2.6	ID	ID	ID	ID

Table A5.2 (continued)

Chemical	Table-note	Trigger values for fresh water (µg/L)				Trigger values for marine water (µg/L)			
		Level of protection (% species)				Level of protection (% species)			
		99	**95**	**90**	**80**	**99**	**95**	**90**	**80**
Organic alcohols									
Ethanol		400	1400	2400 C	4000 C	ID	ID	ID	ID
Ethylene glycol		ID	ID	ID	ID	ID	ID	ID	ID
Isopropyl alcohol		ID	ID	ID	ID	ID	ID	ID	ID
Chlorinated alkanes									
Chloromethanes									
Dichloromethane		ID	ID	ID	ID	ID	ID	ID	ID
Chloroform		ID	ID	ID	ID	ID	ID	ID	ID
Carbon tetrachloride		ID	ID	ID	ID	ID	ID	ID	ID
Chloroethanes									
1,2-dichloroethane		ID	ID	ID	ID	ID	ID	ID	ID
1,1,1-trichloroethane		ID	ID	ID	ID	ID	ID	ID	ID
1,1,2-trichloroethane		5400	6500	7300	8400	140	1900	5800C	18000 C
1,1,2,2-tetrachloroethane		ID	ID	ID	ID	ID	ID	ID	ID
Pentachloroethane		ID	ID	ID	ID	ID	ID	ID	ID
Hexachloroethane	B	290	360	420	500	ID	ID	ID	ID
Chloropropanes									
1,1-dichloropropane		ID	ID	ID	ID	ID	ID	ID	ID
1,2-dichloropropane		ID	ID	ID	ID	ID	ID	ID	ID
1,3-dichloropropane		ID	ID	ID	ID	ID	ID	ID	ID
Chlorinated alkenes									
Chloroethylene		ID	ID	ID	ID	ID	ID	ID	ID
1,1-dichloroethylene		ID	ID	ID	ID	ID	ID	ID	ID
1,1,2-trichloroethylene		ID	ID	ID	ID	ID	ID	ID	ID
1,1,2,2-tetrachloroethylene		ID	ID	ID	ID	ID	ID	ID	ID
3-chloropropene		ID	ID	ID	ID	ID	ID	ID	ID
1,3-dichloropropene		ID	ID	ID	ID	ID	ID	ID	ID
Anilines									
Aniline		8	250A	1100 A	4800 A	ID	ID	ID	ID
2,4-dichloroaniline		0.6	7	20	60C	ID	ID	ID	ID
2,5-dichloroaniline		ID	ID	ID	ID	ID	ID	ID	ID
3,4-dichloroaniline		1.3	3	6C	13C	85	150	190	260
3,5-dichloroaniline		ID	ID	ID	ID	ID	ID	ID	ID
Benzidine		ID	ID	ID	ID	ID	ID	ID	ID
Dichlorobenzidine		ID	ID	ID	ID	ID	ID	ID	ID
Aromatic hydrocarbons									
Benzene		600	950	1300	2000	500C	700C	900C	1300 C
Toluene		ID	ID	ID	ID	ID	ID	ID	ID
Ethylbenzene		ID	ID	ID	ID	ID	ID	ID	ID
o-xylene		200	350	470	640	ID	ID	ID	ID
m-xylene		ID	ID	ID	ID	ID	ID	ID	ID
p-xylene		140	200	250	340	ID	ID	ID	ID

Table A5.2 (continued)

Chemical	Table-note	Trigger values for fresh water (µg/L)				Trigger values for marine water (µg/L)			
		Level of protection (% species)				Level of protection (% species)			
		99	**95**	**90**	**80**	**99**	**95**	**90**	**80**
m+p-xylene		ID	ID	ID	ID	ID	ID	ID	ID
Cumene		ID	ID	ID	ID	ID	ID	ID	ID
Polycyclic aromatic hydrocarbons									
Naphthalene		2.5	16	37	85	50C	70C	90C	120C
Anthracene	B	ID	ID	ID	ID	ID	ID	ID	ID
Phenanthrene	B	ID	ID	ID	ID	ID	ID	ID	ID
Fluoranthene	B	ID	ID	ID	ID	ID	ID	ID	ID
Benzo(a)pyrene	B	ID	ID	ID	ID	ID	ID	ID	ID
Nitrobenzenes									
Nitrobenzene		230	550	820	1300	ID	ID	ID	ID
1,2-dinitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
1,3-dinitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
1,4-dinitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
1,3,5-trinitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
1-methoxy-2-nitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
1-methoxy-4-nitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
1-chloro-2-nitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
1-chloro-3-nitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
1-chloro-4-nitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
1-chloro-2,4-dinitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
1,2-dichloro-3-nitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
1,3-dichloro-5-nitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
1,4-dichloro-2-nitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
2,4-dichloro-2-nitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
1,2,4,5-tetrachloro-3-nitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
1,5-dichloro-2,4-dinitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
1,3,5-trichloro-2,4-dinitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
1-fluoro-4-nitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
Nitrotoluenes									
2-nitrotoluene		ID	ID	ID	ID	ID	ID	ID	ID
3-nitrotoluene		ID	ID	ID	ID	ID	ID	ID	ID
4-nitrotoluene		ID	ID	ID	ID	ID	ID	ID	ID
2,3-dinitrotoluene		ID	ID	ID	ID	ID	ID	ID	ID
2,4-dinitrotoluene		16	65C	130C	250C	ID	ID	ID	ID
2,4,6-trinitrotoluene		100	140	160	210	ID	ID	ID	ID

Table A5.2 (continued)

Chemical	Table-note	Trigger values for fresh water (µg/L)				Trigger values for marine water (µg/L)			
		Level of protection (% species)				Level of protection (% species)			
		99	**95**	**90**	**80**	**99**	**95**	**90**	**80**
1,2-dimethyl-3-nitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
1,2-dimethyl-4-nitrobenzene		ID	ID	ID	ID	ID	ID	ID	ID
4-chloro-3-nitrotoluene		ID	ID	ID	ID	ID	ID	ID	ID
Chlorobenzenes and chloronaphthalenes									
Monochlorobenzene		ID	ID	ID	ID	ID	ID	ID	ID
1,2-dichlorobenzene		120	160	200	270	ID	ID	ID	ID
1,3-dichlorobenzene		160	260	350	520C	ID	ID	ID	ID
1,4-dichlorobenzene		40	60	75	100	ID	ID	ID	ID
1,2,3-trichlorobenzene	B	3	10	16	30C	ID	ID	ID	ID
1,2,4-trichlorobenzene	B	85	170C	220C	300C	20	80	140	240
1,3,5-trichlorobenzene	B	ID	ID	ID	ID	ID	ID	ID	ID
1,2,3,4-tetrachlorobenzene	B	ID	ID	ID	ID	ID	ID	ID	ID
1,2,3,5-tetrachlorobenzene	B	ID	ID	ID	ID	ID	ID	ID	ID
1,2,4,5-tetrachlorobenzene	B	ID	ID	ID	ID	ID	ID	ID	ID
Pentachlorobenzene	B	ID	ID	ID	ID	ID	ID	ID	ID
Hexachlorobenzene	B	ID	ID	ID	ID	ID	ID	ID	ID
1-chloronaphthalene		ID	ID	ID	ID	ID	ID	ID	ID
Polychlorinated biphenyls (PCBs) and dioxins									
Capacitor 21	B	ID	ID	ID	ID	ID	ID	ID	ID
Aroclor 1016	B	ID	ID	ID	ID	ID	ID	ID	ID
Aroclor 1221	B	ID	ID	ID	ID	ID	ID	ID	ID
Aroclor 1232	B	ID	ID	ID	ID	ID	ID	ID	ID
Aroclor 1242	B	0.3	0.6	1.0	1.7	ID	ID	ID	ID
Aroclor 1248	B	ID	ID	ID	ID	ID	ID	ID	ID
Aroclor 1254	B	0.01	0.03	0.07	0.2	ID	ID	ID	ID
Aroclor 1260	B	ID	ID	ID	ID	ID	ID	ID	ID
Aroclor 1262	B	ID	ID	ID	ID	ID	ID	ID	ID
Aroclor 1268	B	ID	ID	ID	ID	ID	ID	ID	ID
2,3,4’-trichlorobiphenyl	B	ID	ID	ID	ID	ID	ID	ID	ID
4,4’-dichlorobiphenyl	B	ID	ID	ID	ID	ID	ID	ID	ID
2,2’,4,5,5’-pentachloro-1,1’-biphenyl	B	ID	ID	ID	ID	ID	ID	ID	ID
2,4,6,2’,4’,6’-hexachlorobiphenyl	B	ID	ID	ID	ID	ID	ID	ID	ID
Total PCBs	B	ID	ID	ID	ID	ID	ID	ID	ID
2,3,7,8-TCDD	B	ID	ID	ID	ID	ID	ID	ID	ID
Phenols and xylenols									
Phenol		85	320	600	1200 C	270	400	520	720
p2,4-dimethylphenol		ID	ID	ID	ID	ID	ID	ID	ID
Nonylphenol		ID	ID	ID	ID	ID	ID	ID	ID
2-chlorophenol	T	340C	490C	630C	870C	ID	ID	ID	ID

Table A5.2 (continued)

Chemical	Table-note	Trigger values for fresh water (µg/L)				Trigger values for marine water (µg/L)			
		Level of protection (% species)				Level of protection (% species)			
		99	**95**	**90**	**80**	**99**	**95**	**90**	**80**
3-chlorophenol	T	ID	ID	ID	ID	ID	ID	ID	ID
4-chlorophenol	T	160	220	280C	360C	ID	ID	ID	ID
2,3-dichlorophenol	T	ID	ID	ID	ID	ID	ID	ID	ID
2,4-dichlorophenol	T	120	160C	200C	270C	ID	ID	ID	ID
2,5-dichlorophenol	T	ID	ID	ID	ID	ID	ID	ID	ID
2,6-dichlorophenol	T	ID	ID	ID	ID	ID	ID	ID	ID
3,4-dichlorophenol	T	ID	ID	ID	ID	ID	ID	ID	ID
3,5-dichlorophenol	T	ID	ID	ID	ID	ID	ID	ID	ID
2,3,4-trichlorophenol	T	ID	ID	ID	ID	ID	ID	ID	ID
2,3,5-trichlorophenol	T	ID	ID	ID	ID	ID	ID	ID	ID
2,3,6-trichlorophenol	T	ID	ID	ID	ID	ID	ID	ID	ID
2,4,5-trichlorophenol	T,B	ID	ID	ID	ID	ID	ID	ID	ID
2,4,6-trichlorophenol	T,B	3	20	40	95	ID	ID	ID	ID
2,3,4,5-tetrachlorophenol	T,B	ID	ID	ID	ID	ID	ID	ID	ID
2,3,4,6-tetrachlorophenol	T,B	10	20	25	30	ID	ID	ID	ID
2,3,5,6-tetrachlorophenol	T,B	ID	ID	ID	ID	ID	ID	ID	ID
Pentachlorophenol	T,B	3.6	10	17	27A	11	22	33	55A
Nitrophenols									
2-nitrophenol		ID	ID	ID	ID	ID	ID	ID	ID
3-nitrophenol		ID	ID	ID	ID	ID	ID	ID	ID
4-nitrophenol		ID	ID	ID	ID	ID	ID	ID	ID
2,4-dinitrophenol		13	45	80	140	ID	ID	ID	ID
2,4,6-trinitrophenol		ID	ID	ID	ID	ID	ID	ID	ID
Organic sulfur compounds									
Carbon disulfide		ID	ID	ID	ID	ID	ID	ID	ID
Isopropyl disulfide		ID	ID	ID	ID	ID	ID	ID	ID
n-propyl sulfide		ID	ID	ID	ID	ID	ID	ID	ID
Propyl disulfide		ID	ID	ID	ID	ID	ID	ID	ID
Tert-butyl sulfide		ID	ID	ID	ID	ID	ID	ID	ID
Phenyl disulfide		ID	ID	ID	ID	ID	ID	ID	ID
Bis(dimethylthiocarbamyl)sulfide		ID	ID	ID	ID	ID	ID	ID	ID
Bis(diethylthiocarbamyl)disulfide		ID	ID	ID	ID	ID	ID	ID	ID
2-methoxy-4H-1,3,2-benzodioxaphosphorium-2-sulfide		ID	ID	ID	ID	ID	ID	ID	ID
Xanthates									
Potassium amyl xanthate		ID	ID	ID	ID	ID	ID	ID	ID
Potassium ethyl xanthate		ID	ID	ID	ID	ID	ID	ID	ID
Potassium hexyl xanthate		ID	ID	ID	ID	ID	ID	ID	ID
Potassium isopropyl xanthate		ID	ID	ID	ID	ID	ID	ID	ID
Sodium ethyl xanthate		ID	ID	ID	ID	ID	ID	ID	ID

Table A5.2 (continued)

Chemical	Table-note	Trigger values for fresh water (µg/L)				Trigger values for marine water (µg/L)			
		Level of protection (% species)				Level of protection (% species)			
		99	95	90	80	99	95	90	80
Sodium isobutyl xanthate		ID	ID	ID	ID	ID	ID	ID	ID
Sodium isopropyl xanthate		ID	ID	ID	ID	ID	ID	ID	ID
Sodium sec-butyl xanthate		ID	ID	ID	ID	ID	ID	ID	ID
Phthalates									
Dimethylphthalate		3000	3700	4300	5100	ID	ID	ID	ID
Diethylphthalate		900	1000	1100	1300	ID	ID	ID	ID
Dibutylphthalate	B	9.9	26	40.2	64.6	ID	ID	ID	ID
Di(2-ethylhexyl)phthalate	B	ID	ID	ID	ID	ID	ID	ID	ID
Miscellaneous industrial chemicals									
Acetonitrile		ID	ID	ID	ID	ID	ID	ID	ID
Acrylonitrile		ID	ID	ID	ID	ID	ID	ID	ID
Poly(acrylonitrile-co-butadiene-costyrene)		200	530	800C	1200 C	200	250	280	340
Dimethylformamide		ID	ID	ID	ID	ID	ID	ID	ID
1,2-diphenylhydrazine		ID	ID	ID	ID	ID	ID	ID	ID
Diphenylnitrosamine		ID	ID	ID	ID	ID	ID	ID	ID
Hexachlorobutadiene		ID	ID	ID	ID	ID	ID	ID	ID
Hexachlorocyclo-pentadiene		ID	ID	ID	ID	ID	ID	ID	ID
Isophorone		ID	ID	ID	ID	ID	ID	ID	ID
Organochlorine pesticides									
Aldrin	B	ID	ID	ID	ID	ID	ID	ID	ID
Chlordane	B	0.03	0.08	0.14	0.27C	ID	ID	ID	ID
DDE	B	ID	ID	ID	ID	ID	ID	ID	ID
DDT	B	0.006	0.01	0.02	0.04	ID	ID	ID	ID
Dicofol	B	ID	ID	ID	ID	ID	ID	ID	ID
Dieldrin	B	ID	ID	ID	ID	ID	ID	ID	ID
Endosulfan	B	0.03	0.2A	0.6A	1.8A	0.005	0.01	0.02	0.05A
Endosulfan alpha	B	ID	ID	ID	ID	ID	ID	ID	ID
Endosulfan beta	B	ID	ID	ID	ID	ID	ID	ID	ID
Endrin	B	0.01	0.02	0.04C	0.06A	0.004	0.008	0.01	0.02
Heptachlor	B	0.01	0.09	0.25	0.7A	ID	ID	ID	ID
Lindane		0.07	0.2	0.4	1.0A	ID	ID	ID	ID
Methoxychlor	B	ID	ID	ID	ID	ID	ID	ID	ID
Mirex	B	ID	ID	ID	ID	ID	ID	ID	ID
Toxaphene	B	0.1	0.2	0.3	0.5	ID	ID	ID	ID
Organophosphorus pesticides									
Azinphos methyl		0.01	0.02	0.05	0.11A	ID	ID	ID	ID
Chlorpyrifos	B	0.000 04	0.01	0.11A	1.2A	0.000 5	0.009	0.04A	0.3A
Demeton		ID	ID	ID	ID	ID	ID	ID	ID
Demeton-S-methyl		ID	ID	ID	ID	ID	ID	ID	ID
Diazinon		0.000 03	0.01	0.2A	2A	ID	ID	ID	ID

Table A5.2 (continued)

Chemical	Table-note	Trigger values for fresh water (µg/L)				Trigger values for marine water (µg/L)			
		Level of protection (% species)				Level of protection (% species)			
		99	**95**	**90**	**80**	**99**	**95**	**90**	**80**
Dimethoate		0.1	0.15	0.2	0.3	ID	ID	ID	ID
Fenitrothion		0.1	0.2	0.3	0.4	ID	ID	ID	ID
Malathion		0.002	0.05	0.2	1.1A	ID	ID	ID	ID
Parathion		0.0007	0.004C	0.01C	0.04A	ID	ID	ID	ID
Profenofos	B	ID	ID	ID	ID	ID	ID	ID	ID
Temephos	B	ID	ID	ID	ID	0.0004	0.05	0.4	3.6A
Carbamate and other pesticides									
Carbofuran		0.06	1.2A	4A	15A	ID	ID	ID	ID
Methomyl		0.5	3.5	9.5	23	ID	ID	ID	ID
S-methoprene		ID	ID	ID	ID	ID	ID	ID	ID
Pyrethroids									
Deltamethrin		ID	ID	ID	ID	ID	ID	ID	ID
Esfenvalerate		ID	0.001*	ID	ID	ID	ID	ID	ID
Herbicides and fungicides									
Bypyridilium herbicides									
Diquat		0.01	1.4	10	80A	ID	ID	ID	ID
Paraquat		ID	ID	ID	ID	ID	ID	ID	ID
Phenoxyacetic acid herbicides									
MCPA		ID	ID	ID	ID	ID	ID	ID	ID
2,4-D		140	280	450	830	ID	ID	ID	ID
2,4,5-T		3	36	100	290A	ID	ID	ID	ID
Sulfonylurea herbicides									
Bensulfuron		ID	ID	ID	ID	ID	ID	ID	ID
Metsulfuron		ID	ID	ID	ID	ID	ID	ID	ID
Thiocarbamate herbicides									
Molinate		0.1	3.4	14	57	ID	ID	ID	ID
Thiobencarb		1	2.8	4.6	8C	ID	ID	ID	ID
Thiram		0.01	0.2	0.8C	3A	ID	ID	ID	ID
Triazine herbicides									
Amitrole		ID	ID	ID	ID	ID	ID	ID	ID
Atrazine		0.7	13	45C	150C	ID	ID	ID	ID
Hexazinone		ID	ID	ID	ID	ID	ID	ID	ID
Simazine		0.2	3.2	11	35	ID	ID	ID	ID
Urea herbicides									
Diuron		ID	ID	ID	ID	ID	ID	ID	ID
Tebuthiuron		0.02	2.2	20	160C	ID	ID	ID	ID
Miscellaneous herbicides									
Acrolein		ID	ID	ID	ID	ID	ID	ID	ID
Bromacil		ID	ID	ID	ID	ID	ID	ID	ID
Glyphosate		370	1200	2000	3600A	ID	ID	ID	ID
Imazethapyr		ID	ID	ID	ID	ID	ID	ID	ID
Ioxynil		ID	ID	ID	ID	ID	ID	ID	ID
Metolachlor		ID	ID	ID	ID	ID	ID	ID	ID

Table A5.2 (continued)

Chemical	Table-note	Trigger values for fresh water (µg/L)				Trigger values for marine water (µg/L)			
		Level of protection (% species)				Level of protection (% species)			
		99	95	90	80	99	95	90	80
Sethoxydim		ID	ID	ID	ID	ID	ID	ID	ID
Trifluralin	B	2.6	4.4	6	9A	ID	ID	ID	ID
Generic groups of chemicals									
Surfactants									
Linear alkylbenzene sulfonates (LAS)		65	280	520C	1000 C	ID	ID	ID	ID
Alcohol ethoxyolated sulfate (AES)		340	650	850C	1100 C	ID	ID	ID	ID
Alcohol ethoxylated surfactants (AE)		50	140	220	360C	ID	ID	ID	ID
Oils and petroleum hydrocarbons		ID	ID	ID	ID	ID	ID	ID	ID
Oil spill dispersants									
BP 1100X		ID	ID	ID	ID	ID	ID	ID	ID
Corexit 7664		ID	ID	ID	ID	ID	ID	ID	ID
Corexit 8667			ID	ID	ID	ID	ID	ID	ID
Corexit 9527		ID	ID	ID	ID	230	1100	2200	4400 A
Corexit 9550		ID	ID	ID	ID	ID	ID	ID	ID

Notes:
ID = Insufficient data to derive a reliable trigger value. Users advised to check if a low reliability value or an environmental concern level (ECL) is given in Section 8.3.7 (ANZECC and ARMCANZ 2000a).
* = *High reliability* figure for esfenvalerate derived from mesocosm NOEC data (no alternative protection levels available).
A = Figure may not protect key test species from acute toxicity (and chronic) — check Section 8.3.7 4 (ANZECC and ARMCANZ 2000a) for spread of data and its significance. 'A' indicates that trigger value > acute toxicity figure; note that trigger value should be <1/3 of acute figure (see Section 8.3.4.4 of ANZECC and ARMCANZ 2000a).
B = Chemicals for which possible bioaccumulation and secondary poisoning effects should be considered (see Sections 8.3.3.4 and 8.3.5.7 of ANZECC and ARMCANZ 2000a).
C = Figure may not protect key test species from chronic toxicity (this refers to experimental chronic figures or geometric mean for species) — check Section 8.3.7 for spread of data and its significance. Where grey shading and 'C' coincide, refer to text in Section 8.3.7 of ANZECC and ARMCANZ (2000a).
D = Ammonia as TOTAL ammonia as [NH_3-N] at pH 8. For changes in trigger value with pH, refer to Section 8.3.7.2 (ANZECC and ARMCANZ 2000a).
E = Chlorine as total chlorine, as [Cl]; see Section 8.3.7.2 (ANZECC and ARMCANZ 2000a).
F = Cyanide as un-ionised HCN, measured as [CN]; see Section 8.3.7.2 (ANZECC and ARMCANZ 2000a).
G = Sulfide as un-ionised H_2S, measured as [S]; see Section 8.3.7.2 (ANZECC and ARMCANZ 2000a).
H = Chemicals for which algorithms have been provided in Table 3.4.3 (ANZECC and ARMCANZ 2000a) to account for the effects of hardness. The values have been calculated using a hardness of 30 mg/L $CaCO_3$. These should be adjusted to the site-specific hardness (see Section 3.4.3 of ANZECC and ARMCANZ 2000a).
J = Figures protect against toxicity and do not relate to eutrophication issues. Refer to Section 3.3 if eutrophication is the issue of concern.
T = Tainting or flavour impairment of fish flesh may possibly occur at concentrations below the trigger value; see Sections 4.4.5.3/3 and 8.3.7 (ANZECC and ARMCANZ 2000a).
Notes on trigger values:
1. Some values are the trigger values applying to typical slightly–moderately disturbed systems; see Table 3.4.2 and Section 3.4.2.4 (ANZECC and ARMCANZ 2000a) for guidance on applying these levels to different ecosystem conditions.
2. Where the final water quality guideline to be applied to a site is below current analytical practical quantitation limits, see Section 3.4.3.3 (ANZECC and ARMCANZ 2000a) for guidance.
3. Most trigger values listed here for metals and metalloids are *high reliability* figures, derived from field or chronic 'no observable effect concentration' (NOEC) data (see Section 3.4.2.3 of ANZECC and ARMCANZ 2000a). The exceptions are *moderate reliability* for freshwater aluminium (pH >6.5), manganese and marine chromium (III).
4. Most trigger values listed here for non-metallic inorganics and organic chemicals are *moderate reliability* figures, derived from acute LC_{50} data (see Section 3.4.2.3 for reference to Volume 2 of ANZECC and ARMCANZ 2000a). The exceptions are *high reliability* for freshwater ammonia, 3,4-DCA, endosulfan, chlorpyrifos, esfenvalerate, tebuthiuron, three surfactants and marine for 1,1,2-TCE and chlorpyrifos.
Source: ANZECC and ARMCANZ (2000a)

A5.3 Boron

Table A5.3 Maximum boron concentrations in irrigation or soil water tolerated by a variety of crops, without reduction in yields

Species name	Common name
Very sensitive (threshold 0.3–0.5 mg/L)	
Citrus limon	Lemon
Rubus sp	Blackberry
Sensitive (threshold 0.5–0.75 mg/L)	
Persea americana	Avocado
C. x paradisi	Grapefruit
C. sinensis	Orange
Prunus armeniaca	Apricot
P. persica	Peach
P. avium	Cherry
P. domestica	Plum
Diospyros kaki	Persimmon
Ficus carica	Fig, kadota
Vitis vinifera	Grape
Juglans regia	Walnut
Carya illinoinenis	Pecan
Allium cepa	Onion
A. sativum	Garlic
Ipomea batatas	Sweet potato
Triticum aestivum	Wheat
Helianthus annuus	Sunflower
Vigna radiata	Bean, mung
Sesamum indicum	Sesame
Lupinus hartwegii	Lupine
Fragaria sp.	Strawberry
Helianthus tuberosus	Artichoke, Jerusalem
Phaseolus vulgaris	Bean, kidney
P. vulgaris	Bean, snap
P. lunatus	Bean, lima
Arachis hypogaea	Peanut
Moderately sensitive (threshold 1.0–2.0 mg/L)	
Brassica oleracea botrytis	Broccoli
Capsicum annuum	Pepper, red
Pisum sativa	Pea
Daucus carota	Carrot
Raphanus sativus	Radish
Solanum tuberosum	Potato
Cucumis stivus	Cucumber
Lactuca sativa	Lettuce
Moderately tolerant (threshold 2.0–4.0 mg/L)	
Brassica oleracea capitata	Cabbage
B. rapa	Turnip
Poa pratensis	Bluegrass, Kentucky
Hordeum vulgare	Barley
Vigna unguiculata	Cowpea
Avena sativa	Oats
Zea mays	Corn
Cynara scolymus	Artichoke
Nicotiana tabacum	Tobacco
Brassica juncea	Mustard
Melilotus indica	Clover, sweet
Cucurbita pepo	Squash

Table A5.3 (continued)

Species name	Common name
Cucumis melo	Muskmelon
B. oleracea botrytis	Cauliflower
Tolerant (threshold 4.0-6.0 mg/L)	
Medicago sativa	Alfalfa
Vicia benghalensis	Vetch, purple
Petroselinum crispum	Parsley
Beta vulgaris	Beet, red
B. vulgaris	Sugar beet
Lycopersicum	Tomato
Very tolerant (threshold 6.0–15.0 mg/L)	
Sorghum bicolor	Sorghum
Gossypium hirsutum	Cotton
Apium graveolens	Celery
Asparagus officinalis	Asparagus

Note: Boron tolerance may vary, depending upon climate, soil conditions and crop variety.
Source: Maas (1986, 1990b); Keren and Bingham (1985).

Table A5.4 Maximum boron concentrations in irrigation or soil water tolerated by a variety of ornamentals, without reduction in yields

Species name	Common name
Very sensitive (threshold <0.5 mg/L)	
Mahonia aquifolium	Oregon grape
Photinia x *fraseri*	Photinia
Xylosma congestum	Xylosma
Elaeagnus pungens	Thorny elaeagnus
Viburnum tinus	Laurustinus
Ligustrum japonicum	Wax-leaf privet
Feijoa sellowiana	Pineapple guava
Euonymus japonica	Spindle tree
Pittosporum tobira	Japanese pittosporum
Ilex cornuta	Chinese holly
Juniperus chinensis	Juniper
Lantana camara	Yellow sage
Ulmus americana	American elm
Sensitive (threshold 0.5–1.0 mg/L)[a]	
Zinnia elegans	Zinnia
Viola tricolor	Pansy
V. odorata	Violet
Delphinium sp	Larkspur
Abelia x *grandiflora*	Glossy abelia
Rosmarinus officinalis	Rosemary
Platycladus orientalis	Oriental arborvitae
Pelargonium x *hortorum*	Geranium
Moderately sensitive (threshold 1.0–2.0 mg/L)[a]	
Gladiolus sp	Gladiolus
Calendula officinalis	Marigold
Euphorbia pulcherrima	Poinsettia
Callistephus chinensis	China aster
Gardenia sp	Gardenia
Podocarpus macrophyllus	Southern yew
Syzygium paniculatum	Brush cherry

Table A5.4 (continued)

Species name	Common name
Moderately sensitive (threshold 1.0–2.0 mg/L (continued)	
Cordyline indivisa	Blue dracaena
Leucophyllus frutescens	Ceniza
Moderately tolerant (threshold 2–4 mg/L)[a]	
Callistemon citrinus	Bottlebrush
Eschscholzia californica	California poppy
Buxus microphylla	Japanese boxwood
Nerium oleander	Oleander
Hibiscus rosa-sinensis	Chinese hibiscus
Lathyrus odoratus	Sweet pea
Dianthus caryophyllus	Carnation
Tolerant (threshold 6–8 mg/L)	
Raphiolepis indica	Indian hawthorn
Carissa grandiflora	Natal plum
Oxalis bowiei	Oxalis

Note: Boron tolerance may vary, depending on climate, soil conditions and crop variety.
Source: Maas (1986)

A5.4 Cadmium

Table A5.5 Guidelines values for cadmium in recycled water

Limit	Value
Long-term trigger value in irrigation water	0.01 mg/L
Short-term trigger value in irrigation water (short-term use)	0.05 mg/L
Cumulative contaminant loading in soil receiving irrigation water	2 kg/ha

Table A5.6 Relationship between irrigation water chloride concentration or salinity, and risk of increasing crop uptake of cadmium

Chloride (mg/L)	Water quality parameter Total dissolved solids (mg/L)	Electrical conductivity (dS/m)	Likelihood of increasing crop cadmium concentrations
<350	<1100	<1.9	Low
350–750	1100–1650	1.9–2.8	Moderate
>750	>1650	>2.8	High

Source: Modified from ANZECC and ARMCANZ (2000a); electrical conductivity and chloride data from Australian sewage treatment plants

Table A5.7 Relative cadmium uptake and contamination risk groups for some fruit and vegetables

Likelihood	Fruit and vegetables	Potato varieties
High	Beetroot, carrot, eggplant, garlic, lettuce parsnip, pea	Toolangi delight, Kennebec, Crystal, Nadine
Moderate	Broccoli, bok choy, brussel sprout, cabbage, capsicum, caulifower, celery, onion, tomato	Wilcrisp, Sebago, Nooksak, Winlok, Tarago, Pontiac, Atlanic, Desiree, Delaware
Low	Alfalfa, cucumber, green bean	Wilwash, Russet Burbank, Lehmi Russet

Source: NCMC 2003; McLaughlin 1999

A5.5 Nutrient uptake by crops

Table A5.8 Approximate nutrient uptake in vegetable crops

Crop	Yield (t/ha)	Crop fraction	Uptake (kg/ha) Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Cabbage	50	Total	147	24	147	36	13
Capsicum	20	Total	41	4	69	52	7
Carrots	44	Root	100	14	90	15	6
		Leaf	110	5	180	160	12
		Total	210	19	270	175	10
Cauli-flower	50	Curd	119	23	134	55	10
		Leaf	62	5	91	72	8
		Total	181	28	225	127	18
Celery	190	Total	308	97	700	290	38
Cucumber	18	Fruit	28	5	45	4	2
		Leaf and stem	38	7	75	30	6
		Total	66	12	120	34	8
Lettuce	50	Total	100	18	180	10	3
Potato	40	Tuber	132	15	180	10	3
		Leaf and stem	132	8	130	56	18
		Total	264	23	310	66	21
Tomato	57	Leaf and stem	32	13	45	68	14
		Fruit	79	33	147	6	8
		Total	111	46	192	74	22
	194	Leaf and stem	211	49	241	315	58
		Fruit	361	84	615	33	29
		Total	572	133	856	348	87

Source: Modified from Creswell and Huett (1998)

Table A5.9 Nitrogen and phosphorus removal (kg/ha/crop) with harvestable portions of crops from specific locations

Crop	Area of NSW	Harvestable portion (t/ha)	Nitrogen (kg/ha)	Phosphorus (kg/ha)	Reference
Vegetables					
Cabbage		50	147	24	a
Carrots		44	100	14	a
Cauliflower		50	119	23	a
Celery		190	308	79	a
Cucumber		18	28	5	a
Green beans		4.5	160	4	a
Lettuce		50	100	18	a
Potato		40	132	15	a
Sweet potato		24	59	14	a
Tomato		57	79	33	a
Tomato		194	361	84	a
Bean, dwarf		15	38	6	b
Broccoli		20	90	13	b
Brussels sprouts		25	163	21	b
Carrot		80	104	28	b
Cauliflower		40	112	18	b
Celery, rooted		50	125	33	b
Chinese cabbage		70	105	28	b
Cucumber, pickle		70	105	21	b
Florence fennel		40	80	12	b
Lettuce, iceberg		60	78	15	b
Kale		20	120	16	b
Kohlrabi		45	126	20	b
Leek		55	138	19	b
Lettuce, head		50	90	15	b
Onion		60	108	21	b
Radicchio		25	63	10	b
Radish, small		30	60	9	b
Red beet		60	168	30	b
Red cabbage		50	110	18	b
Savoy cabbage		40	140	20	b
Spinach		30	108	15	b
White cabbage		80	160	26	b
Potatoes		31.7	105	12	c
Lettuce		25.4	51	9	c
Carrots		35.4	80	11	c
Tomatoes (glasshouse)		51.3	95	22	c
Tomatoes (field)		38	53	22	c
Celery		95.8	155	40	c
Cauliflowers		38	90	17	c
Cucumbers		37.6	58	10	c
Beetroot		17.7	50	9	c
Chinese cabbage		17.5	26	7	c
Onions		44	79	15	c

Table A5.9 (continued)

Crop	Area of NSW	Harvestable portion (t/ha)	Nitrogen (kg/ha)	Phosphorus (kg/ha)	Reference
Grain crop					
Barley	Northwest	1.7	31	7	d
	Central west	1.5	27	6	d
	South Riverina	1.7	31	7	d
Canola	Central west	1.5	69	11	d
	Southwest slopes	1.5	69	11	d
Faba beans	Northwest	1.2	49	6	d
	Riverina	2.3	94	12	d
Grain sorghum	Northwest	2.5	53	8	d
	Central west	2.5	53	8	d
	Riverina	2.8	59	8	d
Lupins	Central west	1.4	70	7	d
	Southwest	1.3	65	7	d
Maize	Northwest	5.8	93	17	d
	Central west	5.6	90	17	d
	Riverina	7.0	112	21	d
	Coastal	7.0	112	21	d
Oats	Northwest	1.1	19	4	d
	Central west	1.4	24	6	d
	Riverina	1.6	27	6	d
	Tablelands	1.1	19	4	d
Field pea	Statewide	1.0	40	2	d
Soybean	Northwest	1.8	119	11	d
	Riverina	2.2	145	13	d
Summer grain legumes — cowpeas, mung beans, pigeon pea		1.0	40	2	d
Sunflower	Northwest	1.2	62	7	d
	Riverina	1.7	88	10	d
Triticale	Central west	2.3	46	9	d
	Southwest	2.1	42	8	d
Wheat	Northwest	1.7	37	7	d
	Central west	1.5	33	6	d
	South Riverina	1.9	42	8	d
Forage crop					
Forage millet	Northwest	6.0	102	12	d
	Riverina	5.0	85	10	d
	Coast	9.0	153	18	d
Forage sorghum	Northwest	7.0	126	21	d
	Riverina	6.0	108	18	d
	Coast	10.0	180	30	d
Maize	North west	12.0	132	24	d
	Riverina coast	13.0	143	26	d
Summer grain legumes	North	3.0	51	12	d
Winter cereals	Statewide	5.0	75	15	d
Winter grain legumes	Statewide	4.0	108	12	d
Stubbles for hay					
Wheat straw	Northwest	1.7	9	2	d
	Central west	1.5	8	2	d
	South Riverina	1.9	10	2	d

Table A5.9 (continued)

Crop	Area of NSW	Harvestable portion (t/ha)	Nitrogen (kg/ha)	Phosphorus (kg/ha)	Reference
Barley straw	Northwest–central	1.7	9	2	d
	West–south	1.5	8	2	d
	Riverina	1.7	9	2	d
Oat straw	Northwest	1.1	8	1	d
	Central west	1.4	10	1	d
	South Riverina	1.6	11	2	d
	Tablelands	1.1	8	1	d
Lupin straw	Statewide	nr			d
Pea straw	Statewide	0.5	6	1	d
Triticale	Central west	2.3	12	2	d
	Southwest	2.1	11	2	d
Grain sorghum	Northwest	3.0	36	6	d
	Central west	3.0	36	6	d
	Riverina	3.5	42	7	d
Maize	Northwest	7.0	63	21	d
	Central west	7.0	63	21	d
	Riverina	9.0	81	27	d
	Coastal	9.0	81	27	d
Soybean	Northwest	0.9	7	1	d
	Riverina	1.1	9	1	d
Pastures for all NSW (active growth period)					
Kikuyu	September–March	30.0	780	90	d
Phalaris	March–November	9.0	99	27	d
Perennial ryegrass	March–November	6.0	210	18	d
Fescue	September–May	11	264	44	d
Lucerne	All year	29	1015	116	d
White clover	September–February	20.0	740	80	d

NSW = New South Wales
Sources:
a Creswell and Huett 1998 (New South Wales, Australian dataset)
b Fink et al 1999 (European dataset)
c Creswell and Huett (1998)
d NSW Agriculture (1995)

Table A5.10 Mean nutrient concentrations in harvestable portions of crops

Crop species	Crop moist-ure (%)	Mean nutrient removed: Nitrogen (kg/t FW)	Mean nutrient removed: Phosphorus (kg/t FW)	Crop species	Crop moist-ure (%)	Mean nutrient removed: Nitrogen (kg/t FW)	Mean nutrient removed: Phosphorus (kg/t FW)
Fruit beverages				**Harvested grains**			
Apple	84	0.32	0.08	**Cereals**			
Apricot	83	2.3	0.32	Barley	11	na	2.7
Avocado		1.3	0.17	Cereal rye	11	14	3.4
Babaco	94	2.1		Maize	10	13	2.3
Banana	70–80	2.2	0.52	Millet/ canary seed	11	20	3.3
Black currant	80	1.8	0.34	Oats	11	16	2.7
Blackberry	84	1.9	0.22	Rice (grain and hulls)	14	10.3	2.4
Blueberry	85	1.1	0.13	Sesame	5	34	7.2
Cantaloupe/ melon	87	1.9	0.59	Sorghum	10	17	2.3
Carambola	91	1.2	0.17	Triticale	11	16	2.4
Casimiroa	80	0.14	0.2	Wheat	11	na	2.5
Cherry	80	1.5	0.21	**Grain legumes**			
Citrus fruit		2.9	0.4	Chickpea	10	33	3.8
Coffee		46	3.4	Cowpea	10	39	6.9
Cranberry	88	0.5	0.1	Faba bean	10	38	3.6
Currants	82	2.2	0.48	Field pea	10	35	3.6
Custard apple		2.6	0.3	Lablab	11	36	10
Date	21	3.6	0.46	Lentil	10	37	3.3
Fig	83	2.2	0.28	Lupin (sweet)	9	48	3.3
Gooseberry	87	1.3	0.35	Lupin (albus)	9	57	3.6
Grape (table)	~80	1.3	0.27	Lupin (sandplain)	8	51	3.8
Grape (wine berries)		1	0.26	Lupin (yellow)	9	61	4.3
Grapefruit	89	1.1	0.21	Mung bean	9	41	7.7
Guava	83	1.2	0.26	Green mung bean	9	42	7.2
Kiwifruit	~84	1.5	0.21	Black mung bean	10	40	6
Lemons and limes	87	1.9	0.15	Narbon bean	11	39	4.4
Longan	72	1.6	0.06	Navy bean	10	39	4.5
Longanberry		2.8	0.24	Pigeon pea	10	31	7.6
Lychee		2	0.4	Vetch (common)	10	42	4.2

Table A5.10 (continued)

Crop species	Crop moisture (%)	Mean nutrient removed: Nitrogen (kg/t FW)	Mean nutrient removed: Phosphorus (kg/t FW)	Crop species	Crop moisture (%)	Mean nutrient removed: Nitrogen (kg/t FW)	Mean nutrient removed: Phosphorus (kg/t FW)
Fruit beverages (continued)				**Pasture legumes**			
Mandarin		1.6	0.16	Lucerne seed		60	6.8
Mango	90	6.5	0.75				
Mangosteen	85	0.8	0.2	Medic seed	10	64	6.8
Mulberry	89	3.5	0.38	Serradella	10		4.9
Nectarine	86	1.4	0.22				
Orange	82	1.3	0.18	**Oilseed crops**			
Passionfruit		3.3	0.4	Canola/rape	8.5	35	5.1
Pawpaw		1.3	0.3	Cotton		22	6.6
Peach/ peacharine	86	1.2	0.2	Linola	w/w	31	4.4
Pear	85	0.24	0.03	Linseed/flax	8.5	25	3.8
Pepino	93	1		Mustard	8.5	33	8.1
Persimmon		1	0.22	Peanut	10	36	3.2
Pineapple		0.78	0.07	Safflower	8.5	29	3.1
Plum	86	1.5	0.19	Soybean	8.5	62	5.5
Prune		5.6	0.9	Sunflower	8.5	30	7.8
Quince				**Other crops**			
Rambutan				Hops	0	54	7.4
Raspberry	84	1.8	0.29	Lavender	30	4.5	0.45
Roselle				Poppy	11.5	21	5.7
Stonefruit		1.2	0.12	Pyrethrum		17	2.2
Strawberry	91	1.9	0.26	Tobacco		39	2.5
Tangelo							
Tea (pluck leaves)		40	4				
Watermelon	94	1.5	0.25				
Harvested vegetables				**Livestock fodder**			
Artichoke (edible)	84	4.3	0.77	***Hay***			
Asparagus	94	2.2	0.41	Lucerne		28	2
Beans (all types)	91	3.8	0.39	Clover or medic		22 [a]	1.7
Beetroot	91	2	0.3	Clover/grass		21 [a]	2
Broccoli (all types)	90	5.4	0.82	Oaten		13	1.6
Brussel sprouts	88	5.9	0.86	Pasture		18 [a]	1.8
Cabbage (all types)	92	3.4	0.6	Sorghum		16	
Capsicum	92	2.2	0.31	Chopped corn		12	2.4
Carrot	89	1.6	0.4				
Cassava	66	2.6	0.4	***Silage***			
Cauliflower	91	3.1	0.59	Grass		24 [a]	2.8
Celery	95	1.3	0.29	Pasture		26 [a]	2.8

Table A5.10 (continued)

Crop species	Crop moist-ure (%)	Mean nutrient removed		Crop species	Crop moist-ure (%)	Mean nutrient removed	
		Nitrogen (kg/t FW)	Phosphorus (kg/t FW)			Nitrogen (kg/t FW)	Phosphorus (kg/t FW)
Harvested vegetables (continued)				***Silage (continued)***			
Chicory (roots)	80	2.2	0.61	Maize		12 [a]	1.9
Chilli (red)	82	2.2	1.2	Oaten		20 [a]	2.5
Chilli (green)	81	4.5	1.2	Sorghum		15	
Chives	90	2.4	0.51	Unspecified		13	
Chokos				***Grain***			
Cucumber	96	1.4	0.26	Barley		16	2.7
Eggplant	93	1.8	0.25	Oats		15	3.2
Fennell	94	1.5	0.26	Sorghum		15	3.2
Garlic (bulbs)	61	8.2	1.7	Wheat		28	3.2
Gherkin	93	2.2	0.38				
Ginger	89	1.8	0.4	**Sugarcane**			
Horshradish	76	7.2	0.8	**District**			
Leek	91	2	0.19	Mossman–Gordonvale	10	0.75	0.1
Lettuce	96	1.9	0.37	Babinda–Tully	12	0.75	0.11
Mushroom	91	6	0.8	Herbert	5	0.67	0.11
Okra (edible portion)	90	3.1	0.6	Burdekin	91	1.11	0.24
Onion	89	1.9	0.42	Central	17	0.9	0.15
Parsley	83	5.8	0.7	Bundaberg	32	0.88	0.16
Parsnip	81	3.8	0.88	Mary-borough–Rocky Point	59	1.15	0.17
Peas	75	11.2	1.33	**Queens-land**	**32**	**0.89**	**0.15**
Peas (snow)	88	4.8		(average of districts above)			
Peppers	74	5.9	0.78				
Potato (tubers)	80	3	0.42				
Potato (sweet)	76	2.4	0.53				
Pumpkin	90	2.1	0.56				
Radish	93	3.5	0.31				
Rhubarb	95	1.1	0.17				
Silverbeet	93	2.9	0.42				
Squash	92	3.9	0.34				
Spinach	93	3.2	0.3				
Sweetcorn (ears)		3.9	0.56				
Tomato	94	1.6	0.33				
Turnip	93	1.9	0.5				
Zucchini	94	2.9	0.28				

FW = fresh weight; **a** Indicates expressed on an oven-dry basis
Source: ANZECC and ARMCANZ (2000a)

A5.6 Salinity

Table A5.11 Conversion factors for electrical conductivity measurements

If you have these units:	Multiply by the numbers shown below to convert to these units:				
	dS/m	mS/m	µS/m	mS/cm	µS/cm
dS/m	1	100	100000	1	1000
mS/m	0.01	1	1000	0.01	10
µS/m	10^{-5}	0.001	1	10^{-5}	0.01
mS/cm	1	100	100000	1	1000
µS/cm	10^{-3}	0.1	100	0.001	1

Table A5.12 Relative soil salinity tolerance thresholds of turf grasses to salinity in soil extract (ECe) and estimates for irrigation water (ECi)

		ECe			ECi			
Species	Common name	At 80% growth	At 50% growth	Source	25% LF (eg sand)[a]	20% LF (eg sandy loam)[a]	17% LF (eg loam)[a]	12% LF (eg light clay)[a]
Agropyron cristatum	Fairway wheatgrass	6–10, 8[b]		z	8.0	6.9	5.9	4.5
Agropyron smithii	Western wheatgrass	6–10, 8[b]	12–16	z	8.0	6.9	5.9	4.5
Agrostris canina	Velvet bentgrass		3	w	1.3	1.1	0.9	0.7
Agrostis palustris	Creeping bentgrass	0–10, 3.7[b]	8–12	w, z	3.7	3.2	2.7	2.1
Agrostris tenuis	Colonial bentgrass	0–3, 1.5[b]	3	w, z	1.5	1.3	1.1	0.8
Axonopus species	Carpetgrass	0–1, 1.5[b]	4	w, z	1.5	1.3	1.1	0.8
Buchloe dactyloides	Buffalograss	0–10, 5.3[b]	13	z	5.3	4.6	3.9	3.0
Bouteloua gracilis	Blue grama	2–10, 5.2[b]	–	z	5.2	4.5	3.8	2.9
Eremochloa ophiuroides	Centipede-grass	0–3, 1.5[b]	8–9	z	1.5	1.3	1.1	0.8
Festuca arundinacea	Tall fescue	5–10, 6.5[b]	8–12	w, z	6.5	5.6	4.8	3.7
Festuca elatior	Meadow fescue		4	w	1.7	1.5	1.2	1.0
Festuca longifolia	Hard fescue	3–6, 4.5[b]	4	w, z	4.5	3.9	3.3	2.5
Festuca ovina	Sheep fescue		4	w	1.7	1.5	1.2	1.0
Festuca rura L. trichophylla	Slender creep. Red fescue	3–10, 6.3[b]	8–12	z	6.3	5.4	4.6	3.5

Table A5.12 (continued)

Species	Common name	ECe At 80% growth	ECe At 50% growth	Source	ECi 25% LF (eg sand)[a]	ECi 20% LF (eg sandy loam)[a]	ECi 17% LF (eg loam)[a]	ECi 12% LF (eg light clay)[a]
Festuca ruba L. spp ruba	Creeping red fescue	3–6, 4.5[b]	8–12	z	4.5	3.9	3.3	2.5
Festuca rubra commutata	Chewings fescue		4	w	1.7	1.5	1.2	1.0
Lolium multiflorum	Annual ryegrass		4	w	1.7	1.5	1.2	1.0
Lolium perenne	Perennial ryegrass	3–10, 6.5[b]	8–10	z	6.8	5.9	5.0	3.8
Pennisetum clandestinum	Kikuyu	6–10, 8.0[b]	–	z	8.0	6.9	5.9	4.5
Poa annua	Annual bluegrass	0–3, 1.5[b]	–	z	1.5	1.3	1.1	0.8
Poa pratensis	Kentucky bluegrass	0–6, 3.0[b]	3–30	z	3.0	2.6	2.2	1.7
Poa trivialis	Rough bluegrass	0–3, 1.5[b]	4	w, z	1.5	1.3	1.1	0.8
Punccinella ssp	Alkaligrass	6–12, 8.5[b]	20–30	z	8.5	7.3	6.3	4.8
Puccinellia airoides	Nuttall alkali grass		30	w	12.7	11.0	9.3	7.1
Puccinellia distans	Weeping alkali grass		30	w	12.7	11.0	9.3	7.1
Puccinellia lemmoni	Lemon alkali grass		30	w	12.7	11.0	9.3	7.1
Buchloe dactyloides	Buffalo grass		8	w	3.4	2.9	2.5	1.9
Cynodon dactylon	CT-2	7	16	x	7.0	6.0	5.1	3.9
Cynodon dactylon	Legend	7	17	x	7.0	6.0	5.1	3.9
Cynodon dactylon	JT1	11	20	x	11.0	9.5	8.1	6.2
Cynodon dactylon	Hatfield	8	18	x	8.0	6.9	5.9	4.5
Cynodon dactylon	Conquest	8	18	x	8.0	6.9	5.9	4.5
Cynodon dactylon	Riley's Super Sport	9	18.5	x	9.0	7.8	6.6	5.1
Cynodon dactylon	Wintergreen	4	13	x	4.0	3.4	2.9	2.2
Cynodon dactylon	Royal Cape II	7	15.5	x	7.0	6.0	5.1	3.9
Cynodon dactylon	Plateau	4	14	x	4.0	3.4	2.9	2.2
Cynodon dactylon	Mountain Green	9	17	x	9.0	7.8	6.6	5.1
Cynodon dactylon	Winter Gem	9	18	x	9.0	7.8	6.6	5.1
Cynodon dactylon	Oz-E-Green	7	22	x	7.0	6.0	5.1	3.9

Table A5.12 (continued)

Species	Common name	ECe At 80% growth	ECe At 50% growth	Source	ECi 25% LF (eg sand)[a]	ECi 20% LF (eg sandy loam)[a]	ECi 17% LF (eg loam)[a]	ECi 12% LF (eg light clay)[a]
Cynodon dactylon	Windsor Green	11	19	x	11.0	9.5	8.1	6.2
Cynodon species	Bermuda grass (couch grass)		18	w	7.6	6.6	5.6	4.3
Cynodon species	Bermuda grass, hybrids	0–10, 3.7[b]	11–33	z	3.7	3.2	2.7	2.1
Digitaria didactyla	Aussiblue	1–2.8	4–8.5	x	1.6	1.4	1.2	0.9
Distichlis spicata	NyPa Turf	12	27	x	12.0	10.3	8.8	6.7
Distichlis sppstricta	Saltgrass	6–10, 8.0[b]>	>40	w, z	8.0	6.9	5.9	4.5
Eremochloa ophiuroides	TifBlair	1–1.5	3–4	x	1.3	1.1	0.9	0.7
Paspalum notatum	Bahiagrass		3	w	1.3	1.1	0.9	0.7
Paspalum vaginatum	Seashore paspalum (salt water couch)	0–20, 8.6[b]	30–31	w, z	8.6	7.4	6.3	4.8
Paspalum vaginatum	Sea Isle 2000	11–24	25–30	x	17.5	15.1	12.9	9.8
Paspalum vaginatum	Saltene	24	31	x	24.0	20.7	17.6	13.5
Paspalum vaginatum	Velvetene	14	40	x	14.0	12.1	10.3	7.9
Paspalum vaginatum	Sea Isle 1	4	13	x	1.0	0.9	0.7	0.6
Pennisetum clandestinum	Kikuyu	6–10, 8[b]		z	8.0	6.9	5.9	4.5
Sporobulus virginicus	Rottnest	3	12	x	3.0	2.6	2.2	1.7
Sporobulus virginicus	RB1	19	37	x	19.0	16.4	14.0	10.7
Sporobulus virginicus	Gladstone	22	30	x	22.0	19.0	16.2	12.4
Stentoaphrum secundatum	Saphire	10.5	16	x	10.5	9.1	7.7	5.9
Stentoaphrum secundatum	Palmetto	16	18	x	16.0	13.8	11.8	9.0
Stentoaphrum secundatum	Shademaster	16.5	19	x	16.5	14.2	12.1	9.3
Stentoaphrum secundatum	Sir James	5	19	x	5.0	4.3	3.7	2.8
Stentoaphrum secundatum	Sir Walter	3	16	x	3.0	2.6	2.2	1.7
Stentoaphrum secundatum	ST-26	3	16	x	3.0	2.6	2.2	1.7
Stentoaphrum secundatum	ST-85	5	21	x	5.0	4.3	3.7	2.8

Table A5.12 (continued)

Species	Common name	ECe At 80% growth	ECe At 50% growth	Source	ECi 25% LF (eg sand)[a]	ECi 20% LF (eg sandy loam)[a]	ECi 17% LF (eg loam)[a]	ECi 12% LF (eg light clay)[a]
Stentoaphrum secundatum	ST-91	3	9	x	3.0	2.6	2.2	1.7
Stentoaphrum secundatum	Velvet	3	10.5	x	3.0	2.6	2.2	1.7
Stentoaphrum secundatum	St Augustine-grass	0–18, 6.5[b]	29	z	6.5	5.6	4.8	3.7
Zoysia matrella	Manila grass		30	w	12.7	11.0	9.3	7.1
Zoysia matrella	Cavalier	4	14	x	4.0	3.4	2.9	2.2
Zoysia matrella	G1	13	24	x	13.0	11.2	9.6	7.3
Zoysia matrella	Royal	5	23	x	5.0	4.3	3.7	2.8
Zoysia matrella	Diamond	5	21	x	5.0	4.3	3.7	2.8
Zoysia matrella	Zorro	9	20	x	9.0	7.8	6.6	5.1
Zoysia spp	Hybrid Zoysia grass	0–11, 2.4[b]	16	z	2.4	2.1	1.8	1.3
Zoysia tenuifolia	Mascarene grass		30	w	12.7	11.0	9.3	7.1

EC = electrical conductivity in dS/m; ECe = electrical conductivity of a soil paste extract; ECi = electrical conductivity of irrigation water; LF = leaching fraction.
Note: Values in this table are indicative only; salt tolerance of all plants will vary depending on a range of factors, such as soil type, drainage, climate and turf maturity.
a ECi has been estimated from average or mid-range ECe 80% growth, assuming limited rainfall and the specified LF, using equation 9 from Ayers and Westcot (1985). Where no ECe 80% growth was reported but average ratio (0.42) of 50%:80% growth for species was reported, this was used to estimated the ECi.
b Average root salinity tolerance (ECe dS/m)
Sources:
w = Marcum (1999)
x = Loch et al (in press). ECe values where quoted as ECi. Growth threshold was assumed to be 80% growth
z = Carrow and Duncan (1998)

Table A5.13 Water salinity criteria for salt tolerance thresholds of turf grasses

Relative salt tolerance (producing an acceptable turf quality)[a]	Water salinity as total dissolved salts (mg/L)	Turfgrass species/variety
Tolerant	Up to 3600	Common couchgrass Tifway couchgrass Tifgreen couchgrass Santa Ana couchgrass Kikuyu Seaside creeping bentgrass
Moderate tolerance	Up to 1800	Strawberry clover Tall fescue Perennial ryegrass
Low tolerance	Less than 1200	Creeping bentgrass Kentucky bluegrass Red fescue Highland bentgrass Annual wintergrass

a Salt tolerance of grasses will vary depending on a range of factors, such as soil type, drainage and turf maturity
Source: DHS and EPA (1999)

Table A5.14 Salinity tolerance of some Australian native plants

Species	Common name	Salinity tolerance threshold (ECe dS/m)	Source	ECi [a]			
				25% LF (eg sand)	20% LF (eg sandy loam)	17% LF (eg loam)	12% LF (eg light clay)
Acacia acuminata	Jam	4–8	w	6.0	5.2	4.4	3.4
A. aff lineolata		8–16	s	12.0	10.3	8.8	6.7
A. ampliceps	Salt wattle	>16	s	16.0	13.8	11.8	9.0
A. ampliceps		8–16	w	12.0	10.3	8.8	6.7
A. brumalis		8–16	s	12.0	10.3	8.8	6.7
A. colletoides	Spine wattle	4–8	s	6.0	5.2	4.4	3.4
A. cyclops	Coastal wattle	>8	u	8.0	6.9	5.9	4.5
A. cyanophylla	Orange wattle	>8	u	8.0	6.9	5.9	4.5
A. implexa	Hickory wattle	2–4	w	3.0	2.6	2.2	1.7
A. iteaphylla	Flinders Range wattle	2–4	w	3.0	2.6	2.2	1.7
A. ligulata	Umbrella bush	8–16	s	12.0	10.3	8.8	6.7
A. longifolia	Sydney golden wattle	2–4	w	3.0	2.6	2.2	1.7
A. macono-chieana		8–16	w	12.0	10.3	8.8	6.7
A. mearnsii	Late black wattle	2–4	w	3.0	2.6	2.2	1.7
A. melanoxylon	Tasmanian blackwood	2–4	w	3.0	2.6	2.2	1.7
A. merrallii	Merrall's wattle	4–8	s	6.0	5.2	4.4	3.4
A. microbotrya	Manna wattle	<2	s	1.5	1.3	1.1	0.8
A. mutabilis ssp *stipulifera*		8–16	s	12.0	10.3	8.8	6.7
A. pendula	Weeping myall	4–8	w	6.0	5.2	4.4	3.4
A. prainii	Prain's wattle	4–8	s	6.0	5.2	4.4	3.4
A. pulchella	Western prickly moses	>8	u	8.0	6.9	5.9	4.5
A. redolens	Ravensthorpe source	4–8	w	6.0	5.2	4.4	3.4
A. retinodes	Wirilda	4–8	w	6.0	5.2	4.4	3.4
A. salicina	Coobah, willow wattle	8–16	w	12.0	10.3	8.8	6.7
A. saligna	Golden wreath wattle	4–8	w	6.0	5.2	4.4	3.4
A. stenophylla	River myall	>16	s	16.0	13.8	11.8	9.0
A. stenophylla		>16	w	16.0	13.8	11.8	9.0
A. victoriae		4–8	w	6.0	5.2	4.4	3.4
Agonis flexuosa	WA peppermint	<2	s	1.5	1.3	1.1	0.8
Allocasuarina lehmannii	Buloke	4–8	w	6.0	5.2	4.4	3.4
A. verticillata	Drooping sheoak	4–8	w	6.0	5.2	4.4	3.4

Table A5.14 (continued)

Species	Common name	Salinity tolerance threshold (ECe dS/m)	Source	ECi [a] 25% LF (eg sand)	20% LF (eg sandy loam)	17% LF (eg loam)	12% LF (eg light clay)
Atriplex amnicola	River saltbush	>16	s	16.0	13.8	11.8	9.0
A. bunburyana	Silver saltbush	>16	s	16.0	13.8	11.8	9.0
A. cinerea	Grey saltbush	>16	s	16.0	13.8	11.8	9.0
A. lentiformis	Quailbrush	>16	s	16.0	13.8	11.8	9.0
A. muelleri		>16	s	16.0	13.8	11.8	9.0
A. nummularia	Old man saltbush	>16	s	16.0	13.8	11.8	9.0
A. semibaccata	Creeping saltbush	>16	s	16.0	13.8	11.8	9.0
A. undulata	Wavy-leafed saltbush	>16	s	16.0	13.8	11.8	9.0
Banksia spp	Banksia	>8	u	8.0	6.9	5.9	4.5
Callistemon citrinus	Crimson bottlebrush	>8	u	8.0	6.9	5.9	4.5
C. paludosus	River bottlebrush	4–8	s	6.0	5.2	4.4	3.4
C. phoeniceus	Lesser bottlebrush	4–8	s	6.0	5.2	4.4	3.4
C. salignus	Willow bottlebrush	2–4	s	3.0	2.6	2.2	1.7
C. viminalis	Bottlebrush	6–8	u	7.0	6.0	5.1	3.9
Calocephalus brownii	Pincushion bush	6–8	u	7.0	6.0	5.1	3.9
Casuarina cristata ssp *cristata*	Black oak, belah	4–8	s	6.0	5.2	4.4	3.4
C. cristata ssp *pauper*	Belah (WA ssp)	4–8	w	6.0	5.2	4.4	3.4
C. cunning-hamiana	River sheoak	4–8	w	6.0	5.2	4.4	3.4
C. equisetifolia	Horsetail sheoak	8–16	s	12.0	10.3	8.8	6.7
C. equisetifolia	Beach-oak	4–6	u	5.0	4.3	3.7	2.8
C. glauca		8–16	w	12.0	10.3	8.8	6.7
C. littoralis		2–4	s	3.0	2.6	2.2	1.7
C. obesa	Salt sheoak	>16	s	16.0	13.8	11.8	9.0
C. obesa		>16	w	16.0	13.8	11.8	9.0
C. stricta		2–4	s	3.0	2.6	2.2	1.7
C. torulosa		2–4	s	3.0	2.6	2.2	1.7
Correa alba	White correa	>8	u				
Corymbia citriodora ssp *variegata*	Lemon-scented gum	2–4	w	3.0	2.6	2.2	1.7

Table A5.14 (continued)

Species	Common name	Salinity tolerance threshold (ECe dS/m)	Source	ECi [a] 25% LF (eg sand)	20% LF (eg sandy loam)	17% LF (eg loam)	12% LF (eg light clay)
Corymbia maculata	Spotted gum	2–4	w	3.0	2.6	2.2	1.7
Dodonaea viscosa	Dodonaea	4–6	t	5.0	4.3	3.7	2.8
Eucalyptus accedens	Powderbark wandoo	<2	s	1.5	1.3	1.1	0.8
E. aggregata	Black gum	2–4	w	3.0	2.6	2.2	1.7
E. anceps		4–8	s	6.0	5.2	4.4	3.4
E. angustissima ssp *angustissima*	Narrow leaved mallee	2–4	w	3.0	2.6	2.2	1.7
E. argophloia		1.3	v	1.3	1.1	1.0	0.7
E. astringens	Brown mallet	4–8	w	6.0	5.2	4.4	3.4
E. bicostata	Eurabbie	2–4	s	3.0	2.6	2.2	1.7
E. botryoides	Southern mahogany	2–4	w	3.0	2.6	2.2	1.7
E. brachycorys	Comet Vale mallee	4–8	s	6.0	5.2	4.4	3.4
E. brockwayi	Dundas mahogany	2–4	w	3.0	2.6	2.2	1.7
E. calycogona ssp *calycogona*		2–4	s	3.0	2.6	2.2	1.7
E. camaldulensis	River red gum	4–8	w	6.0	5.2	4.4	3.4
E. campaspe	Silver gimlet	4–8	w	6.0	5.2	4.4	3.4
E. camphora	Swamp gum	2–4	w	3.0	2.6	2.2	1.7
E. celastroides ssp *celastroides*	Mealy blackbutt	2–4	s	3.0	2.6	2.2	1.7
E. cinerea	Argyle apple	2–4	s	3.0	2.6	2.2	1.7
E. cladocalyx	Sugar gum	2–4	w	3.0	2.6	2.2	1.7
E. clelandii	Cleland's blackbutt	2–4	s	3.0	2.6	2.2	1.7
E. concinna	Victoria Desert mallee	2–4	s	3.0	2.6	2.2	1.7
E. conferrumin-ata	Bald Island marlock	2–4	s	3.0	2.6	2.2	1.7
E. coolabah	Coolibah	2–4	w	3.0	2.6	2.2	1.7
E. cornuta		2–4	w	3.0	2.6	2.2	1.7
E. crenulata	Victorian silver gum	2–4	w	3.0	2.6	2.2	1.7
E. diptera	Two-winged gimlet	4–8	s	6.0	5.2	4.4	3.4
E. diversifolia	Coastal mallee	2–4	s	3.0	2.6	2.2	1.7
E. elata	River peppermint	2–4	s	3.0	2.6	2.2	1.7
E. famelica	Salt mallee	4–8	w	6.0	5.2	4.4	3.4
E. flocktoniae	Merrit	2–4	s	2.0	1.7	1.5	1.1
E. foliosa		4–8	s	6.0	5.2	4.4	3.4
E. forrestiana ssp *forrestiana*	Fuschia mallee	2–4	s	3.0	2.6	2.2	1.7

Table A5.14 (continued)

Species	Common name	Salinity tolerance threshold (ECe dS/m)	Source	ECi [a] 25% LF (eg sand)	20% LF (eg sandy loam)	17% LF (eg loam)	12% LF (eg light clay)
E. globulus ssp *bicostata*	Blue gum	2–4	w	3.0	2.6	2.2	1.7
E. globulus ssp *globulus*	Blue gum	2–4	w	3.0	2.6	2.2	1.7
E. gompho-cephala	Tuart	4–8	w	6.0	5.2	4.4	3.4
E. grandis	Rose gum	2–4	w	3.0	2.6	2.2	1.7
E. griffithsii	Griffith's grey gum	2–4	s	3.0	2.6	2.2	1.7
E. halophila	Salt lake mallee	8–16	w	12.0	10.3	8.8	6.7
E. hypochlam-ydea ssp *ecdysiastes*		2–4	s	3.0	2.6	2.2	1.7
E. incrassata	Ridge-fruited mallee	8–16	s	12.0	10.3	8.8	6.7
E. kondininensis	Kondinin blackbutt	8–16	w	12.0	10.3	8.8	6.7
E. largiflorens	Black box, river box	4–8	w	6.0	5.2	4.4	3.4
E. leptocalyx	Hopetoun mallee	4–8	s	6.0	5.2	4.4	3.4
E. lesouefii	Goldfields blackbutt	4–8	s	6.0	5.2	4.4	3.4
E. leucoxylon	SA blue gum	4–8	w	6.0	5.2	4.4	3.4
E. leucoxylon ssp *petiolaris*	Eyre Peninsula blue gum	4–8	s	6.0	5.2	4.4	3.4
E. longicornis	Red morrell	2–4	s	3.0	2.6	2.2	1.7
E. loxophleba ssp *lissophloia*	York gum	4–8	s	4.0	3.4	2.9	2.2
E. loxophleba ssp *loxophleba*	York gum	2–4	w	3.0	2.6	2.2	1.7
E. macrandra	Long-flowered marlock	2–4	s	3.0	2.6	2.2	1.7
E. megacornuta	Warted yate	2–4	s	3.0	2.6	2.2	1.7
E. melliodora	Yellow box	4–8	w	4.0	3.4	2.9	2.2
E. merrickiae	Goblet mallee	2–4	s	3.0	2.6	2.2	1.7
E. microcarpa	Grey box	2–4	w	3.0	2.6	2.2	1.7
E. mimica		4–8	s	6.0	5.2	4.4	3.4
E. moluccana	Grey box	4–8	w	6.0	5.2	4.4	3.4
E. occidentalis	Flat top yate	8–16	w	12.0	10.3	8.8	6.7
E. ovata	Swamp gum	2–4	w	3.0	2.6	2.2	1.7
E. ovularis	Small-fruited mallee	2–4	s	3.0	2.6	2.2	1.7
E. pileata	Ravensthorpe mallee	6–8	u	7.0	6.0	5.1	3.9

Table A5.14 (continued)

Species	Common name	Salinity tolerance threshold (ECe dS/m)	Source	ECi [a] 25% LF (eg sand)	20% LF (eg sandy loam)	17% LF (eg loam)	12% LF (eg light clay)
E. platycorys	Boorabbin mallee	4–8	s	6.0	5.2	4.4	3.4
E. platypus ssp *platypus*	Round-leaved moort	8–16	w	12.0	10.3	8.8	6.7
E. polyanthemos	Red box	<2	s	1.5	1.3	1.1	0.8
E. polybractea	Blue mallee	4–8	w	6.0	5.2	4.4	3.4
E. quinquen-ervia		4–8	w	6.0	5.2	4.4	3.4
E. raveretiana	Black ironbox	4–8	w	6.0	5.2	4.4	3.4
E. rigens		4–8	s	6.0	5.2	4.4	3.4
E. robusta	Swamp mahogany	4–8	w	6.0	5.2	4.4	3.4
E. rudis	Flooded gum	4–8	w	6.0	5.2	4.4	3.4
E. salicola	Salt gum	4–8	w	6.0	5.2	4.4	3.4
E. saligna	Sydney blue gum	2–4	w	3.0	2.6	2.2	1.7
E. salmono-phloia	Salmon gum	2–4	s	3.0	2.6	2.2	1.7
E. sargentii ssp *sargentii*	Salt river gum	8–16	w	12.0	10.3	8.8	6.7
E. sideroxylon	Red ironbark	6–8	u	7.0	6.0	5.1	3.9
E. sideroxylon		2–4	w	3.0	2.6	2.2	1.7
E. spathulata ssp *spathulata*	Swamp mallet	8–16	w	12.0	10.3	8.8	6.7
E. stricklandii	Strickland's gum	4–8	s	6.0	5.2	4.4	3.4
E. stypheloides		4–8	w	6.0	5.2	4.4	3.4
E. talyuberlup	Pretty yate	<2	s	1.5	1.3	1.1	0.8
E. tereticornis	Forest red gum	4–8	w	6.0	5.2	4.4	3.4
E. torquata	Coral gum	2–4	s	3.0	2.6	2.2	1.7
E. tricarpa	Three-fruited red ironbark	2–4	w	3.0	2.6	2.2	1.7
E. varia ssp *salsuginosa*		4–8	s	6.0	5.2	4.4	3.4
E. vegrandis		4–8	s	6.0	5.2	4.4	3.4
E. viminalis ssp *viminalis*	Manna gum	2–4	w	3.0	2.6	2.2	1.7
E. wandoo	Wandoo	4–8	w	6.0	5.2	4.4	3.4
E. xanthonema		4–8	s	6.0	5.2	4.4	3.4
E. yilgarnensis		2–4	s	3.0	2.6	2.2	1.7
Frankenia spp		>16	s	16.0	13.8	11.8	9.0
Hakea suaveolens	Sweet hakea	4–6	u	5.0	4.3	3.7	2.8
Halosarcia spp	Samphire	>16	s	16.0	13.8	11.8	9.0

Table A5.14 (continued)

Species	Common name	Salinity tolerance threshold (ECe dS/m)	Source	ECi [a] 25% LF (eg sand)	20% LF (eg sandy loam)	17% LF (eg loam)	12% LF (eg light clay)
Hibbertia scandens	Snake vine	>8	u	8.0	6.9	5.9	4.5
Lagunaria patersonii	Norfolk Island hibiscus	6–8	s	7.0	6.0	5.1	3.9
Leptospermum laevigatum	Tea tree	>8	u	8.0	6.9	5.9	4.5
Maireana brevifolia	Small-leaved bluebush	4–8	s	6.0	5.2	4.4	3.4
Melaleuca acuminata	Broombush	4–8	w	6.0	5.2	4.4	3.4
M. armillaris	Bracelet honey-myrtle	4–8	w, u	6.0	5.2	4.4	3.4
M. bracteata	River teatree	4–8	w	6.0	5.2	4.4	3.4
M. brevifolia	Mallee honeymyrtle	4–8	s	6.0	5.2	4.4	3.4
M. cuticularis	Salt paperbark	8–16	w	8.0	6.9	5.9	4.5
M. dealbata		4–8	s	6.0	5.2	4.4	3.4
M. decussata	Cross-leaf honeymyrtle	4–8	w	6.0	5.2	4.4	3.4
M. diosmifolia	Cajeput tree	>8	u	8.0	6.9	5.9	4.5
M. ericifolia	Swamp paperbark	4–8	w	6.0	5.2	4.4	3.4
M. halmatorum		>16	w	16.0	13.8	11.8	9.0
M. halmaturo-rum ssp *cymbifolia*		>16	s	16.0	13.8	11.8	9.0
M. halmaturo-rum ssp *halmaturo-rum*	SA swamp paperbark	>16	s	16.0	13.8	11.8	9.0
M. hamulosa		8–16	s	12.0	10.3	8.8	6.7
M. lanceolata	Rottnest Island teatree	8–16	w	12.0	10.3	8.8	6.7
M. lateriflora		4–8	w	6.0	5.2	4.4	3.4
M. leucadendra	Cadjeput	8–16	w	12.0	10.3	8.8	6.7
M. linariifolia	Narrow-leaved paperbark	4–8	w	6.0	5.2	4.4	3.4
M. microphylla		4–8	s	6.0	5.2	4.4	3.4
M. nesophila	Western tea-myrtle	4–8	u	6.0	5.2	4.4	3.4
M. preissiana	Moonah	2–4	s	3.0	2.6	2.2	1.7
M. quinquin-ervia	Five-veined paperbark	4–8	s	6.0	5.2	4.4	3.4
M. rhaphio-phylla		4–8	s	6.0	5.2	4.4	3.4
M. squarrosa	Scented paperbark	4–8	s	6.0	5.2	4.4	3.4

Table A5.14 (continued)

Species	Common name	Salinity tolerance threshold (ECe dS/m)	Source	ECi [a]			
				25% LF (eg sand)	20% LF (eg sandy loam)	17% LF (eg loam)	12% LF (eg light clay)
M. styphelioides	Prickly-leaved paperbark	6–8	s	7.0	6.0	5.1	3.9
M. thyoides		>16	s	16.0	13.8	11.8	9.0
M. thyoides		>16	w	16.0	13.8	11.8	9.0
M. uncinata	Broombush	4–8	w	6.0	5.2	4.4	3.4
M. viminea		6–8	u	7.0	6.0	5.1	3.9
Myoporum desertii	Turkey bush	4–8	s	6.0	5.2	4.4	3.4
M. insulare	Boobialla	4–8	s	6.0	5.2	4.4	3.4
M. spp	Boobialla	8	u	8.0	6.9	5.9	4.5
Paspalum vaginatum	Saltwater couch	>16	s	16.0	13.8	11.8	9.0
Pittosporum phyiliaeoides	Native apricot	4–8	s	6.0	5.2	4.4	3.4
Puccinellia ciliata	Puccinellia	>16	s	16.0	13.8	11.8	9.0
Sarcocornia spp *(S quinqueflora)*	Glasswort, samphire	>16	s	16.0	13.8	11.8	9.0
Sporobolus virginicus	Marine couch	>16	s	16.0	13.8	11.8	9.0
Syzygium paniculatum	Bush cherry	4–6	u	5.0	4.3	3.7	2.8
Westringia fruticosa	Rosemary westringia	>8	u	8.0	6.9	5.9	4.5

EC = electrical conductivity in dS/m; ECe = electrical conductivity of a soil paste extract; ECi = electrical conductivity of irrigation water; LF = leaching fraction.

Values in this table are indicative only. Salt tolerance of all plants will vary depending on a range of factors, such as soil type, drainage, climate and maturity (seedlings can be more sensitive). If original references have quoted a >ECe tolerance, this ECe has been used to conservatively estimate ECi; if a <ECe has been quoted, 75% of this ECe has been used to estimate ECi. For reference ‘u’, ECe quoted is approximately 25% growth reduction.

a ECi has been estimated from ECe assuming limited rainfall and the specified LF using equation 9 from Ayers and Westcot (1985). Where more than one ECe value was found in the literature, the ANZECC and ARMCANZ (2000a) value has been used, or the lowest value reported.

Sources:
s = Agriculture WA (2003)
t = Maas (1986)
u = Cresswell and Weir (1997)
w = Macar and Crawford (2004).

Table A5.15 Approximate salinity tolerance of fruit, vegetable, grain and pasture crops

Scientific name	Common name	Salinity tolerance threshold (ECe dS/m)	Source	ECi [a]			
				25% LF (eg sand)	20% LF (eg sandy loam)	17% LF (eg loam)	12% LF (eg light clay)
Fruit crops							
Prunus dulcis	Almond	1.5–4	t, u	2.8	2.4	2.0	1.5
Malus sylvestris	Apple	1	t	1.0	0.9	0.7	0.6
Prunus armeniaca	Apricot	1.6	o	1.6	1.4	1.2	0.9
Persea americana	Avocado	1.3	t	1.3	1.1	1.0	0.7
Rubus spp	Blackberry, boysenberry, etc	1.5	o	1.5	1.3	1.1	0.8
Vitis spp	Grape	1.5–8	t, u, r	4.8	4.1	3.5	2.7
Citrus paradisi	Grapefruit	1.8–6	t, u	3.9	3.4	2.9	2.2
Citrus limonea	Lemon	1–6	t, u	3.5	3.0	2.6	2.0
Olea europaea	Olive	4	t	4.0	3.4	2.9	2.2
Citrus sinensis	Orange	1.7–6	t, u	3.9	3.3	2.8	2.2
Prunus persica	Peach	3.2	t	3.2	2.8	2.4	1.8
Pyrus spp	Pear	1	t	1.0	0.9	0.7	0.6
Cucurbita pepo pepo	Pumpkin	1.5–3*	o	2.3	1.9	1.7	1.3
Capsicum annuum	Pepper	1.5	o	1.5	1.3	1.1	0.8
Prunus domestica	Plum	1.5	o	1.5	1.3	1.1	0.8
Cucumis melo	Rockmelon	2.2	t	2.2	1.9	1.6	1.2
Fragaria spp	Strawberry	1	o	1.0	0.9	0.7	0.6
Lycopersicon esculentum	Tomato	2.3–2.5	t,o	2.4	2.1	1.8	1.3
Cucurbita pepo melopepo	Zucchini	4.7	o	4.7	4.1	3.5	2.6
Grain crops							
Hordeum vulgare	Barley	8	o	8.0	6.9	5.9	4.5
Brassica napus	Canola (oilseed rape)	2–4	r	3.0	2.6	2.2	1.7
Vicia faba	Faba bean	2–4	r	3.0	2.6	2.2	1.7
Lupinus angustifolium	Narrow-leaf lupin	2–4	r	3.0	2.6	2.2	1.7
Avena sativa	Oats	5	t	5.0	4.3	3.7	2.8
Zea mays	Corn, grain, sweet	1.7	t	1.7	1.5	1.3	1.0
Gossypium hirsutum	Cotton	7.7	t	7.7	6.6	5.7	4.3
Vigna unguiculata	Cowpea (seed)	1.6	t	1.6	1.4	1.2	0.9
Vigna unguiculata var Caloona	Cowpea, Caloona	2.0	t	2.0	1.7	1.5	1.1
Vinum usitatissimum	Flax/Linseed	1.7	t	1.7	1.5	1.3	1.0
Sorghum	Peanut	3.2	t	3.2	2.8	2.4	1.8
Sorghum, crooble	Phasey bean, Murray	0.8	t	0.8	0.7	0.6	0.4
Soybean	Rice, paddy	3	t	3.0	2.6	2.2	1.7
Carthamus tinctorius	Safflower	6.5	t	6.5	5.6	4.8	3.7
Sorghum bicolor	Sorghum	6.8	t	6.8	5.9	5.0	3.8

Scientific name	Common name	Salinity tolerance threshold (ECe dS/m)	Source	ECi [a]			
				25% LF (eg sand)	20% LF (eg sandy loam)	17% LF (eg loam)	12% LF (eg light clay)
Grain crops (continued)							
Sorghum almum	Sorghum, crooble	8.3	t	8.3	7.2	6.1	4.7
Glycine max	Soybean	5.0	t	5.0	4.3	3.7	2.8
Saccharum officinarum	Sugarcane	1.7	t	1.7	1.5	1.3	1.0
Helianthus annuus	Sunflower	5.5	t	5.5	4.7	4.0	3.1
Triticum turgidum	Wheat, durum	5.7	t	5.7	4.9	4.2	3.2
Triticum aestivum	Wheat	2–6	r, t	4.0	3.4	2.9	2.2
Pasture crops							
Trifolium michelianum	Balansa clover	4–8	r	6.0	5.2	4.4	3.4
Hordeum vulgare	Barley (forage)	6	o	6.0	5.2	4.4	3.4
Medicago truncatula	Barrel medic	<2	r	1.5	1.3	1.1	0.8
Cynodon dactylon	Bermuda grass	6.9	o	6.9	5.9	5.1	3.9
Trifolium alexandrinum	Berseem clover	2–4	r	3.0	2.6	2.2	1.7
Lotus corniculatus	Birdsfoot trefoil (narrow leaf)	5	o	5.0	4.3	3.7	2.8
	Brome, meadow	4.4	x	4.4	3.8	3.2	2.5
Bromus inermis	Brome, smooth	1.5–3	o	2.3	1.9	1.7	1.3
Medicago polymorpha ssp *brevispina*	Burr medic	2–4	r	3.0	2.6	2.2	1.7
Trifolium	Clovers (alsike, ladino, red)	1.5	o	1.5	1.3	1.1	0.8
Dactylis glomerata	Cocksfoot	<2	r	1.5	1.3	1.1	0.8
Pennisetum clandestinum	Kikuyu	2–4	r	3.0	2.6	2.2	1.7
Eragrostris spp	Lovegrass	2	o	2.0	1.7	1.5	1.1
Medicago sativa	Lucerne (alfalfa)	2	o	2.0	1.7	1.5	1.1
Alopecurus pratensis	Meadow foxtail	1.5	o	1.5	1.3	1.1	0.8
Medicago murex	Murex medic	<2	r	1.5	1.3	1.1	0.8
Avena sativa	Oats (forage)	2.6	x	2.6	2.2	1.9	1.5
Dactylis glomerata	Orchard grass	1.5	o	1.5	1.3	1.1	0.8
Pisum sativum	Pea	2.5	t	2.5	2.2	1.8	1.4
Lolium perenne	Perennial ryegrass	5.6	o	5.6	4.8	4.1	3.1
Trifolium resupinatum	Persian clover	4–8	r	6.0	5.2	4.4	3.4
Phalaris aquatica	Phalaris	2–4	r	3.0	2.6	2.2	1.7
Phalaris tuberosa (aquatica)	Phalaris	4.2	t	4.2	3.6	3.1	2.4
Chloris gayana	Rhodes grass	4–8	r	6.0	5.2	4.4	3.4
Trifolium hirtum	Rose clover	<2	r	1.5	1.3	1.1	0.8
Secale cereale	Rye (forage)	2.5	x	2.5	2.2	1.8	1.4

Scientific name	Common name	Salinity tolerance threshold (ECe dS/m)	Source	ECi [a]			
				25% LF (eg sand)	20% LF (eg sandy loam)	17% LF (eg loam)	12% LF (eg light clay)
Pasture crops (continued)							
Ornithopus spp	Serradella	<2	r	1.5	1.3	1.1	0.8
Sorghum bicolor	Sorghum	4–8	r	6.0	5.2	4.4	3.4
Medicago littoralis	Strand medic	<2	r	1.5	1.3	1.1	0.8
Trifolium fragiferum	Strawberry clover	1.5	o	1.5	1.3	1.1	0.8
Trifolium subteranneum	Subterraneum clover	<2	r	1.5	1.3	1.1	0.8
Sorghum sudanense	Sudangrass	2.8	o	2.8	2.4	2.1	1.6
Melilotus officinalis	Sweet clover	4	x	4.0	3.4	2.9	2.2
Festuca arundinacea	Tall fescue	3.9–8	r, o	6.0	5.1	4.4	3.3
Thinopyrum elongatum	Tall wheat grass	4–8	r	6.0	5.2	4.4	3.4
Phleum pratense	Timothy	2	x	2.0	1.7	1.5	1.1
	Triticale (forage)	6.1	x	6.1	5.3	4.5	3.4
Vicia angustifolia	Vetch (common or spring)	3	o, x	3.0	2.6	2.2	1.7
Agropyron sibiricum	Wheatgrass, standard crested	3.5	o	3.5	3.0	2.6	2.0
Agropyron cristatum	Wheatgrass, fairway crested	7.5	o	7.5	6.5	5.5	4.2
Trifolium repens	White clover (NZ)	1	t	1.0	0.9	0.7	0.6
Trifolium semipilosum	White clover (Safari)	1.5	t	1.5	1.3	1.1	0.8
Ornithopus compressus	Yellow serradella	<2	r	1.5	1.3	1.1	0.8
Vegetables							
Asparagus officinalis	Asparagus	4.1	o	4.1	3.5	3.0	2.3
Phaseolus vulgaris	Bean	1	o	1.0	0.9	0.7	0.6
Beta vulgaris	Beet, garden	4	o	4.0	3.4	2.9	2.2
Beta vulgaris	Beet, sugar	7	t	7.0	6.0	5.1	3.9
Brassica oleracea botrytis	Broccoli	2.8	o	2.8	2.4	2.1	1.6
Brassica oleracea capitata	Cabbage	1.8	o	1.8	1.6	1.3	1.0
Daucus carota	Carrot	1	o	1.0	0.9	0.7	0.6
Brassica oleracea	Cauliflower	2.5	t	2.5	2.2	1.8	1.4
Apium graveolens	Celery	1.8	o	1.8	1.6	1.3	1.0
Cucumis sativus	Cucumber	2.5	o	2.5	2.2	1.8	1.4
Solanum melongena	Eggplant	1.1	t	1.1	0.9	0.8	0.6
Brassica campestris	Kale	6.5	t	6.5	5.6	4.8	3.7
Lactuca sativa	Lettuce	1.3	o	1.3	1.1	1.0	0.7
Allium cepa	Onion	1.2	o	1.2	1.0	0.9	0.7
Solanum tuberosum	Potato	1.7	o	1.7	1.5	1.3	1.0
Raphanus sativus	Radish	1.2	o	1.2	1.0	0.9	0.7

Scientific name	Common name	Salinity tolerance threshold (ECe dS/m)	Source	ECi[a]			
				25% LF (eg sand)	20% LF (eg sandy loam)	17% LF (eg loam)	12% LF (eg light clay)
Vegetables (continued)							
Rosmarinus lockwoodii	Rosemary	4.5	t	4.5	3.9	3.3	2.5
Rosmarinus officinalis	Rosemary	6–8	o	7.0	6.0	5.1	3.9
Spinacia oleracea	Spinach	2	o	2.0	1.7	1.5	1.1
Cucurbita maxima	Squash	2.5	t	2.5	2.2	1.8	1.4
Cucurbita pepo melopepo	Squash, scallop	3.2	o	3.2	2.8	2.4	1.8
Zea mays	Sweet corn	1.7–1.8	t,o	1.7	1.5	1.3	1.0
Ipomoea batatas	Sweet potato	1.5	o	1.5	1.3	1.1	0.8
Brassica rapa	Turnip	0.9	o	0.9	0.8	0.7	0.5

EC = electrical conductivity in dS/m; ECe = electrical conductivity of a soil paste extract; ECi = electrical conductivity of irrigation water; LF = leaching fraction.

Values in this table are indicative only; salt tolerance of all plants will vary depending on a range of factors, such as soil type, drainage, climate and maturity (seedlings can be more sensitive).

a ECi has been estimated from ECe threshold assuming limited rainfall and the specified LF using equation 9 from Ayers and Westcot (1985). If original references have quoted a >ECe tolerance, this ECe has been used to conservatively estimate ECi; if a <ECe has been quoted, 75% of this ECe has been used to calculate ECi. Where more than one ECe threshold value was reported, the mid-range value was used to estimate the ECi.

Sources:
o = Maas (1986) (* = estimates)
r = Agriculture WA (2003)
t = ANZECC and ARMCANZ (2000), Maas (1987)
u = Cresswell and Weir (1997)
x = Kotuby-Amacher et al (1987)

Table A5.16 Approximate salinity tolerance of some ornamental plants

Scientific name	Common name	Soil salinity tolerance threshold (ECe dS/m)	Source	ECi[a]			
				25% LF (eg sand)	20% LF (eg sandy loam)	17% LF (eg loam)	12% LF (eg light clay)
Abelia x *grandiflora*	Glossy abelia	2–4	p	3.0	2.6	2.2	1.7
Acacia cyanophylla	Orange wattle	>8	p	8.0	6.9	5.9	4.5
Acacia longifolia var *sophorae*	Coast wattle	>8	p	8.0	6.9	5.9	4.5
Acanthus mollis	Bear's breeches	<2	p	1.5	1.3	1.1	0.8
Agapanthus spp	African lily	4–6	p	5.0	4.3	3.7	2.8
Agave attenuata	Century plant	4–6	p	5.0	4.3	3.7	2.8
Alyxia buxifolia	Sea-box	>8	p	8.0	6.9	5.9	4.5
Araucaria heterophylla	Norfolk Island pine	>8	p	8.0	6.9	5.9	4.5
Arbutus unedo	Irish strawberry tree	2–4	p	3.0	2.6	2.2	1.7
Arctotheca calendula	Capeweed	>8	p	8.0	6.9	5.9	4.5
Arecastrum romanzoffianum	Queen palm	4–6	p	5.0	4.3	3.7	2.8
Aster spp	Aster	2–4	p	3.0	2.6	2.2	1.7
Baccharis pilularis	Coyote bush	>8	p	8.0	6.9	5.9	4.5

Table A5.16 (continued)

Scientific name	Common name	Soil salinity tolerance threshold (ECe dS/m)	Source	ECi[a] 25% LF (eg sand)	ECi[a] 20% LF (eg sandy loam)	ECi[a] 17% LF (eg loam)	ECi[a] 12% LF (eg light clay)
Bauhinia purpurea	Orchid tree	4–6	p	5.0	4.3	3.7	2.8
Begonia spp	Begonia	<2	p	1.5	1.3	1.1	0.8
Berberis thunbergii	Barberry	<2	p	1.5	1.3	1.1	0.8
Berberis x *mentorensis*	Barberry	2–4	p	3.0	2.6	2.2	1.7
Bougainvillea spectabilis	Bougainvillea	6–8	p	7.0	6.0	5.1	3.9
Brahea edulis	Guadalupe palm	6–8	p	7.0	6.0	5.1	3.9
Brunfelsia paucifIora	Yesterday, today and tomorrow	4–6	p	5.0	4.3	3.7	2.8
Buxus microphylla	Boxwood	4–6	p	5.0	4.3	3.7	2.8
Buxus microphylla var *Japonica*	Boxwood	1.7	t	1.7	1.5	1.3	1.0
Camellia spp	Camellia	<2	p	1.5	1.3	1.1	0.8
Carissa grandiflora	Natal plum	>8	p	8.0	6.9	5.9	4.5
Carpobrotus chilensis	Pigfaces	>8	p	8.0	6.9	5.9	4.5
Carpobrotus edulis	Pigfaces	>8	p	8.0	6.9	5.9	4.5
Cedrus atlantica	Blue atlas cedar	<2	p	1.5	1.3	1.1	0.8
Cedrus deodara	Deodar cedar	2–4	p	3.0	2.6	2.2	1.7
Ceratonia siliqua	Carob	2–4	p	3.0	2.6	2.2	1.7
Chamaerops humilis	European fan palm	6–8	p	7.0	6.0	5.1	3.9
Chrysanthemum spp	Chrysanthemum	4–6	p	5.0	4.3	3.7	2.8
Cinnamomum camphora	Camphor tree	2–4	p	3.0	2.6	2.2	1.7
Clivia miniata	Kaffir lily	2–4	p	3.0	2.6	2.2	1.7
Coprosma repens	Mirror plant	>8	p	8.0	6.9	5.9	4.5
Cordyline indivisa	Blue dracaena	6–8	p	7.0	6.0	5.1	3.9
Cortaderia sellowiana	Pampus grass	>8	p	8.0	6.9	5.9	4.5
Cotoneaster congestus	Pyrenees cotoneaster	<2	p	1.5	1.3	1.1	0.8
Cotoneaster horizontalis	Rock cotoneaster	<2	p	1.5	1.3	1.1	0.8
Crassula argentea	Jade plant	2–4	p	3.0	2.6	2.2	1.7
Crassula ovata		6–8	p	7.0	6.0	5.1	3.9
Cupressus arizonica	Arizona cypress	4–6	p	5.0	4.3	3.7	2.8
Cupressus sempervirens	Italian cypress	4–6	p	5.0	4.3	3.7	2.8
Cyclamen spp	Cyclamen	4–6	p	5.0	4.3	3.7	2.8
Cytisus x *praecox*	Broom	<2	p	1.5	1.3	1.1	0.8
Dahlia spp	Dahlia	<2	p	1.5	1.3	1.1	0.8
Delasperma spp	Iceplants	>8	p	8.0	6.9	5.9	4.5
Dianthus caryophyllus	Carnation	4–6	p	5.0	4.3	3.7	2.8
Dodonaea viscosa	Dodonaea	4–6	p	5.0	4.3	3.7	2.8
Dracaena andivisa	Dracaena	4–8	t, p	6.0	5.2	4.4	3.4
Drosanthemum spp	lceplants, pigfaces	>8	p	8.0	6.9	5.9	4.5
Elaeagnus angusitfolia	Russian olive	6–8	p	7.0	6.0	5.1	3.9
Elaeagnus pungens		4–6	p	5.0	4.3	3.7	2.8
Ensete ventricosum	Abyssinian banana	<2	p	1.5	1.3	1.1	0.8
Euonymus alatus	Euonymus	<2	p	1.5	1.3	1.1	0.8
Euonymus japonica	Evergreen spindle-tree	6–8	p	7.0	6.0	5.1	3.9
Euonymus japonica var *grandiflora*	Euonymus	7	t	7.0	6.0	5.1	3.9

Table A5.16 (continued)

Scientific name	Common name	Soil salinity tolerance threshold (ECe dS/m)	Source	ECi[a] 25% LF (eg sand)	20% LF (eg sandy loam)	17% LF (eg loam)	12% LF (eg light clay)
Euphorbia pulcherrima	Poinsettia	2–4	p	3.0	2.6	2.2	1.7
Felecia amelloides	Blue daisy	2–4	p	3.0	2.6	2.2	1.7
Ficus benjamina	Java fig	2–4	p	3.0	2.6	2.2	1.7
Ficus carica	Fig	6–8	p	7.0	6.0	5.1	3.9
Ficus microcarpa	Small-leaf fig	>8	p	8.0	6.9	5.9	4.5
Forsythia x *intermedia*	Showy golden-bells	2–4	p	3.0	2.6	2.2	1.7
Fragaria chiloensis	Strawberry	<2	p	1.5	1.3	1.1	0.8
Fraxinus pennsylvanica	Green ash	4–6	p	5.0	4.3	3.7	2.8
Fuchsia spp	Fuchsia	<2	p	1.5	1.3	1.1	0.8
Gardenia spp	Gardenia	<2	p	1.5	1.3	1.1	0.8
Gelsemium sempervirens	Carolina jasmine	2–4	p	3.0	2.6	2.2	1.7
Geranium spp	Geranium	2–4	p	3.0	2.6	2.2	1.7
Gladiolus spp	Gladiolus	2–4	p	3.0	2.6	2.2	1.7
Gleditsia triacanthos	Honey locust	6–8	p	7.0	6.0	5.1	3.9
Hedera canariensis	Algerian ivy	1–4	p,t	1.0	0.9	0.7	0.6
Hibiscus rosasinensis	Chinese hibiscus	6–8	p	7.0	6.0	5.1	3.9
Hymenocyclus spp	lceplants	>8	p	8.0	6.9	5.9	4.5
Ilex cornuta	Chinese holly cv. Burford	2–4	p	3.0	2.6	2.2	1.7
Juglans regia	Walnut	4–6	p	5.0	4.3	3.7	2.8
Juniperus chinensis	Juniper	1.5–6	t, p	3.8	3.2	2.8	2.1
Juniperus virginiana	Eastern red cedar	2–4	p	3.0	2.6	2.2	1.7
Lagerstroemia indica	Crepe myrtle	2–4	p	3.0	2.6	2.2	1.7
Lagunaria patersonii	Norfolk Island hibiscus	>8	p	8.0	6.9	5.9	4.5
Lampranthus spp	Iceplants	>8	p	8.0	6.9	5.9	4.5
Lantana camara	Lantana	1.8–6	t,p	3.9	3.4	2.9	2.2
Leucophyllum frutescens	Texas sage	>8	p	8.0	6.9	5.9	4.5
Ligustrum japonicum	Japanese privet	4–6	p	5.0	4.3	3.7	2.8
Ligustrum lucidum	Privet	2	t	2.0	1.7	1.5	1.1
Lilium spp	Lily	<2	p	1.5	1.3	1.1	0.8
Limonium perezii	Sea lavender	2–4	p	3.0	2.6	2.2	1.7
Lippia canescens repens	Lippia	>8	p	8.0	6.9	5.9	4.5
Liquidambar styracifiua	Sweet gum	6–8	p	7.0	6.0	5.1	3.9
Liriodendron tulipifera	Tulip tree	2–4	p	3.0	2.6	2.2	1.7
Lonicera japonica	Honeysuckle	2–4	p	3.0	2.6	2.2	1.7
Magnolia grandifIora	Magnolia	2–4	p	3.0	2.6	2.2	1.7
Magnolia grandiflora	Southern magnolia	4–6	p	5.0	4.3	3.7	2.8
Mahonia aquifolium	Oregon grape holly	<2	p	1.5	1.3	1.1	0.8
Mathiola incana	Stock	2–4	p	3.0	2.6	2.2	1.7
Metrosideros excelsa	New Zealand Christmas tree	6–8	p	7.0	6.0	5.1	3.9
Moraea vegeta	Iris	>8	p	8.0	6.9	5.9	4.5
Nandina domestica	Heavenly bamboo	1–4	t,o	2.5	2.2	1.8	1.4
Nerium oleander	Oleander	6–8	p	7.0	6.0	5.1	3.9

Table A5.16 (continued)

Scientific name	Common name	Soil salinity tolerance threshold (ECe dS/m)	Source	ECi[a] 25% LF (eg sand)	20% LF (eg sandy loam)	17% LF (eg loam)	12% LF (eg light clay)
Olea europaea	Olive	6–8	p	7.0	6.0	5.1	3.9
Ophiopogon jaburan	Lily-turf	6–8	p	7.0	6.0	5.1	3.9
Ophiopogon japonicus	Lily-turf	2–4	p	3.0	2.6	2.2	1.7
Pachysandra terminalis	Japanese spurge	<2	p	1.5	1.3	1.1	0.8
Panicum coloratum	Bambatsi	1.5	t	1.5	1.3	1.1	0.8
Pelargonium australe	Austral stork's bill	>8	p	8.0	6.9	5.9	4.5
Persea americana	Avocado	<2	p	1.5	1.3	1.1	0.8
Philodendron selloum	Philodendron	4–6	p	5.0	4.3	3.7	2.8
Phoenix dactylifera	Date palm	>8	p	8.0	6.9	5.9	4.5
Phormium tenax	New Zealand flax	4–6	p	5.0	4.3	3.7	2.8
Photinia x *fraseri* *Robusta*	Photinia	<2	p	1.5	1.3	1.1	0.8
Picea pungens	Blue spruce	<2	p	1.5	1.3	1.1	0.8
Pinus brutia	Calabrian pine	2–4	w	3.0	2.6	2.2	1.7
Pinus halepensis	Allepo pine	6–8	p	7.0	6.0	5.1	3.9
Pinus pinaster	Maritime pine	4–8	w	4.0	3.4	2.9	2.2
Pinus pinea	Italian stone pine	>8	p	8.0	6.9	5.9	4.5
Pinus ponderosa	Ponderosa pine	4–6	p	5.0	4.3	3.7	2.8
Pinus radiata	Radiata pine	4–8	w	6.0	5.2	4.4	3.4
Pinus thunbergiana	Japanese black pine	4–6	p	5.0	4.3	3.7	2.8
Pittosporum crassifolium	Karo	6–8	p	7.0	6.0	5.1	3.9
Pittosporum tobira	Pittosporum	2–4	p	3.0	2.6	2.2	1.7
Platycladus orientalis	Oriental arborvitae	4–6	p	5.0	4.3	3.7	2.8
Podocarpus macrophyllus	cv. Maki	2–4	p	3.0	2.6	2.2	1.7
Primula spp	Primula	<2	p	1.5	1.3	1.1	0.8
Prunus cerasifera	Cherry plum	4–6	p	5.0	4.3	3.7	2.8
Prunus domestica	Plum	2–4	p	3.0	2.6	2.2	1.7
Prunus malus	Apple	4–6	p	5.0	4.3	3.7	2.8
Pseudotsuga menziesii	Douglas fir	<2	p	1.5	1.3	1.1	0.8
Pyracantha braperi	Pyracantha	2–6	t, p	4.0	3.4	2.9	2.2
Pyracantha koidzumii	Firethorn	2–4	p	3.0	2.6	2.2	1.7
Pyrus kawakamii	Evergreen pear	>8	p	8.0	6.9	5.9	4.5
Raphiolepis indica	Indian hawthorn	4–6	p	5.0	4.3	3.7	2.8
Rhamnus alternus	Italian blackthorn	2–4	p	3.0	2.6	2.2	1.7
Rhododendron spp	Azalea, rhododendron	<2	p	1.5	1.3	1.1	0.8
Robinia pseudoacacia	Black locust	6–8	p	7.0	6.0	5.1	3.9
Rosa spp	Rose	<2	p	1.5	1.3	1.1	0.8
Rosa spp	Rose cv. Grenoble	2–4	p	3.0	2.6	2.2	1.7
Saintpaulia ionantha	African violet	<2	p	1.5	1.3	1.1	0.8
Salix purpurea	Blue willow	<2	p	1.5	1.3	1.1	0.8
Salix vitellina	Golden willow	4–6	p	5.0	4.3	3.7	2.8
Scaevola calendulacea	Dune fan flower	>8	p	8.0	6.9	5.9	4.5
Schinus molle var *areira*	Pepper tree	2–4	w	3.0	2.6	2.2	1.7
Shepherdia argentea	Buffaloberry	4–6	p	5.0	4.3	3.7	2.8
Spiraea spp	Spiraea	<2	p	1.5	1.3	1.1	0.8

Table A5.16 (continued)

Scientific name	Common name	Soil salinity tolerance threshold (ECe dS/m)	Source	ECi[a] 25% LF (eg sand)	ECi[a] 20% LF (eg sandy loam)	ECi[a] 17% LF (eg loam)	ECi[a] 12% LF (eg light clay)
Strelitzia reginae	Bird of paradise	2–4	p	3.0	2.6	2.2	1.7
Tamarix pentandra	Tamarix	>8	p	8.0	6.9	5.9	4.5
Thuja orientalis	Aborvitae	2	t	2.0	1.7	1.5	1.1
Thuja orientalis	Chinese arbovitae	4–6	p	5.0	4.3	3.7	2.8
Tilia cordata	Linden	<2	p	1.5	1.3	1.1	0.8
Trachelospermum jasminoides	Star jasmine	<2	p	1.5	1.3	1.1	0.8
Viburnum spp	Viburnum	1.4	t	1.4	1.2	1.0	0.8
Viburnum tinus	Viburnum	2–4	p	3.0	2.6	2.2	1.7
Vinea minor	Dwarf running myrtle	2–4	p	3.0	2.6	2.2	1.7
Viola hederacea	Violet	<2	p	1.5	1.3	1.1	0.8
Washingtonia robusta	Cotton palm	2–4	p	3.0	2.6	2.2	1.7
Xylosma senticosa	Xylosma	1.5–6	t, p	3.8	3.2	2.8	2.1
Yucca aloifolia	Spanish bayonet	>8	p	8.0	6.9	5.9	4.5
Yucca filamentosa	Adam’s-needle yucca	2–4	p	3.0	2.6	2.2	1.7
Zinnia elegans	Zinnia	2–4	p	3.0	2.6	2.2	1.7
	Common name						
	Alders	<2	x	1.5	1.3	1.1	0.8
	American holly	2–3	x	2.5	2.2	1.8	1.4
	American linden	<2	x	1.5	1.3	1.1	0.8
	American sycamore	2–3	x	2.5	2.2	1.8	1.4
	Ash (European, green, white)	3–4	x	3.5	3.0	2.6	2.0
	Austrian pine	3–4	x	3.5	3.0	2.6	2.0
	Bald cypress	3–4	x	3.5	3.0	2.6	2.0
	Beech	<2	x	1.5	1.3	1.1	0.8
	Birch (river, white)	2–3	x	2.5	2.2	1.8	1.4
	Blue spruce	2–3	x	2.5	2.2	1.8	1.4
	Box elder	2–3	x	2.5	2.2	1.8	1.4
	Catalpas	2–3	x	2.5	2.2	1.8	1.4
	Chinese date	3–4	x	3.5	3.0	2.6	2.0
	Cottonwoods	3–4	x	3.5	3.0	2.6	2.0
	Dawn redwood	<2	x	1.5	1.3	1.1	0.8
	Eastern redbud	<2	x	1.5	1.3	1.1	0.8
	European hornbeam	<2	x	1.5	1.3	1.1	0.8
	European larch	3–4	x	3.5	3.0	2.6	2.0
	Filbert/hazel	<2	x	1.5	1.3	1.1	0.8
	Firs	2–3	x	2.5	2.2	1.8	1.4
	Flowering crabapple	3–4	x	3.5	3.0	2.6	2.0
	Giant sequoia	<2	x	1.5	1.3	1.1	0.8
	Ginkgo	2–3	x	2.5	2.2	1.8	1.4
	Golden rain tree	3–4	x	3.5	3.0	2.6	2.0
	Hackberry	2–3	x	2.5	2.2	1.8	1.4
	Hawthorn	2–3	x	2.5	2.2	1.8	1.4
	Horsechestnut	3–4	x	3.5	3.0	2.6	2.0
	Japanese arborvitae	<2	x	1.5	1.3	1.1	0.8

Table A5.16 (continued)

Scientific name	Common name	Soil salinity tolerance threshold (ECe dS/m)	Source	ECi[a] 25% LF (eg sand)	20% LF (eg sandy loam)	17% LF (eg loam)	12% LF (eg light clay)
	Littleleaf linden	<2	x	1.5	1.3	1.1	0.8
	Locust (black, Idaho, New Mexico)	3–4	x	3.5	3.0	2.6	2.0
	Lodgepole, SW white,	2–3	x	2.5	2.2	1.8	1.4
	London plane tree	2–3	x	2.5	2.2	1.8	1.4
	Maples (Norway, hedge)	3–4	x	3.5	3.0	2.6	2.0
	Maples (sugar, red)	<2	x	1.5	1.3	1.1	0.8
	Mountain ash	2–3	x	2.5	2.2	1.8	1.4
	Norway spruce	<2	x	1.5	1.3	1.1	0.8
	Oaks (bur, gambel, shingle)	2–3	x	2.5	2.2	1.8	1.4
	Oaks (English, northern red, white)	3–4	x	3.5	3.0	2.6	2.0
	Paper birch	3–4	x	3.5	3.0	2.6	2.0
	Pines (bristlecone, limber)	2–3	x	2.5	2.2	1.8	1.4
	Poplars	3–4	x	3.5	3.0	2.6	2.0
	Scots pine	<2	x	1.5	1.3	1.1	0.8
	Silver linden	2–3	x	2.5	2.2	1.8	1.4
	Spruce (Englemann, white)	2–3	x	2.5	2.2	1.8	1.4
	Tamarack	3–4	x	3.5	3.0	2.6	2.0
	Walnut (black, English)	2–3	x	2.5	2.2	1.8	1.4
	Willows	3–4	x	3.5	3.0	2.6	2.0
	Yellow poplar	<2	x	1.5	1.3	1.1	0.8

EC = electrical conductivity in dS/m; ECe = electrical conductivity of a soil paste extract; ECi = electrical conductivity of irrigation water; LF = leaching fraction.
Values in this table are indicative only; salt tolerance of all plants will vary depending on a range of factors, such as soil type, drainage, climate and maturity (seedlings can be more sensitive.
a ECi has been estimated from ECe assuming limited rainfall and the specified LF using equation 9 from Ayers and Westcot (1985).). If original references have quoted a >ECe tolerance, this ECe has been used to conservatively estimate ECi; if a <ECe has been quoted, 75% of this ECe has been used to estimate ECi. Where an ECe range is quoted, the middle of the range was used to estimated ECi.
Sources:
o = Maas (1986)
p = Cresswell and Weir (1997)
t = ANZECC and ARMCANZ (2000), Maas (1987)
w = Agriculture WA (2003)
x = Kotuby-Amacher, Koenig & Kitchen (1997).

Table A5.17 Approximate sodium and chloride concentrations that can cause foliar injury in crop plants from saline sprinkling water

Sensitive	Moderately sensitive	Moderately tolerant	Tolerant
Sodium (mg/L)			
<115	115–230	230–460	>460
Chloride (mg/L)			
<175	175–350	350–700	>700
Almond	Pepper	Barley	Cauliflower
Apricot	Potato	Maize	Cotton
Citrus	Tomato	Cucumber	Sugar beet
Plum		Lucerne	Sunflower
Grape		Safflower	
		Sesame	
		Sorghum	

Note: Degree of injury is affected by site-specific environmental and agricultural conditions
Source: ANZECC and ARMCANZ (2000a) and Maas (1990a)

Table A5.18 Tolerance of some fruit crop cultivars and rootstocks to chloride in soil water (from saturation paste extract)

Crop	Rootstock or cultivar	Maximum chloride in soil water without leaf injury (mg/L)
	Rootstock	
Avocado	West Indian	535
	Guatemalan	425
	Mexican	355
Citrus	Sunki mandarin, grapefruit, Cleopatra mandarin, Rangapur lemon	1775
	Sampson tangelo, rough lemon, sour orange, Ponkan mandarin	1065
	Citrumelo 4475, trifoliate orange, Cuban shaddock, Calamondin, sweet orange, Savage citrange, Rusk citrange, Troyer citrange	710
Grape	Salt Creek, 1613–3	2840
	Dog ridge	2130
Stone fruit	Marianna	1775
	Lovell, Shalil	710
	Yunnan	535
	Cultivar	
Berries	Boysenberry	710
	Olallie blackberry	710
	Indian summer raspberry	355
Grape	Thompson seedless, Perlette	1420
	Cardinal, Black rose	710
Strawberry	Lassen	535
	Shasta	355

Source: Modified from Maas (1986)

Table A5.19 Tolerance of agricultural crops to soil extractable chloride

Crop	Chloride in saturated soil extacts (mg/L)
Alfalfa	710
Barley (forage)[a]	2130
Barley	2840
Bean	355
Beet, red	1420
Bermudagrass	2485
Broad bean	533
Broccoli	887
Cabbage	532
Carrot	355
Celery	532
Clover, alsike	532
Clover, Berseem	532
Clover, ladino	532
Clover, red	532
Clover, strawberry	532
Cotton	2662
Cowpea	1775
Cucumber	887
Fescue, tall	1420
Flax	532
Foxtail, meadow	532.
Hardinggrass	1597
Lettuce	355
Lovegrass	710
Maize	532
Onion	355
Orchardgrass	532
Pepper	532
Potato	532
Radish	355
Rice, paddy [ab]	1065
Ryegrass, perennial	1952
Sesbania [a]	710
Sorghum	2485
Spinach	710
Squash, scallop	1065
Squash, zucchini	1597
Strawberry	355
Sudangrass	1065
Sugar beet [a]	2485
Sugarcane	532
Sweet potato	532
Tomato	887
Trefoil, big	710
Trefoil, narrow-leaf birdsfoot	1775
Turnip	355
Vetch, common	1065

Table A5.19 (continued)

Crop	Chloride in saturated soil extacts (mg/L)
Wheat, durum	1952
Wheat [a]	2130
Wheatgrass, fairway crested	2662
Wheatgrass, standard crested	1242
Wheatgrass, tall	2662
Wildrye, beardless	1065

a Less tolerant during emergence and seedling stage of growth
b Values for rice refer to the Cl^- concentration in the soil water during the flooded growing conditions.
Note: These data serve only as a guideline to relative tolerances among crops. Absolute tolerances vary depending on climate, soil conditions and cultural practices.
Source: Maas 1990

A5.7 Hydraulic conductivity

Table A5.20 Approximate values for soil saturated hydraulic conductivity (K_{sat}) and impacts on utility

K_{sat} (cm/hour)	Utility
36	Typical of beach sand.
18	Typical of very sandy soil, too rapid to effectively filter nutrients in wastewater.
1.8	Typical of moderately permeable soils, K_{sat} between 1 and 15 cm/hour considered suitable for most agricultural, recreational and urban uses calling for good drainage.
0.18	Typical of fine textured, compacted or poorly structured soils. Too slow for proper operation of septic tank drain fields, most types of irrigation, and many recreational uses, such as playgrounds.
$<3.6 \times 10^{-5}$	Extremely slow; typical of compacted clay. K_{sat} of 10^{-5} to 10^{-8} cm/hour may be required where impermeable material is needed, as for wastewater lagoon lining or landfill cover material.

Source: Brady and Weil (2002)

A5.8 Sodium

Table A5.21 Effect of sodium, expressed as sodium adsorption ratio (SAR), on crop growth and quality under non-saline conditions

SAR tolerance and range	Crop	Growth response under field conditions
Extremely sensitive SAR = 2–8	Avocado, deciduous fruits, nuts, citrus	Leaf tip burn, leaf scorch
Sensitive SAR = 8–18	Beans	Stunted growth
Medium SAR = 18–46	Clover, oats, tall fescue, rice, dallis grass	Stunted growth, possible sodium toxicity, possible calcium or magnesium deficiency
High SAR = 46–102	Wheat, cotton, lucerne, barley, beets, rhodes grass	Stunted growth, soil structural problems

Source: ANZECC and ARMCANZ (2000a)

Table A5.22 Potential sodicity hazards from irrigation waters of varying sodium adsorption ratio and salinity, expressed as electrical conductivity or total dissolved salts

Sodium adsorption ratio (SAR)	Electrical conductivity (ECi)	Total dissolved salts[a] (TDS)	Sodicity hazard	Likelihood estimate (dependent on specific site conditions)
<3	<0.2	<0.128	Severe	Almost certain
	0.2–0.7	128–448	Slight–moderate	Likely–possible
	>0.7	>448	None	Unlikely
3–6	<0.3	<192	Severe	Almost certain
	0.3–1.2	192–768	Slight–moderate	Likely–possible
	>1.2	>768	None	Unlikely
6–12	<0.5	<320	Severe	Almost certain
	0.5–1.9	320–1216	Slight–moderate	Likely–possible
	>1.9	>1216	None	Unlikely
>12	<1.3	<192	Severe	Almost certain
	1.3–2.9	832–1856	Slight–moderate	Likely–possible
	>2.9	>1856	None	Unlikely

a TDS calculated as EC × 640 (DNR 1997)
Source: Ayers (1977)

A5.9 Phosphorus status in soils

As an example of phosphorus loads in soils, soil-extractable (Colwell) phosphorus values for successful production of a range of pastures and crops on a range of soil types are summarised below in Table A5.23. The values given in the table should be used as a guide to soil fertility in relation to crop productivity. More detailed information for specific crop species can be found in Moody and Bolland (1999) and in appropriate local crop management guidelines. Where Colwell phosphorus values exceed these recommended levels, land managers should seek specific local advice as to whether it is advisable to load the system with any more phosphorus.

Table A5.23 Phosphorus (P) status in soils (extractable — mg/kg)

Soil P status	Soil P sorption category	Low (eg dryland pasture)	Moderate (eg grain crops)	High (eg vegetables)
Low	Low	<10	<15	<20
	Moderate–high	<20	<30	<50
Medium	Low	10–30	15–45	20–60
	Moderate–high	20–60	30–90	50–150
High	Low	>30	>45	>60
	Moderate–high	>60	>90	>150

Source: Moody and Bolland (1999)

Table A5.24 groups Australian native plants alphabetically within seven assessed sensitivity groups, from the least sensitive (Score 1 — grow best with 0.9 g single superphosphate per litre of potting mix) to the most sensitive (Score 7 — grow best without superphosphate).

Table A5.25 gives the phosphorus sensitivity of some South African Proteaceae, Table A5.26 lists some phosphorus-sensitive Australian native plants, and Table A5.27 gives the maximum available phosphorus tolerance of a range of Australian native plants at different levels of iron availability.

Table A5.24 Relative phosphorus (P) sensitivity of a range of Australian native plants

Score 1	Plants healthy across P addition range, with no growth without P to the greatest growth with highest P addition
Abutilon	*indicum, leucopetalum, oxycarpum*
Acacia	*amblyphylla, ampliceps, aphanoclada, bivenosa, brachystachya, calcigera, chrysella, colletioides, delibrata, dentifera, dictyoneura, elata, estrophiolata, extensa, floribunda, gracilifolia, graffiana, gregorii, guinetii, hakeoides, harveyi, holosericea, horridula, howittii, inaequilatera, iodomorpha, jibberdingensis, juncifolia, lanigera, lasiocalyx, lasiocarpa, leiophylla, leptocarpa, linophylla, littorea, longifolia, meissneri, microbotrya, o'shanessii, oncinophylla, oxycedrus, paraneura, pendula, polybotrya, prainii, pulchella, quadrimarginea, quornensis, ramulosa, retinoides, rigens, rostellifera, rotundifolia, sclerophylla, sclerosperma, stenophylla, subcaerulea, subtessaragona, tetragonophylla, translucens, tysonii, venulosa, verniciflua, verticillata, wiseana*
Agonis	*flexuosa, grandiflora, juniperina, marginata*
Allocasuarina	*corniculata, decaisneana, dielsiana, huegeliana, lehmanniana, meulleriana, pusilla, scleroclada, striata, verticillata*
Alternanthera	*nodiflora*
Alyogyne	*cuneiformis, hakeifolia*
Anigozanthos	*bicolor, humilis, manglesii*
Aotus	*ericoides*
Atriplex	*acutibracta, amnicola, leptocarpa, lindleyi, nummularia, rhagodioides, semibaccata, stipitata, suberecta, undulata*
Banksia	*audax, elderana, laevigata, lanata, littoralis, menziesii, petiolaris, speciosa*
Beaufortia	*micrantha, orbifolia*
Beyeria	*lechenaultii*
Billardiera	*cymosa*
Bonamia	*rosea*
Boronia	*denticulata*
Bossiaea	*ericocarpa, foliosa, heterophylla, pulchella, rhombifolia*
Brachychiton	*acerifolius, diversifolia*
Brachysema	*aphyllum, lanceolatum, latifolium*
Callistemon	*brachyandrus, citrinus, glaucus, phoenicius, pinifolius, pungens, rigidus, rugulosus, sieberi, speciosus, viminalis*
Callitris	*columnellaris, preissii*
Calocephalus	*brownii, citreus*
Calothamnus	*asper, chrysantherus, quadrifidus, sanguineus, tuberosus, validus, villosus*
Canavalia	*papuana*
Casuarina	*cristata, glauca*
Chorizema	*cordatum, dicksonii, diversifolium, ilicifolium*
Conostylis	*aculeata, candicans*
Convolvulus	*erubescens, remotus*
Crotalaria	*retusa, novae-hollandiae*
Daviesia	*benthamii, corymbosa, flexuosa, latifolia, longifolia*
Diplolaena	*grandiflora*
Diplopeltis	*eriocarpa*
Dodonaea	*aperta, ceratocarpa, hackettiana, inaequifolia, lobulata, microzyga, ptarmicifolia, stenozyga, viscosa*
Dryandra	*baxteri, ferruginea, fraseri, nobilis, serratuloides, sessilis, shuttlworthiana, stuposa*
Enchylaena	*tomentosa*
Eremaea	*ebracteata, pauciflora*
Gastrolobium	*spinosum*
Goodenia	*stapfiana*
Goodia	*lotifolia*

Table A5.24 (continued)

Score 1	Plants healthy across P addition range, with no growth without P to the greatest growth with highest P addition
Gossypium	*sturtianum*
Grevillea	*crithmifolia, robusta*
Hakea	*arborescens, brooksiana, commutata, coriacea, dactyloides, eriantha, falcata, macraeana, nodosa, suaveolens, verrucosa, vittata*
Hannafordia	*quadrivalvis*
Hardenbergia	*comptoniana*
Hibiscus	*farragei*
Hovea	*crispa, trisperma*
Hypocalymma	*angustifolium*
Indigofera	*australis*
Isopogon	*ceratophyllus*
Isotropis	*atropurpurea, divergens*
Jacksonia	*sternbergiana*
Kennedia	*beckxiana, eximea, prorepens, rubicunda, stirlingii*
Keraudrenia	*hermanniifolia*
Kunzea	*ambigua, baxteri, ericifolia, pomifera, teretifolius*
Labichea	*lanceolata*
Lamarchea	*hakeifolia*
Lambertia	*propinqua*
Lasiopetalum	*baueri*
Lavatera	*plebia*
Lawrencia	*densiflora, glomerata, repens, spicata, virid-grisea*
Leptospermum	*continentale, coriaceum, flavescens, juniperinum, laevigatum, lanigerum, myrsinoides*
Linum	*marginale*
Lobelia	*heterophylla, tenuior*
Lotus	*australis, cruentus*
Lysiphyllum	*cunninghamii*
Maireana	*brevifolia, sedifolia*
Melaleuca	*acerosa, acuminata, armillaris, brevifolia, cardiophylla, citrina, cliffortioides, coccinea, concreta, cordata, cucullata, cuticularis, decussata, densa, depressa, diosmifolia, dissitiflora, elliptica, ericifolia, filifolia, fulgens, gibbosa, glaberrima, globifera, glomerata, halmaturorum, hamulosa, huegelii, holosericea, hypericifolia, incana, lanceolata, lateralis, lateriflora, lateritia, laxiflora, leiocarpa, leucadendra, microphylla, nesophylla, pentagona, pulchella, radula, rhaphiophylla, sheathiana, spathulata, spicigera, squamea, squarrosa, steedmanii, striata, stypheloides, suberosa, subfalcata, thymoides, thyoides, trichophylla, uncinata, undulata, urceolaris, viminea, viridiflora, wilsonii*
Mirbelia	*spinosa*
Myoporum	*acuminatum*
Myriocephalus	*stuartii*
Neptunia	*monosperma*
Olearia	*teretifolia*
Orthrosanthus	*multifrorus*
Oxylobium	*atropurpurea, cuneatum, lanceolatum, racemosum*
Pandorea	*pandorana*
Pavonia	*hastata*
Petalostylis	*labicheoides, millefolium*
Petrophile	*canescens, carduacea, diversifolia, heterofolia, longifolia, serruriae*
Phymatocarpus	*porphyrocephalus*
Pittosporum	*phylliraeiodes*
Plantago	*varia*

Table A5.24 (continued)

Score 1	**Plants healthy across P addition range, with no growth without P to the greatest growth with highest P addition**
Podolepis	*rugata*
Psoralea	*cinerea, martinii, plumosa*
Pultenaea	*reticulata*
Radyera	*farragei*
Regelia	*ciliata*
Rhagodia	*candolleana, crassifolia, parabolica, preissii, spinescens*
Samolus	*junceus*
Senna	*artemisioides, helmsii, odorata, pleurocarpa, venusta*
Sesbania	*cannabina, simpliciuscula*
Sida	*calyxhymenia, rholenae*
Solanum	*linearifolium, simile, symonii*
Stylidium	*adnatum*
Swainsona	*canescens, colutoides, formosus, tephrotricha, villosa*
Templetonia	*egena, sulcata*
Thomasia	*petalocalyx*
Thryptomene	*australis*
Velleia	*cycnopotamica, panduriformis, trinervis*
Villarsia	*capitata*
Viminaria	*juncea*
Wahlenbergia	*preissii*
Waitzia	*acuminata*
Xanthorrhoea	*quadrangulata, semiplana*
Zygophyllum	*aurantiacum*
Score 2	**Plants healthy across P addition range, but with some growth without phosphorus Greatest growth was with highest P addition**
Acacia	*complanata, cuthbertsonii, fasciculifera, pyrifolia, validinevia, viscidula*
Actinostrobus	*pyramidalis*
Banksia	*ashbyi, brownii, caleyi, lemanniana, nutans, occidentalis, pilostylis, prionotes, pulchella, repens, violacea*
Dodonaea	*hexandra*
Dryandra	*arborea, carduacea, formosa, obtusa*
Flindersia	*australis*
Hakea	*cycloptera, gibbosa, muelleriana*
Isopogon	*dubius*
Platylobium	*obtusangulum*

Table A5.24 (continued)

Score 3	**All plants healthy, with some growth without P** **Largest plants with second highest P rate, no P toxicity evident**
Abutilon	*lepidum*
Acacia	*amoena, blakelyi, deanei, difformis, dodonaeifolia, eremaea, exocarpoides, fauntleroyi, hemignosta, leptospermoides, maitlandii, megalantha, monticola, murrayana, neriifolia, orthocarpa, oxyclada, pachyacra, parramattensis, pellita, perangusta, pruinocarpa, pubicosta, pyrifolia, rubida, semilunata, siculiformis, torulosa, trachycarpa, triptera, uncinata, vestita, wildenowiana, xanthina, xylocarpa*
Allocasuarina	*campestris, lehmanniana*
Alternanthera	*nana*
Amaranthus	*pallidiflorus*
Anigozanthos	*viridis*
Banksia	*aemula, candolleana, coccinea, leptophylla, marginata, robur*
Bossiaea	*ensata, scolopendria*
Canavalia	*maritima*
Casuarina	*obesa*
Crotalaria	*cunninghamii*
Daviesia	*acicularis, decurrens, physodes, revoluta, rhombifolia, teretifolia, umbellata*
Dillwynia	*brunioides, dillwynioides*
Dryandra	*calophylla, carduacea, carlenoides, mucronulata, polycephala, quercifolia, tenuiifolia, vestita*
Gastrolobium	*bilobum*
Gomphrena	*affinis*
Hakea	*adnata, baxteri, cristata, epiglottis, ferruginea, flabellifolia, platysperma, sericea, stenophylla*
Jacksonia	*sericea*
Kennedia	*coccinea*
Lotus	*cruentus*
Melochia	*pyramidata*
Mirbelia	*dilatata, ramulosa*
Oxylobium	*capitatum, ellipticum, parviflorum*
Patersonia	*occidentalis*
Petrophile	*fastigiata*
Santalum	*acuminatum*
Senna	*luerssenii, oligophylla, planitiicola*
Score 4	**Slight toxicity at highest P rate, largest plants in second highest P rate**
Abrus	*precatorius*
Acacia	*chincillensis, declinata, erinacea, glaucoptera, havilandii, iteaphylla, lineata, longispinea, lysiphloia, melliodora, merinthopora, papyricarpa, paradoxa, patagiata, rhodophloia, saligna, sessilispica, sibina, stereophylla, subcaerulea, terminalis, triptycha, uncinella, williamsonii*
Adansonia	*gregorii*
Banksia	*attenuata, burdettii, ericifolia, integrifolia, laricina, media, oblonga, tricuspis, ornata, media*
Bossiaea	*aquifolium, webbii*
Brachysema	*aphyllum*
Calothamnus	*pinifolius, rupestris*
Conospermum	*taxifolium*
Crotalaria	*cunninghamii, verrucosa*
Darwinia	*diosmoides*
Daviesia	*angulata, cordata, divaricata, horrida*
Diplopeltis	*huegelii*
Dryandra	*pulchella*

Table A5.24 (continued)

Score 4	**Slight toxicity at highest P rate, largest plants in second highest P rate**
Gastrolobium	*laytonii*
Goodenia	*corynocarpa, redacta*
Gossypium	*robinsonii*
Grevillea	*biternata, pterosperma*
Hakea	*brachyptera, crassifolia, leucoptera, oleifolia, orthorrhyncha, petiolaris, rostrata, salicifolia*
Isopogon	*anethifolius*
Leptospermum	*laevigatum*
Melaleuca	*eleutherostachya, leptospermioides, leucodendron*
Olearia	*floribunda*
Plantago	*drummondii*
Psoralea	*badocana, lachnostachys*
Pultenaea	*dasyphylla*
Senna	*pruinosa*
Sesbania	*erubescens*
Sollya	*heterophylla*
Sphaerolobium	*fornicatum*
Swainsona	*decurrens*
Tephrosia	*flammea*
Score 5	**Severe P toxicity at highest P rate, some toxicity at second highest rate**
Acacia	*ancistrocarpa, citrinoviridis, dawsonii, denticulosa, dictyopyhleba, fauntleroyi, fragilis, gillii, granitica, hilliana, imbricata, latipes, leioderma, lycopodifolia, mollifolia, nodiflora, pachycarpa, phlebopetala, pilligaensis, pinguifolia, pruinosa, pubifolia, pustula, quadrisulcata, retivenia, rossei, rupicoIa, saliciformis, shirleyi, signata, stricta, tenuissima, tetragonocarpa, trachyphloia, urophylla, wanyu*
Amaranthus	*mitchellii*
Banksia	*aculeata, canei, cunninghamii, grandis, victoriae*
Bossiaea	*preissii*
Calothamnus	*affinis, blepharospermus*
Daviesia	*incrassata, mimosioides, polyphylla, wyattiana*
Dodonaea	*caespitosa, microzyga, petiolaris, viscosa* ssp*spathulata*
Dryandra	*ashbyi, cuneata, falcata, foliosissima, nivea, pteridifolia*
Gastrolobium	*spinosum var grandiflorum*
Glycirrhiza	*acanthocarpa*
Gompholobium	*marginatum, tomentosum*
Gomphrena	*canescens*
Gossypium	*australe*
Hakea	*corymbosa, costata, eyreana, minyma, nitida, undulata*
Indigofera	*boviperda, colutea, georgei, hirsuta*
Isopogon	*alicornis*
Jacksonia	*floribunda*
Pultenaea	*capitata*
Sida	*corrugata*
Stylidium	*scandens*
Thespesia	*populneoides*

Table A5.24 (continued)

Score 6	**Considerable P toxicity at highest two P rates, best plants were at the two lowest P rates, plants were smaller without P**
Acacia	*alata, anaticeps, aphylla, aspera, auriculiformis, boormanii, cochlearis, cultriformis, drepanocarpa, dunnii, gilbertii, gladiiformis, hemiteles, hilliana, kempeana, ligustrina, minutifolia, multispicata, nervosa, neurophylla, nitidula, notabilis, rhigiophylla, sessilis, siculiformis, spectabilis, unifissilis, victoriae, wattsiana, wilhemiana*
Achyranthes	*aspera*
Actinostrobus	*arenarius*
Agonis	*acutivalvis, obtusissima*
Alyogyne	*huegelii*
Banksia	*attenuata, baueri, baxteri, benthamiana, blechnifolia, hookeriana, incana, lemanniana, leptophylla, oblongifolia, paludosa, quercifolia, scabrella, sceptrum, seminuda, telmatiaea*
Bossiaea	*laidlawiana, linophylla*
Brachichiton	*diversifolius*
Burtonia	*polyzyga, scabra*
Daviesia	*leptophylla, ulicifolia*
Dichrostachys	*spicata*
Dodonaea	*obulata, peduncularis, physocarpa*
Dryandra	*armata, comosa, hewardiana*
Gompholobium	*latifolium*
Gomphrena	*cunninghamii, fusiformis*
Grevillea	*banksii, thelemanniana*
Hakea	*brownii, cinerea, decurrens, erecta, gilbertii, incrassata, lasianthoides, marginata, obtusa, pandanicarpa, prostrata, pycnoneura, scoparia*
Hardenbergia	*violacea*
Hibiscus	*meraukensis*
Isopogon	*axillaris, formosus*
Jacksonia	*furcellata, lehmannii*
Kennedia	*prostrata*
Lysiphyllum	*calycina, gilvum, sparsiflora*
Nitraria	*billardierei*
Olearia	*pimeleiodes*
Oxylobium	*reticulatum*
Petrophile	*drummmondii, ericifolia*
Porana	*sericea*
Senna	*notabilis*
Sida	*cardiophylla, echinocarpa*
Swainsona	*cyclocarpa*
Templetonia	*retusa*
Tephrosia	*coriacea*
Xylomelum	*angustifolium*
Score 7	**Plants without P in the mix were the only ones that grew well**
Acacia	*polystachya*
Bossiaea	*dentata*
Petrophile	*sessilis*

Source: Handreck (1997)

Table A5.25 Phosphorus sensitivity of some South African Proteaceae

Sensitivity	Proteaceae
Highly sensitive	*Protea compata*, *P. harmeri*, *P. nerifolia*, *Leucadendron uliginosum*, *L. salcifolium*, *Leucospermum cordifolium*
Moderately sensitive	*Protea cyanoides*, *P. longifolia*, *P. coronata*, *Leucadendron coniferum*, *Dryandra formosa*
Slightly sensitive	*Protea eximia*, *P. speciosa*, *P. grandiceps*, *P. macrocephala*, *P. punctata*, *Leucadendron linifolium*, *L. orientale*, *L. rubrum*, *L. elimense*, *L. teratifolium*, *L. strobilinium*, *Serruria florida*, *Aulax pinifolia*
Tolerant	*Protea repens*, *P. roupelliaea*, *P. mundii*, *P. nana*, *P. obtusifolia*, *P. longifolia*, *Leucadendron salignum*, *L. procerum*, *L. gandogeri*

Source: Leake (1996a)

Table A5.26 Some phosphorus-sensitive Australian native plants

Phosphorus-sensitive Australian native plants
Acacia baileyana, *A. iteaphylla*, *A. obtusata*, *A. suaveolens*, *A. verticillata*
Banksia aemula, *B. ericiflia*, *B. longifolia*, *B. robur*
Beaufortia squarrosa
Boronia megastigmata
Callistemon citrinus
Grevillia aquifolium, *G. glabella*, *G* . ‘Poorinda firebird’
Hakea laurina
Pultenaea pedunculata
Telopea speciosissima

Source: Leake (1996b)

Table A5.27 Maximum available phosphorus (DTPA-extractable) tolerance of a range of Australian native plants at two levels of iron availability

At 34 mg/kg iron Maximum P tolerance (mg/kg)	At 19 mg/kg iron Maximum P tolerance (mg/kg)	Species
3	<3	*Acacia merrallii*, *Grevillea leucopteris*, *Hakea bucculenta*, *H. francisiana*, *H. petiolaris*
5	<3	*Acacia imbricata*, *Banksia benthamiana*, *B. brownii*, *B. lemanniana*, *B. leptophylla*, *B. sphaerocarpa*, *Grevillea banksii*, *Hakea salicifolia*
5	3	*Acacia baileyana*, *A. decurrens*, *A. spectablis*, *Hakea sericea*
8	7	*Acacia dealbata*, *A. glaucoptera*, *A. ligulata*, *A. lineata*, *A. montana*, *A. myrtifolia*, *A. retinoides*, *Hakea laurina*
11	3	*Banksia tricuspis*, *Hakea rostrata*
11	10	*Acacia argyrophylla*, *A. baileyana purpurea*, *A. burkittii*, *A. calamifolia*, *A. floribunda*, *A. iteaphylla*, *A. menzalii*, *A. papyrocarpa*, *A. paradoxa*, *A. rigens*, *A.rivalis*, *A. rotundifolia*, *A. sclerophylla*, *Banksia laricina*, *B. speciosa*, *Grevillea intricata*, *G. robusta*, *Hakea suberea*
<20	<14	*Acacia cyclops*, *A. fimbriata*, *A. hakeoides*, *A. longifolia var sophorae*, *A. melanoxylon*, *A. nyssophylla*, *A. pendula*, *A. ramulosa*, *Hakea Muelleriana*
<20	<25	*Acacia longifolia*, *A. saligna*, *A. truncata*, *A. victoriae*, *Hakea Leucoptera*

DTPA = diethylene triamine penta-acetate
Source: Handreck (1991)

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Appendix 6 Nutrient transport and buffer strips

Nutrients attached to soil particles can be transported with soils via water erosion and wind. In the case of water erosion, the sediments and nutrients may end up in waterways, causing eutrophication and other forms of pollution. Phosphorus and nitrogen are the main elements of concern. Sediment transport to waterways is best managed through runoff control.

This appendix highlights the major risk factors associated with nutrient transport to rivers via runoff from agricultural land (see Table A6.1). The main risk factors are climate, slope, soil type, and the tillage and grazing practices used to manage the soil surface. Medium and high-risk situations must be actively managed. It is easier to manage runoff that is diffuse rather than concentrated, which means that land managers can make substantial contributions to runoff and sediment-transport control.

Table A6.1 Assessing the broad risk of sediment and nutrient transport to surface waters via runoff

Factor	Low risk	Medium risk	High risk
Land use involves:	no tillage and no over-grazing	minimum tillage or some overgrazing	annual traditional tillage or extensive overgrazing (ie is there bare ground at times?)
Catchment is located in:	Mediterranean-climate areas of southern Australia	subtropical and semiarid areas	wet tropics and wet–dry tropics
Agricultural land in the catchment:	is on slopes of <5%	is on gentle hills with no alluvial flats	is on moderate to steep slopes
Soils used for cropping are:	well aggregated	sandy or weakly aggregated	dispersive (sodic), slaking or silty

Source: Adapted from Prosser et al (2000)

Vegetated buffer strips can be effective in removing suspended sediments and nutrients attached to soil particles, provided the slope of the land is no more than 10%, water is neither concentrated nor moving in a gully, and the bulk of the soil has vegetative cover. Land with a slope above 10% should not be irrigated, regardless of water source, and land with a slope above 15% should not be cultivated.

Most sediment transport from agricultural land occurs in a few discrete events per year. Buffer strips of grass or perennial shrubs or trees can be effective in widths from 2–30 metres, depending on site-specific conditions. *Designing Filter Strips to Trap Sediment and Attached Nutrient* (Prosser and Karssies 2001) provides detailed methodology for calculating the appropriate width for vegetated buffer strips to trap sediments, tailored to specific situations; also, Prosser et al (2000) outlines the broader range of issues that need to be canvassed when considering the efficacy of buffer strips.

Vegetated buffer strips have a finite capacity — if soils become saturated with phosphorus or nitrogen, soluble nutrient transport will increase. Where surface water flow is slowed by buffer strips, or soils have high permeability (hydraulic conductivity), loss of soluble nutrients may be greater than nutrient transfer in suspended material.

In addition to vegetated buffer strips, engineering solutions such as permanent diversion grade banks, permanent waterways with vegetated cover, and temporary grade furrows can be used (eg see Hutchison 2002). Wherever possible, control with vegetated buffer strips or combinations of engineering solutions and vegetated buffer strips would be preferable.

In addition to surface transport of nutrients in sediments, soluble nutrients can also move through the soil profile in water and be transported to ground and surface waters. Soluble nutrients in waterways tend to be more immediately biologically active than sediment-bound nutrients.

Table A6.2 highlights the major risk factors associated with soluble nutrient transport to groundwaters via leaching for agricultural land. Soil type and profile, irrigation and nutrient inputs are the important factors to consider. Medium and high-risk situations must be actively managed.

Table A6.2 Assessment of the risk of nutrient transfer to groundwaters

Factor	Low risk	Moderate risk	High risk
Soils are:	10% sand	30% sand	90% sand
Subsoils are:	sealed and clayey	moderately clayey, with small cracks	sandy or extensively cracked clays
Land use has:	no irrigation, drains or gullies	some gullies or constructed drains	intensive irrigation with dense drainage networks (natural or constructed)
Land use involves:	no fertiliser application or low animal stocking rates	low fertiliser application rates or intensive animal stocking rates	high fertiliser application or intensive feedlots

Source: Adapted from Prosser et al (2000)

On most soils, nitrogen is generally considered the element most likely to leach (in the form of nitrate). However, on sandy soils with low clay contents, considerable amounts of phosphorus may also be leached. The principal preventive measures include:

- careful site selection for irrigation schemes, taking into account soil texture and underlying groundwater aquifer characteristics
- careful nutrient balancing and fertiliser application
- careful irrigation management, paying attention to crop demand, seasonal rainfall and soil type.

Details of appropriate strategies can be found in Appendix 4 of these guidelines, and in various industry manuals for best management practice.

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Appendix 7 Communication case studies

A7.1 Caboolture Shire Council water recycling scheme

A7.1.1 Background

Caboolture shire, in southeastern Queensland, is one of the fastest growing areas in Australia, with a population (in 2005) of 130 000 people. The Caboolture River runs through the centre of the town and supplies a small part of the town's drinking water via a small weir, with the bulk of the drinking water supply being imported from Brisbane City Council.

The South Caboolture Sewage Treatment Plant is about a kilometre downstream from the drinking water weir. The flow regimes of the Caboolture River have been insufficient to flush the river effectively throughout the year and, by the 1990s, eutrophication of the river had become a significant problem. The sewage treatment plant was identified as a principal point source of nutrient inflow to the river, and it became apparent that the Queensland Environment Protection Authority might soon require improved protection of the river. A likely solution would have been the construction of an ocean outfall pipeline to Moreton Bay.

In 1995, the Caboolture Shire planning engineer was keen to address the problems facing the shire's overall water management. He identified water recycling as a possible means to reduce both nutrient discharge to the river and the shire's dependence on outside sources of drinking water supplies. The initial proposal was to significantly upgrade the South Caboolture Sewage Treatment Plant and then pump the highly treated effluent back up above the weir for drinking water reuse. The scheme would have involved negligible elevation, and therefore minimal pumping costs.

A7.1.2 Initial communication strategy

The planning engineer proposed the scheme to the shire councillors, many of whom, including the mayor, became strong advocates. The council implemented a strategy aimed at convincing the community that their shire would be a world leader and pioneer of water recycling systems. The treatment process would employ state-of-the-art technology, and provide significant environmental and economic benefits to the community. The shire council expected that the community would see the scheme as a significant cultural achievement for Caboolture.

The plan was announced amid much fanfare in February 1996. A process of public consultation was initiated a few months later, with the distribution of brochures outlining the project to households and the establishment of a telephone hotline service for the community to provide feedback. The brochures depicted a number of possible variations to the scheme, including recycling back into the town water supply. At the time, the council public relations officer reported that there had been 'a slow initial response to the invitation to comment on the scheme' (Anon 1996a).

The Caboolture Shire Mayor enthused about the effectiveness and environmental friendliness of water recycling projects and assured the community that any drinking water reuse would only be considered after exhaustive tests by health authorities (Anon 1996a).

A7.1.3 Community response

Within a couple of weeks of the brochure distribution, it became clear that there would be considerable community resistance to recycling drinking water. The local newspaper presented a 'vox populi' section on the question 'to drink or not to drink?' (Anon 1996b). The article reported some support for drinking water recycling based largely on the suggestion that it could not be any worse than the current poor-quality town water. However, the majority of reported respondents indicated that they would be opposed to drinking recycled water, and some were concerned about children bathing in it. One respondent volunteered that the recycled water would be better used for agricultural purposes, while others suggested that the water would be drinkable, provided 'we can get assurances it is absolutely purified'.

A7.1.4 Damage limitation and continued opposition

Soon, the council shifted into 'damage control' mode and stepped up its public education campaign. The campaign focused on a scientific presentation of information such as water quality data, health effects and descriptions of relative risk. The council sponsored two full-day community workshops in August 1996. Speakers included the Caboolture Shire Council water resources planning manager, a representative of the Sunshine Coast Environment Council and other experts, including microbiologists and water engineers. However, the presentation of such dry technical information proved to be no match for the opposing arguments, which were highly emotional.

In spite of council attempts to improve public relations, significant community opposition persisted. In September 1996, the mayor attempted to allay community concerns by giving an assurance that no decision would be made on the possible reuse of treated water for at least four years and that 'before doing so, the public will be surveyed to gauge acceptance' (Anon 1996c).

Opposition to the proposal continued to smoulder and the council was presented in November with a community petition opposing any plans involving drinking water recycling. The petition organiser reported that the signatories 'were worried about a number of things including health, the effect on real-estate prices and the fact that their children would have to drink water that was more chemically treated' (Anon 1996c).

Local government elections took place in early 1997. Although water recycling proposals were not the only issues arising during the election campaign, they were among the major issues. Both the mayor and another vocal supporter of the recycling scheme were not returned to the following council. All of the returned and newly elected councillors had a campaign policy of not proceeding with the drinking water recycling proposals and not considering drinking water recycling in the future. Nearly a decade later, Caboolture Shire Council continues to stand by this policy.

A7.1.5 A new approach

After the election, the council changed its approach to advocate recycling for non-drinking water purposes only. In 1998, the council built a water reclamation plant, primarily to augment flow regimes in the Caboolture River. Some water is also being used for irrigation of sporting fields, parks, median strips and certain council construction activities. The shire is currently extending a pipeline to an industrial estate for some industrial reuse, which although probably not economically favourable, is considered a beneficial use for some of the highly treated water.

A7.1.6 Lessons learnt

The experiences of Caboolture provide valuable lessons in stakeholder communication for water recycling schemes. They suggest that proposals for such direct drinking water recycling schemes are highly likely to meet with very similar community opposition at any location in Australia (Marks 2004). Direct drinking water reuse is also not currently supported by health regulatory agencies. However, the advantage of hindsight suggests that attempts to simply inform communities that a planned water recycling scheme will be good for them are not sufficient. In this case, a much earlier and broader public education campaign might have been much more effective. More importantly, communities must be offered opportunities for real involvement in planning and decision-making processes. After all, in a democratic society, communities will eventually find an effective means for exercising their rights to choose.

A7.2 Mawson Lakes development

A7.2.1 Background

Mawson Lakes is a greenfield housing development located 12 km north of the Adelaide central business district. Construction began in July 1997, and is expected to be completed in 2010, with a final population of 10 000 residents. The development is a joint venture between the South Australian Government’s Land Management Corporation and private industry. It incorporates a dual-reticulation system that provides households with drinking water for drinking uses, and recycled water for non-drinking purposes, such as toilet flushing, garden watering and car washing. The recycled water is also used for irrigation of public open space within the development.

It is mandatory for the dual-reticulation system to be installed in all residential dwellings at the time of construction. When purchasing properties, residents agree, via a covenant on the property title, to use the recycled water. Recycled water began flowing through the appropriate part of the system on 1 April 2005. Until that time, drinking water was delivered through both sets of pipes.

A7.2.2 Communication strategy

The developer provided information about the dual-reticulation system to prospective and actual property purchasers from the inception of the project. This information, which was not very detailed, was contained within the sale contract and in a general information booklet about the development. An interactive demonstration board with details of the dual-reticulation system was placed in the sales office. People wanting additional information were directed to contact SA Water.

At the time of house construction, householders were required to erect recycled water signage in accordance with *South Australian Reclaimed Water Guidelines* (DHS and EPA 1999). Thus, garden taps and toilet cisterns were required to have signs marked ‘Water not suitable for drinking’. Also, all recycled water pipes and fittings above and below ground had to be coloured lilac, in accordance with Australian plumbing standards. SA Water managers dealing with the dual-reticulation system were proactive in addressing community meetings and answering questions about recycled water. Communication with local school children, most of whom were living in the development, was a feature of the curriculum.

A7.2.3 Conflicting information

Although accurate information was provided to residents by SA Water, some conflicting information was provided by other sources. For example, a 1999 newspaper article incorrectly implied that the exclusive source of recycled water would be stormwater collected from wetlands (Anon 1999). In fact, treated municipal sewage was always intended to be a major source of the water. The article also implied that the recycled water would be priced at between 25 cents and 40 cents per kilolitre. However, no information regarding pricing had been disclosed by SA Water at that time. The perception of very inexpensive recycled water may also have been promoted by real estate agents (Marks and Zadoroznyj 2005) and in promotional material provided by the developer (Hurlimann et al 2005).

In 2000, residents from 20 of approximately 200 occupied households were surveyed in face-to-face interviews (Marks et al 2003). This qualitative research indicated that although considerable information had been provided, it did not automatically lead to high levels of awareness. For example, some residents incorrectly believed that recycled water was already being supplied through the dual system in 2000. In fact, drinking water was being supplied via both delivery systems at that time. There was also some confusion about the proposed source of the recycled water and the price that customers would be charged; this was attributed to the misleading sources described above.

A particular difficulty affecting communications with Mawson Lakes' residents was that ultimate ownership of the recycled water system was not resolved by the developers until five years into the project. In 2002, it was agreed that SA Water would become the owner and operator of the system, allowing the organisation to have increased influence on the content of the communications.

A7.2.4 Knowledge, trust and pricing

In 2002, 136 members of the 347 households that were occupied in Mawson Lakes were surveyed. This survey reported that 65% of residents expressed some trust in the water authority, while 15% did not trust the water authority and 19% were undecided (Hurlimann and McKay 2004). Those who trusted the water authority were more confident than those who did not that there would be no health risks associated with the recycled water. Knowledge of the impending dual water supply was a key factor in establishing positive attitudes to recycled water; however, no significant relationship between knowledge and trust was identified (Hurlimann et al 2005). This situation emphasised the role of effective communication as being more than merely the provision of information.

In 2004, Hurlimann et al (2005) used a telephone survey to determine community attitudes to the price of the recycled water supply. Attitudes were influenced primarily by perceptions of fairness, and differed according to demographic variables. These findings highlighted the importance of engaging with residents and establishing a pricing structure that was perceived to be fair.

The price of the recycled water was eventually fixed at 77 cents per kilolitre for the scheme's first operational financial year of 2004–05. SA Water established this price as the most appropriate to achieve their environmental, social and economic objectives. However, the price was considerably higher than the community had expected, based on misinformation and rumour during the previous five years.

A7.2.5 Increased information at a critical stage

Immediately preceding the introduction of recycled water, correspondence about the dual-reticulation system was increased. Each household received an information package on the recycled water system, which included a detailed letter to residents and a series of information sheets. Customers were asked to contact the SA Water Call Centre if they had any enquiries. Fewer than 20 calls were received from approximately 1500 households that received the communication (C Marles, South Australian Water Corporation, pers comm, 2005). However, the majority of the calls related to the pricing structure of recycled water and its relationship to the price of drinking water.

Additional information was made available on the internet, including a variety of educational resources and a recycled water plumbing guide. Signage was strategically placed in public areas, informing residents and visitors that recycled water was used for landscape watering and that the water was not suitable for drinking. Signs were placed at the key entry points to the development, advising that ‘Recycled Water is used at Mawson Lakes’. A customer self-audit program was developed to help detect any cross-connections with the drinking water system. This had the effect of further informing the customer of how their recycled water system worked.

Recycled water was introduced to the system in April 2005. At that time, the SA Water call centre was monitored for calls regarding the recycled water system, but few significant complaints, problems or issues were recorded (Marles 2005). This suggests that the diverse range of communication methods and the considerable time period over which communication was maintained was effective in educating customers, as well as allaying significant emotional responses.

A7.2.6 Ongoing communication and research

Ongoing communication about the recycled water system has been maintained through the Mawson Lakes development and SA Water websites. The call centre continues to be maintained by SA Water to give the community a means for providing feedback about water supply issues and requesting further information if required.

The ongoing research into community attitudes to recycled water at Mawson Lakes has informed the project’s continued communication strategy. An important lesson along the way was the need to proactively address any misconceptions or misinformation that may arise from sources with competing interests to the water recycling organisation. SA Water anticipates that the outcomes of this research will be useful for further assessing the effectiveness of their communication strategies, and in future projects both within South Australia and elsewhere.

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Glossary

activated carbon	Adsorptive carbon particles or granules that have a high capacity to remove trace and soluble components from solution.
acute toxicity	Rapid adverse effect (eg death) caused by a substance in a living organism. Can be used to define either the exposure or the response to an exposure (effect).
ADWG	The 2004 edition of the *Australian Drinking Water Guidelines*, published by the National Health and Medical Research Council (NHMRC) and Natural Resource Management Ministerial Council (NRMMC).
algae	Comparatively simple chlorophyll-bearing plants, most of which are aquatic, and microscopic in size.
anaerobic	Conditions where oxygen is lacking; organisms not requiring oxygen for respiration.
aquatic ecosystem	Any water environment from small to large, from pond to ocean, in which plants and animals interact with the chemical and physical features of the environment.
aquifer	A geological formation or group of formations capable of receiving, storing and transmitting significant quantities of water. Aquifers include confined, unconfined and artesian types.
aquifer storage and recovery (ASR)	The storage of water through wells installed into aquifers, with subsequent retrieval from these same wells during demand for the stored water (eg dry periods for irrigation).
benchmark	A standard or point of reference.
bioavailable	Able to be taken up by organisms.
biochemical oxygen demand (BOD)	The decrease in oxygen content in a sample of water that is brought about by the bacterial breakdown of organic matter in the water (note: BOD_5 is the BOD measured over 5 days).
biodiversity (biological diversity)	The variety of life forms, including the plants, animals and microorganisms, the genes they contain and the ecosystems and ecological processes of which they are a part.
biofilm	Microbial populations that grow on the inside of pipes and other surfaces.
biomass	The living weight of a plant or animal population, usually expressed on a unit area basis.

biosolid	Sewage sludge, organic residual remaining after domestic sewage treatment.
biota	All of the organisms, including animals, fungi and microorganisms, found in a given area.
blackwater	Water containing human excrement.
bloom	An unusually large number of organisms of one or a few species, usually algae, per unit of water.
boron	An inorganic chemical that is a micronutrient for plants with a narrow concentration range between deficiency and toxicity. Water softeners are an important source in wastewaters. The main impact of boron is toxicity to plants after soil accumulation, especially on finer textured, higher pH soils.
buffer distances and strips	A transition zone between areas managed for different objectives to minimise detrimental interactions between the two.
cadmium	A heavy metal that can accumulate in soils and then is taken up through the food chain in plants and animals. Concentrations in recycled waters are generally low; however, saline water and changes in soil pH can release cadmium stored in the soil for uptake by plants.
Campylobacter	A group of bacteria that is a major cause of diarrhoeal illness.
catchment	Area of land that collects rainfall and contributes to surface water (streams, rivers, wetlands) or to groundwater.
cation exchange capacity	The sum of exchangeable cations that a soil can absorb at a specific pH. It is usually expressed in centimoles of charge per kilogram of exchanges ($cmol_c/kg$).
chloramination	Use of chloramines (compounds formed by the reaction of hypochlorous acid or aqueous chlorine with ammonia) as a means of disinfection.
chloride	Chloride in recycled waters comes from a variety of salts (including detergents) and is present as an ion (Cl^-). In addition to its role in salinity, it can be toxic to plants, especially if applied directly to foliage and aquatic biota.
chlorination	Use of chlorine as a means of disinfection.
chlorine demand	The difference between the amount of chlorine added to water and the amount of residual chlorine remaining after a given contact time. Chlorine demand may change with dosage, time, temperature, pH, and the nature and amount of any impurities in the water.
chronic toxicity	Toxicity that acts over a long period of time and that typically affects a life stage (eg reproductive capacity); it can also refer to toxicity resulting from a long-term exposure.

coagulation	Clumping together of very fine particles into larger particles using chemicals (coagulants) that neutralise the electrical charges of the fine particles and destabilise the particles.
Codex Alimentarius	A food quality and safety code developed by the Codex Alimentarius Commission of the Food and Agriculture Organization of the United Nations and the World Health Organization.
coliform bacteria	Group of bacteria whose presence in drinking water can be used as an indicator for operational monitoring.
consumer	An individual or organisation that uses drinking water.
contaminant	Biological or chemical substance or entity, not normally present in a system, capable of producing an adverse effect in a biological system, seriously injuring structure or function.
conventional filtration	The process of passing wastewater through a bed of granular media (eg sand and anthracite to remove particulate matter).
corrective action	Procedures to be followed when monitoring results indicate a deviation occurs from acceptable criteria (adapted from Codex Alimentarius).
critical control point	A point, step or procedure at which control can be applied and that is essential for preventing or eliminating a hazard, or reducing it to an acceptable level (adapted from Codex Alimentarius).
critical limit	A prescribed tolerance that must be met to ensure that a critical control point effectively controls a potential health hazard; a criterion that separates acceptability from unacceptability (adapted from Codex Alimentarius).
crop plants	Plants grown for harvest as food, feed or forage.
Cryptosporidium	Microorganism commonly found in lakes and rivers that is highly resistant to disinfection. *Cryptosporidium* has caused several large outbreaks of gastrointestinal illness, with symptoms that include diarrhoea, nausea and stomach cramps. People with severely weakened immune systems (ie severely immunocompromised people) are likely to have more severe and more persistent symptoms than healthy individuals (adapted from United States Environmental Protection Agency).
Ct	The product of residual disinfectant concentration (C) in milligrams per litre determined before or at taps providing water for human consumption, and the corresponding disinfectant contact time (t) in minutes.
cyanobacteria	Bacteria containing chlorophyll and phycobilins, commonly known as ‘blue-green algae’.
direct drinking water (potable) reuse	The discharge of recycled water directly into a drinking water treatment facility or into a drinking water distribution system.

disinfectant	An oxidising agent (eg chlorine, chlorine dioxide, chloramines and ozone) that is added to water in any part of the treatment or distribution process and is intended to kill or inactivate pathogenic (disease-causing) microorganisms.
disinfectant residual	The amount of free and/or available disinfectant remaining after a given contact time under specified conditions.
disinfection	The process designed to kill most microorganisms in water, including essentially all pathogenic (disease-causing) bacteria. There are several ways to disinfect, with chlorine being most frequently used in water treatment.
disinfection byproduct	Products of reactions between disinfectants, particularly chlorine, and naturally occurring organic material.
distribution system	A network of pipes leading from a treatment plant to customers' plumbing systems.
dose–response	The quantitative relationship between the dose of an agent and an effect caused by the agent.
drinking water	Water intended primarily for human consumption (but excluding bottled water, for the purposes of these guidelines).
drinking water quality management audit	The systematic and documented evaluation of activities and processes to confirm that objectives are being met, and which includes an assessment of management system implementation and capability.
drinking water quality monitoring	The wide-ranging assessment of the quality of water in the distribution system and as supplied to the consumer, which includes the regular sampling and testing performed for assessing conformance with guideline values and compliance with regulatory requirements and agreed levels of service.
drinking water supplier	An organisation, agency or company that has responsibility and authority for treating and/or supplying drinking water.
drinking water supply system (water supply system)	All aspects from the point of collection of water to the consumer (can include catchments, groundwater systems, source waters, storage reservoirs and intakes, treatment systems, service reservoirs and distribution systems, and consumers).
effluent	The out-flow water or wastewater from any water processing system or device.
endocrine disrupter	Substances that can stop the production or block the transmission of hormones in the body.
enteric pathogen	Pathogen found in the gut.
environmental flows	Environmental allocation for surface water rivers, streams or creeks.

environmental management system	The section of an overall management system that includes structure, planning activities, responsibilities, practices, procurements, processes and resources for developing, implementing, achieving, reviewing and maintaining an environmental policy.
environmental values	Particular values or uses (sometimes called beneficial uses) of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health and that require protection from the effects of contaminants, waste discharges and deposits. Several environmental values may be designated for a specific water body.
epidemiology	The study of the distribution and determinants of health and disease states in human populations.
Escherichia coli	Bacterium found in the gut, used as an indicator of faecal contamination of water.
eutrophication	Degradation of water quality due to enrichment by nutrients such as nitrogen and phosphorus, resulting in excessive algal growth and decay and often low dissolved oxygen in the water.
exchangeable sodium percentage (ESP)	The proportion of sodium adsorbed on soil clay mineral surface, as a percentage of total cation exchange capacity (used as a measure of soil sodicity).
exposure	Contact of a chemical, physical or biological agent with the outer boundary of an organism (eg through inhalation, ingestion or dermal contact).
exposure assessment	The estimation (qualitative or quantitative) of the magnitude, frequency, duration, route and extent of exposure to one or more contaminated media.
field capacity	The greatest amount of water that it is possible for a soil to hold in its pore spaces after excess water has drained away.
filtration	Process in which particulate matter in water is removed by passage through porous media.
fire control	Firefighting (not maintenance and drills).
flocculation	Process in which small particles are agglomerated into larger particles (which can settle more easily) through gentle stirring by hydraulic or mechanical means.
Giardia lamblia	A protozoan frequently found in rivers and lakes. If water containing infectious cysts of *Giardia* is ingested, the protozoan can cause a severe gastrointestinal disease called giardiasis.
grab sample	Single sample collected at a particular time and place that represents the composition of the water only at that time and place.

greywater	Wastewater from the hand basin, shower, bath, spa bath, washing machine, laundry tub, kitchen sink and dishwasher. Water from the kitchen is generally too high in grease and oil to be reused successfully without significant treatment.
groundwater	Water contained in rocks or subsoil.
groundwater recharge	Replenishing of groundwater naturally by precipitation or runoff, or artificially by spreading or injection.
guideline	Numerical concentration limit or narrative statement recommended to support and maintain a designated water use.
guideline value	The concentration or measure of a water quality characteristic that, based on present knowledge, either does not result in any significant risk to the health of the consumer (health-related guideline value), or is associated with good quality water (aesthetic guideline value).
hazard	A biological, chemical, physical or radiological agent that has the potential to cause harm.
hazard analysis critical control point (HACCP) system	A systematic methodology to control safety hazards in a process by applying a two-part technique: first, an analysis that identifies hazards and their severity and likelihood of occurrence; and second, identification of critical control points and their monitoring criteria to establish controls that will reduce, prevent, or eliminate the identified hazards.
hazard control	The application or implementation of preventive measures that can be used to control identified hazards.
hazard identification	The process of recognising that a hazard exists and defining its characteristics (AS/NZS 3931:1998).
hazardous event	An incident or situation that can lead to the presence of a hazard (what can happen and how).
heavy metals	Metallic elements with high atomic weights, eg mercury, chromium, cadmium, arsenic and lead. They can cause damage to living organisms at very low concentrations and tend to accumulate in the food chain.
helminth	A worm-like invertebrate of the order Helminthes. A parasite of humans and other animals.
impact	Has an effect on endpoints, such as people, plants, soil, biota, water or a part of the environment.
indicator	Measurement parameter or combination of parameters that can be used to assess the quality of water; a specific contaminant, group of contaminants or constituent that signals the presence of something else (eg *Escherichia coli* indicate the presence of pathogenic bacteria).

indicator organisms	Microorganisms whose presence is indicative of pollution or of more harmful microorganisms.
indirect drinking (potable) reuse	The discharge of recycled water directly into groundwater or surface water with the intent of augmenting drinking water supplies.
industrial wastewater	Wastewater derived from industrial sources or processes.
insignificant	Not valuable or large enough to be considered important.
integrated catchment management	The coordinated planning, use and management of water, land, vegetation and other natural resources on a river or groundwater catchment, based on cooperation between community groups and government agencies to consider all aspects of catchment management.
intentional discharge	Release of water directly into water bodies for environmental allocation. For example, system maintenance, pressure release, flushing and cleaning of systems, fire drills, equipment maintenance.
irrigation	Provision of sufficient water for the growth of crops, lawns, parks and gardens by flood, furrow, drip, sprinkler or subsurface water application to soil.
ISO 9001:2000 (Quality Management)	An international accredited standard that provides a generic framework for quality management systems. Designed to assure conformance to specified requirements by a supplier at all stages during the design, development, production, installation, and servicing of a product, it sets out the requirements needed to achieve an organisation's aims with respect to guaranteeing a consistent end product.
leaching fractions	The ratio of actual drainage water to irrigation water applied.
log removal	Used in reference to the physical–chemical treatment of water to remove, kill, or inactivate microorganisms such as bacteria, protozoa and viruses (1-log removal = 90% reduction in density of the target organism, 2-log removal = 99% reduction, 3-log removal = 99.9% reduction, etc).
loss of biodiversity	Mortality of native biota resulting in reduced ecosystems, species or genetic diversity.
macrophyte	A member of the macroscopic plant life of an area, especially of a body of water; large aquatic plant.
major impact	Potentially lethal to the local ecosystem.
maximum risk	Risk in the absence of preventive measures.
mean	The arithmetic average obtained by adding quantities and dividing the sum by the number of quantities.

microfiltration	The process of passing wastewater through porous membranes in the form of sheets or tubes to remove suspended and particulate material. Pore sizes can be very small and particles down to 0.2 microns can be retained.
microorganism	Organism too small to be visible to the naked eye. Bacteria, viruses, protozoa, and some fungi and algae are microorganisms.
minor impact	Potentially harmful to the local ecosystem.
moderate impact	Potentially harmful to the regional ecosystem.
monitoring	Systematically keeping track of something, including sampling or collecting information and documenting it.
multiple barriers	Use of more than one preventive measure as a barrier against hazards.
municipal	Belonging to a town, city or district that has its own local government. For municipal use of recycled water, this refers to the town, city or district irrigating race tracks, ovals, lawn bowls greens, roadsides, parklands, golf courses and any other area under their control.
Naegleria fowleri	An amoeba that causes a form of meningitis.
nephelometric turbidity unit (NTU)	A measure of turbidity.
nitrification	The oxidation of ammonia nitrogen to nitrate nitrogen in wastewater by biological means.
nitrogen	An important nutrient found in high concentrations in recycled waters, originating from human and domestic wastes. A useful plant nutrient that can also cause off-site problems of eutrophication in lakes, rivers and estuaries. It can also contaminate groundwaters.
nutrient imbalance	Unbalanced supply of plant mineral nutrients resulting in plant deficiencies and toxicities.
operational monitoring	The planned sequence of measurements and observations used to assess and confirm that individual barriers and preventive strategies for controlling hazards are functioning properly and effectively.
osmosis	The process where water flows from a low salinity environment through a membrane to a higher salinity environment to balance the salt concentration on both sides of the membrane.
particle count	The results of a microscopic examination of treated water with a ‘particle counter’ — an instrument that classifies suspended particles by number and size.
pathogen	A disease-causing organism (eg bacteria, viruses and protozoa).

pH	An expression of the intensity of the basic or acid condition of a liquid. Natural waters usually have a pH between 6.5 and 8.5.
phosphorus	An important nutrient found in high concentrations in recycled waters, originating principally from detergents but also from other domestic wastes. A useful plant nutrient that can also cause off-site problems of eutrophication in water bodies.
phreatophytic	Deep-rooted plants (typically trees) that use groundwater.
phytoplankton	Microscopic (up to 1–2 mm in diameter) free-floating or weakly mobile aquatic plants (eg diatoms, dinoflagellates, chlorophytes, blue-greens).
point-of-use treatment device	A treatment device applied to a single tap used for the purpose of reducing contaminants in drinking water at that one tap.
pollutant	Substance that damages the quality of the environment.
polymerase chain reaction (PCR)	Polymerase chain reaction — a method for detecting organisms/biological particles by detecting and amplifying DNA sequences.
ponding	Water gathering in a depression (eg on a roof) from which it cannot drain away.
potable (drinking) water	Water suitable on the basis of both health and aesthetic considerations for drinking or culinary purposes.
preventive measure	Any planned action, activity or process that is used to prevent hazards from occurring or reduce them to acceptable levels.
primary sedimentation	Initial treatment of wastewater involving screening and sedimentation to remove solids.
protozoa	A phylum of single-celled animals.
quality	The totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs; the term 'quality' should not be used to express a degree of excellence (AS/NZS ISO 8402:1994).
quality assurance (QA)	All the planned and systematic activities implemented within the quality system, and demonstrated as needed, to provide adequate confidence that an entity will fulfil requirements for quality (AS/NZS ISO 8402:1994).
quality control (QC)	Operational techniques and activities that are used to fulfil requirements for quality (AS/NZS ISO 8402:1994).
quality management	Includes both quality control and quality assurance, as well as additional concepts of quality policy, quality planning and quality improvement. Quality management operates throughout the quality system (AS/NZS ISO 8402:1994).

quality system	Organisational structure, procedures, processes and resources needed to implement quality management (AS/NZS ISO 8402:1994).
radionuclide	An isotope of an element that is unstable and undergoes radioactive decay.
raw water	Water in its natural state, before any treatment; or the water entering the first treatment process of a water treatment plant.
reclaimed water	Alternative but less accurate term for treated sewage.
recycled water	Water generated from sewage, greywater or stormwater systems and treated to a standard that is appropriate for its intended use.
refractory	A stable material difficult to convert or remove entirely from wastewater.
representative sample	A portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.
reservoir	Any natural or artificial holding area used to store, regulate or control water.
residual risk	The risk remaining after consideration of existing preventive measures.
reverse osmosis (RO)	An advanced method of wastewater treatment that relies on a semipermeable membrane to separate water from its impurities.
risk	The likelihood of a hazard causing harm in exposed populations in a specified time frame, including the magnitude of that harm.
risk assessment	The overall process of using available information to predict how often hazards or specified events may occur (likelihood) and the magnitude of their consequences (adapted from AS/NZS 4360:1999).
risk management	The systematic evaluation of the water supply system, the identification of hazards and hazardous events, the assessment of risks, and the development and implementation of preventive strategies to manage the risks.
runoff	Surface overland flow of water resulting from rainfall or irrigation exceeding the infiltration capacity of the soil.
salinity	The presence of soluble salts in soils or waters. Electrical conductivity and total dissolved salts are measures of salinity.
sandy soils	Soils with a clay content below 16%.
sanitary survey	A review of the water sources, facilities, equipment, operation and maintenance of a public water system to evaluate its adequacy for producing and distributing safe drinking water.

secondary effluent	The liquid portion of wastewater leaving secondary treatment.
secondary treatment	Generally, a level of treatment that removes 85% of BOD and suspended solids, usually by biological or chemical treatment processes. Secondary effluent generally has BOD <30 mg/L, and SS <30 mg/L, but may rise to an SS of >100 mg/L due to algal solids in lagoon or pond systems.
sediment	Unconsolidated mineral and organic particulate material that has settled to the bottom of aquatic environments.
service reservoir/tank	A storage for drinking water, generally within the distribution system, used to meet fluctuating demands, accommodate emergency requirements and/or equalise operating pressures.
sewage	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.
sewer mining	Process of extracting wastewater directly from a sewer (either before or after a sewage treatment plant) for reuse as recycled water.
shandying	Addition of one water source to another, which modifies the quality of the water.
sodicity	This is a condition where the positively charged sodium ions cause the soil particles to repel each other, resulting in soil swelling, dispersion and reduced soil permeability.
sodium	An element found endemic in the environment. High concentrations of sodium in soil relative to calcium and magnesium cause sodicity (ESP >6 or SAR >3).
soil ameliorant	Product that can be added to soils to improve chemical or physical properties (examples include using lime to increase pH, or dolomite or gypsum to reduce soil sodicity).
source water	Water in its natural state, before any treatment to make it suitable for drinking.
species	Generally regarded as a group of organisms that resemble each other to a greater degree than members of other groups and that form a reproductively isolated group that will not normally breed with members of another group. (Chemical species are differing compounds of an element.)
spray irrigation	Water is applied to the plants and soil by spraying, usually from pipes with fixed or moving spray nozzles.
stakeholder	A person or group (eg an industry, a government jurisdiction, a community group, the public, etc) that has an interest or concern in something.

standard (eg water quality standard)	An objective that is recognised in environmental control laws enforceable by a level of government.
storage reservoir	A natural or artificial impoundment used to hold water before its treatment and/or distribution.
stratification	The formation of separate layers (of temperature, plant or animal life) in a lake or reservoir. Each layer has similar characteristics (eg all water in the layer has the same temperature).
surface water	All water naturally open to the atmosphere (eg rivers, streams, lakes and reservoirs).
surrogate	*See* indicator.
target criteria	Quantitative or qualitative parameters established for preventive measures to indicate performance; performance goals.
tertiary treatment	Includes treatment processes beyond secondary or biological processes, which further improve effluent quality. Tertiary treatment processes include detention in lagoons, conventional filtration via sand, dual media or membrane filters, which may include coagulant dosing and land-based or wetland processes.
thermotolerant coliforms	*See* coliform bacteria.
total coliforms	*See* coliform bacteria.
total dissolved salts (TDS)	A measurement of the total dissolved salts in a solution. Major salts in recycled water typically include sodium, magnesium, calcium, carbonate, bicarbonate, potassium, sulphate and chloride. Used as a measure of soil salinity with the units of mg/L.
total quality management	Adds to the concepts of quality management a long-term global management strategy and the participation of all members of the organisation for the benefit of the organisation itself, its members, its customers and society as a whole (AS/NZS ISO 8402:1994).
toxicant	An element or compound with a harmful or lethal effect on the physiology, behaviour, reproduction or survival of an organism.
toxicity	The extent to which a compound is capable of causing injury or death, especially by chemical means.
toxicology	Study of poisons, their effects, antidotes and detection.
turbidity	The cloudiness of water caused by the presence of fine suspended matter.
validation of processes	The substantiation by scientific evidence (investigative or experimental studies) of existing or new processes and the operational criteria to ensure capability to effectively control hazards.

verification of drinking water quality	An assessment of the overall performance of the water supply system and the ultimate quality of drinking water being supplied to consumers; incorporates both drinking water quality monitoring, and monitoring of consumer satisfaction.
virus	Molecules of nucleic acid (RNA or DNA) that can enter cells and replicate in them.
waterlogging	Saturation of soil with water.
water recycling	A generic term for water reclamation and reuse. It can also be used to describe a specific type of 'reuse' where water is recycled and used again for the same purpose (eg recirculating systems for washing and cooling), with or without treatment in between.
watertable	Groundwater in proximity of the soil surface with no confining layers between the groundwater and soil surface.
zooplankton	The animal portion of plankton.

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