Australian Guidelines for Water Recycling:

Managing Health and Environmental Risks

# 2020 Draft of Chapters 1, 2, 3 and 5 and Appendices 2 and 3.

# 1 Introduction

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 safe and 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

Australian towns and cities have limited access to fresh water resources. As populations grow, innovative solutions are required to maintain water supply security. Water supply diversity enhances resilience against supply failures that may be caused by droughts, extreme weather events or other factors. When managed safely and sustainably water recycling can be used to enhance water supply security and diversity.

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. In doing so, recycled water may either augment drinking water supplies directly, or relieve pressures on drinking water supplies by replacing drinking water use for some selected non-drinking applications.

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.

A further potential advantage of water recycling is that it may provide a relatively energy-efficient contribution to municipal water supply portfolios. For this reason, even in circumstances when neither of the above advantages are considered important, water recycling practices may still be beneficial. This advantage may be significant in cases where recycled water can be used in place of other more energy-intensive water sources, such as the need to pump water over long distances.

### 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. Australian communities expect to have safe water and sanitation; therefore, when recycling water, the protection of public health is paramount. Similarly, water managers carry a high level of responsibility for environmental protection, including the protection of aquatic and terrestrial environments. Thus environmental sustainability is an essential characteristic of all water recycling activities. . There are also broader ramifications to consider, such as public and institutional confidence, which can be fragile and, once lost, are difficult to regain.

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

The reuse of municipal wastewaters for some beneficial purposes is well established in Australian towns and cities. Many of these practices were initiated in 1990s in response to increasingly stringent requirements for the discharge of treated effluent to waterways. In particular, limitations on quantities of nutrients (primarily nitrogen and phosphorous) discharged to freshwater systems were increased. As an alternative to enhanced treatment for extensive nutrient removal, it was recognised that nutrient discharge could be reduced by reusing the effluents for uses such as irrigation. Such practices make beneficial use of water, as well as the nutrients.

During the first decade of the 21st Century, much of Australia suffered what became known as the “Millennium Drought”. This historic drought led to significant loss of freshwater supply availability for most Australian towns and cities. The pressures on water supply were exacerbated by continual population growth, with disproportionate growth in some major urban centres. These widespread water shortages refocused attention on water recycling as a means of enhancing urban water availability. Initially, most attention was paid to non-drinking water applications, whereby the use of recycled water could replace some existing uses of freshwater supplies. Subsequently, interest grew in some States and Territories, for the use of recycled water to augment drinking water supplies.

Irrespective of future droughts, continual population increases, a drying climate in some areas and the need for diversity of water supply will mean that water recycling will continue to be an important water supply strategy in the future.

In circumstances where multiple alternative water conservation or augmentation approaches are available, it is necessary for water planners and managers to identify optimum strategies, or combinations of strategies. Due to unique geographic and historic development conditions, it is not possible to generalise the advantages and disadvantages of various strategies in all situations. However, it can be anticipated that strategies that involve water recycling may be rated highly for environmental sustainability in some cases. This may be partially a result of low energy requirements compared to some strategies such as long-distance transfers of water from one area to another. Such environmental sustainability considerations should be included in all water supply assessments.

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 first version of these national guidelines on water recycling were developed as part of the NWQMS in 2006.

The National Water Initiative, signed by the Australian Government and all state and territory governments during 2004-2006, identified the need to develop national guidelines on water recycling as an 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:

* Prior to 2006, state and territory governments had developed their own guidelines, a situation that had led to a lack of uniformity for recycling practice and regulation
* criteria for system management are required to define acceptable levels of performance for the key requirements of public health protection and environmental sustainability
* in the absence of a formally defined risk-management approach, there was a tendency to rely on after-treatment testing as the basis for managing recycled water schemes.

The *Australian Drinking Water Guidelines* (NHMRC–NRMMC 2011) provide a risk management framework, which sets out the principles for ensuring that drinking water is captured, treated and delivered to customers in a way that protects against unacceptable levels of exposure to hazardous substances including pathogens and toxic chemicals. These National Guidelines for Water Recycling were developed to provide an approach consistent with the Australian Drinking Water Guidelines for managing risks associated with recycled water. These risk management frameworks are further described in Section 1.2.2.

Box 1.2, below, shows how these national guidelines relate to state and territory regulation of water recycling projects.

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

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.

## 1.2 Scope of the guidelines

These guidelines are one of four modules of the Australian Guidelines for Water Recycling (AGWR). This first module provides the foundational concepts and risk assessment framework and provides specific guidance for non-potable uses of recycled water. The remaining three modules were developed to provide more specific guidance relating to number of specific water recycling activities. These activities include:

* Augmentation of drinking water supplies using recycled water ([NRMMC, EPHC & NHMRC 2008](#_ENREF_1)).
* Stormwater recycling for residential uses, urban irrigation, agricultural and industrial purposes, as well as fire fighting ([NRMMC, EPHC & NHMRC 2009b](#_ENREF_3)).
* Managed aquifer recharge, as a component of recycled water schemes ([NRMMC, EPHC & NHMRC 2009a](#_ENREF_2)).

These guidelines provide a “what to do” framework for recycled water risk management. They are not intended to provide a “how to do” description. That is, the guidelines do not stipulate specific requirements for details of water treatment, monitoring, training, communication or other aspects of a water recycling project. Such technical guidance may be obtained from other sources such as the Water Services Association of Australia (WSAA).

### 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

**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.

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.

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 by or 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 *Australian Drinking Water Guidelines* (NHMRC–NRMMC 2011) provide a ‘framework for management of drinking water quality’, and the World Health Organization (WHO) *Guidelines for Drinking-water Quality* (WHO 2004) describe ‘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 (i.e. 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 (i.e. ‘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 *Australian Drinking Water Guidelines* (NHMRC–NRMMC 2011). 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.

### 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 (e.g. 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. 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.

### 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 this suite of guidelines are being implemented (Table 1.1).

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 hundreds of agricultural schemes operating across Australia. The framework used to develop these guidelines allows the environmental risk associated with any form of agricultural use of recycled water to be assessed. Some current agricultural uses include:  |
| * horticulture
* trees/woodlots
* pasture/fodder
* dairy pasture
 | * lucerne
* cotton
* flowers
* orchard
 | * nursery
* vegetables
* viticulture
* hydroponics
 | * turf farm
* cane fields
* 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
 |
| Municipal uses |
| Municipal uses for recycled water are diverse, and there are currently hundreds of 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
 |
| **Drinking water (potable uses)** |
| Various approaches to drinking water supply augmentation are available including:* Managed aquifer recharge
* Surface water augmentation
* Direct potable reuse
 |
| 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, utility washing (paths, vehicles, fences etc)
* water features and systems (ponds, fountains, cascades)
 |
| Industrial and commercial uses |
| Industrial uses include: |
| * cooling water
* process water
* washdown water
 |
| **Environmental uses** |
| Environmental uses include:* streams, creeks and 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.

**Step 1**

**Steps 2** **& 3**

**Refer to Chapter 2 and note information needs for risk management plans**

**Use Chapter 3 to provide detail for elements 2 and 3, relating to human health risk**

**Use Chapter 4 to provide detail for elements 2 and 3, relating to environmental health risk**

**Use Chapter 5 to provide detail for elements 4, 5 and 9**

**Step 4**

**Step 5**

**Return to Chapter 2 — consider the requirements of elements 6–10, and document the plan**

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 application of guidelines

Legislative and regulatory requirements can vary across jurisdictions, influencing the implementation of these gudelines. In most cases, it will be necessary to contact the environment, natural resources or health agency in the particular jurisdiction.

# 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 (i.e. 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, including validation of specific treatment technologies that comprise the recycled water scheme

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. This should be done as early as possible in the establishment of a water recycling scheme. 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 (e.g. 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 (e.g. regulators and catchment boards) or be affected by them (e.g. 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 (e.g. 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.

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 (i.e. receiving environments)
* site hydrology (groundwater, soil permeability, drainage)
* the type of crops or plants to be irrigated (i.e. 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 (e.g. bushlands, wetlands).

Box 2.3 Cross-connections and misuse of recycled water

**New South Wales**

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).

**Victoria**

Recycled water cross-connections have been detected both within residential property boundaries and externally within the distribution system due to incorrect marking of pipework. One of the issues encountered was a varied understanding of incident response roles and responsibilities. These need to be established to ensure effective responses are implemented. Information about the nature and concentration of chemicals in recycled water was sometimes inadequate, and. The chemicals present are highly dependent on the source of the sewage from which the recycled water is derived (i.e. commercial, residential sources) and treatment processes. It is paramount that scheme proponents and managers learn from past incidents and take a systematic approach to designing and managing the distribution system adopting safety in design principles, ensure appropriate governance to oversee the management of plumbing and ensure competency at all levels.

### 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).

Where necessary inclusion of additional expertise e.g. from Universities, other research bodies or industry associations could be considered.

#### 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 characters to be included in flow diagrams will be specific for each system, but will need to consider all components from the source water to end use. Further details are provided in Appendix 3.



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

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 (e.g. 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 (e.g. 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 — e.g. 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

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 (e.g. 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 (e.g. 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 hominis* 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. hominis 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.hominis* 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
* information on the potential sources of contamination
* 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 (e.g. 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 (e.g. 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 (e.g. industrial waste discharge)
* diffuse sources of hazards (e.g. those arising from agricultural and animal husbandry activities)
* continuous, intermittent or seasonal pollution patterns
* extreme and infrequent events (e.g. 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 (e.g. 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 (e.g. see WHO 2002). Potential sources of hazards in stormwater sewage and greywater include human and animal faecal waste, household waste, industrial discharges, horticulture, mining and forestry. Hazards can also arise during treatment (e.g. dosing failures), storage and distribution and at receiving sites. Further information on sources of hazards and hazardous events are provided in Appendix 3.

Table 2.2 Potential hazards found in sewage

|  |  |
| --- | --- |
| Classification | Examples of constituents |
| Conventional(chemicals typically measured in milligrams or micrograms per litre)  | * 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 (chemicals typically measured or considered in terms of micrograms or nanograms per litre) | * 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)

#### 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 2.3 and 2.4, below.[[1]](#footnote-1) 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 2.5, 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 (e.g. 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.

Table 2.3 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 2.4 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 populationEnvironment — Potentially harmful to regional ecosystem with local impacts primarily contained to on-site |
| 4 | Major | Health — Major impact for small populationEnvironment — Potentially lethal to local ecosystem; predominantly local, but potential for off-site impacts |
| 5 | Catastrophic | Health — Major impact for large populationEnvironment — Potentially lethal to regional ecosystem or threatened species; widespread on-site and off-site impacts |

Table 2.5 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 2.3 and 2.4

#### 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 (see Box 2.7 and Appendix 3).

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. Storages should be protected from external contamination (e.g from local sources of human or livestock waste). Entry of light should be minimised to restrict algal growth (eg by covering storages)

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)
* signage (eg ‘recycled water — do not drink’)
* site selection.
* anemometer controls, buffer zones, tree and shrub screens, fencing
* control of access; application methods, rates and times (eg spray, microspray, drip or subsurface irrigation; night-time only);
* control rate of application (eg moisture sensors, determination of water and nutrient balances, leach requirements)
* restrictions on use such as types of crop to be irrigated (eg food crops, salt sensitive, phosphorus sensitive) or uses allowed when recycled water is provided for residential use (eg toilet flushing, garden irrigation, car washing)
* harvesting controls (eg no dropped fruit, withholding periods)
* ‘shandying’ recycled water with fresh or desalinated water
* diverter switches to allow householders to chose the volumes and types of greywater recycled

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
* best-practice management of irrigation relating to water and nutrient balances, salinity and sodicity control.

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.

##### 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.

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 (e.g. detention in lagoon or wetland systems).

### 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 at least one 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 (e.g. chlorine residuals for disinfection)
* operational parameters that can be monitored sufficiently frequently to reveal any failures in a timely manner (e.g. online and continuous monitoring of key treatment processes) — in some cases ‘timely’ may mean monitoring regularly rather than frequently (e.g. 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. For example, in the case of filtration there may be a need to adjust coagulant doses or increase the frequency of backwashing. In the case of reduced detention times the cause should be investigated and where possible stopped (e.g. stormwater ingress). Where this is not possible the performance of other barriers (e.g. filtration, disinfection) may need to be increased, on-site restrictions could be tightened of supply stopped.

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.

#### 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.



Figure 2.2 Critical control point decision tree

## 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. They should include procedures for operation of treatment processes, maintenance and calibration of equipment, operational monitoring, and implementation of corrective actions. Further details are provided in Appendix 3.

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
* identify 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 (verification, 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 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. Further details and examples are provided in Appendix 3. 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.

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 (e.g. 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 (e.g. 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 2013)
* 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 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 the initial validation stage or operational monitoring, and the 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 chemical, physical or radiological 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 (e.g. 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 (i.e. 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 (e.g. see Section 4.2.1). Areas requiring monitoring could include:

* soil chemistry and physical properties (e.g. 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 (e.g. 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 2.8). Procedures for sampling and testing should also be documented.

Box 2.8 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 (e.g. 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 (e.g. whether microbial methods measure viability or infectivity)
* quality assurance and validation procedures (e.g. 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 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 non-conformance, 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 non-conformance 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 non-conformance, 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 2.9.

Box 2.9 Hazards and events that may lead to emergency situations

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

* non-conformance with critical limits, guideline values and other requirements
* accidents that increase levels of contaminants or cause failure of treatment systems (e.g. 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 (e.g. flash flooding, cyclones)
* natural disasters (e.g. fire, earthquakes, lightning damage to electrical equipment)
* human actions (e.g. 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 (e.g. 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 2.10 provides a summary of an emergency response protocol.

Box 2.10 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 (i.e. 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 2.10 (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)

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| **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 2.11 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 2.11 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)

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| **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 (e.g. 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 2.12). 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 2.12 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)

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| **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.

### 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

The aim of validation is to obtain evidence that processes will perform effectively in a manner that can be operationally monitored. 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. This can include laboratory based testing, pilot trials and precommissioning testing of full-scale plants. These types of investigation will typically include monitoring removal of hazards (e.g. pathogens or appropriate microbial surrogates).

Validation is particularly important for innovative hazard-control processes and for schemes involving relatively high exposures (e.g. residential use). 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.

An Australian framework for validation has been developed to support implementation of these guidelines (Robillot et al 2016). It has been used to develop protocols for chlorination, membrane bioreactors, UV light disinfection and ozone (WaterSecure 2017a-d) and further protocols are under consideration. Internationally validation protocols have been developed for membrane filtration and UV light disinfection (USEPA 2005, 2006).

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 (e.g. impacts of changes to primary or secondary treatment processes on downstream filtration or disinfection) or when the validated process is to be operated outside the boundary conditions described as part of the original validation. 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 (e.g. earthquakes and flooding), and providing backup systems for emergency use (e.g. 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.

Other possible areas for applied research and development are listed in Box 2.13.

Box 2.13 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 (e.g. 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
* 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.

## 2.10 Documentation and reporting (Element 10)

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| **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)

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| **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)

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| --- | --- |
| **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 (e.g. 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 microbial health risks from recycled water. The Chapter discusses general principles and application of these principles to specific forms of water recycling as follows:

* **General principles**
	+ Identifying acceptable risk and setting health-based targets for use of recycled water (Section 3.1)
	+ Risk assessment (Section 3.2)
	+ Use of preventive measures to achieve health-based targets (Section 3.3)
* **Application to specifc forms of water recycling**
* Hazards in specific source waters (sewage, greywater, stormwater) (Section 3.4)
* Calculating health-based targets for sewage and greywater (Section 3.5)
* Identifying preventive measures for recycled water schemes (Section 3.6)
* Treated sewage as a source of recycled water for use with livestock (Section 3.7)

## 3.1 Identifying acceptable risk and setting health-based targets for use of recycled water

The primary purpose and benefits of wastewater collection, distribution and management infrastructure is the removal of hazardous substances (particularly pathogens) to minimise human exposure to those substances and thereby protect public health. Therefore, by design, many sources of recycled water, such as sewage, industrial and agricultural wastewater, greywater and stormwater, will contain a wide range of hazards that pose risks to human health, including pathogens and hazardous chemicals.

The safe use of recycled water requires hazard concentrations to be reduced, and exposures to be controlled, in order reduce potential health risks to acceptable levels. A key component is to define what is meant by acceptable microbial risk. It is then necessary to translate that acceptable risk into measurable, tangible health-based targets for individual hazards.

Acceptable chemical risk is traditionally defined through the setting of guideline values as described the Phase 2 guidelines (NRMMC et al 2008).

### 3.1.1 Acceptable microbial risk

There are several precedents for determining an acceptable level of microbial risk. Historically, an absence of detectable community epidemic disease outbreaks was sufficient to constitute evidence of adequate safety. This was supported by measuring microbial indicators, principally thermotolerant coliforms (sometimes termed faecal coliforms) and *E. coli*.

A major transformation took place towards the end of the last century when the concept of endemic disease, (i.e. disease that occurs at levels too low to be detected as epidemic outbreaks), was recognised in the United States. Rather than simply avoiding detectable community disease epidemics and outbreaks, the USEPA adopted endemic disease burden targets to protect public health. The US set an acceptable risk level of 1 additional infection per 10,000 people per year (Macler and Regli 1993), (or 10-4 infections per person per year) from the consumption of drinking water.

Building on the US approach, the World Health Organization (WHO) adopted a health-based target for acceptable risk based on the use of the disability-adjusted life year (DALY) (Box 3.1). This target has been defined as 10-6 disability-adjusted life years (1 microDALY, or µDALY) per person per year to provide an acceptable health-based disease burden from the consumption of drinking water in the third edition of its Guidelines for Drinking-water Quality (WHO 2004). This approach has continued with the fourth edition (WHO 2011). In addition to their use in setting acceptable disease burden targets for exposure to specific matrices, such as drinking or recycled water, DALY metrics have been used extensively by agencies such as WHO to assess disease burdens and to identify intervention priorities associated with a broad range of environmental hazards.

Although the two approaches (the use of infection rates in the US versus the use of disease burdens by WHO) are not identical, in practical terms, both metrics usually lead to reasonably equivalent (within approximately one order of magnitude) health-based targets and hence similar treatment and exposure control requirements when applied to recycled water.

These guidelines follow the WHO approach and have set an acceptable risk of 1 additional µDALY per person per year for the use of recycled water. The DALY approach is preferred as it considers the varying severity of outcomes associated with different hazards in a way that simply considering infections does not. For example, there are significant differences between an infection that results in mild self-limiting diarrhoea on the one hand as distinct from more severe outcomes that may arise in some circumstances, such as typhoid, haemolytic uraemic syndrome, hepatitis, diabetes, Guillain–Barré syndrome, reactive arthritis or myocarditis.

The additional 1 µDALY tolerable disease burden benchmark was set based on its approximate similarity to the additional lifetime 70-year risk of cancer of 10–5 (i.e. 1 case per 100,000 people) that is in use by WHO for carcinogenic chemicals. For instance, consumption of drinking water that contains bromate at a concentration equal to its WHO drinking water guideline value would present an additional disease burden for renal cancer of 1.6 µDALY per person per year. In relation to microbial risk, the 1 additional µDALY per person per year is approximately equivalent to an additional annual diarrhoeal risk of illness of 10–3 (i.e. one illness per 1,000 people). By way of comparison, the reported average rate of diarrhoeal illness in Australia is approximately 0.8 cases per person per year (Gibney et al., 2014). As such, the acceptable microbial risk from using recycled water in accordance with these guidelines would be expected to contribute approximately 0.1% additional microbial risk above the endemic background to the community using that water. This level of endemic background risk is orders of magnitude below the level at which epidemic outbreaks would be detected and reported.

|  |
| --- |
| **Box 3.1. Overview of Disability Adjusted Life Years (DALYs).**One DALY can be thought of as one lost year of healthy life. The sum of these DALYs across the population, or the burden of disease, can be thought of as a measurement of the gap between current health status and an ideal health situation where the entire population lives to an advanced age, free of disease and disability.DALYs for a disease or health condition are calculated as the sum of the Years of Life Lost (YLL) due to premature mortality in the population and the Years Lived with Disability (YLD) for people living with the health condition or its consequences: DALY = YLL + YLD.The YLL corresponds to the number of deaths multiplied by the standard life expectancy at the age at which death occurs. The formula for YLL is the following: YLL = N x L; where: N = number of deaths and L = standard life expectancy at age of death in years.The YLD corresponds to the number of years lived with disability multiplied by the average duration of the disease and a weight factor that reflects the severity of the disease on a scale from 0 (perfect health) to 1 (dead). The basic formula for YLD is the following: YLD = I x DW x L; where: I = number of incident cases, DW = disability weight and L = average duration of the case until remission or death (years). Examples of this calculation are given in Appendix 2 and the concept is illustrated below. **Example calculation of DALYs for Norovirus infections** Severities of health impacts (disabilities) are weighted within the range of 0 for good health to 1 for death. Severities for outcomes of microbial infection include: • 0.061 for mild diarrhoea • 0.202 for moderate diarrhoea • 0.281 for severe diarrhoea Using an Australian example, infection with Norovirus causes2: • mild diarrhoea (severity rating of 0.061) lasting 2.1 days in 92.2% of cases • moderate diarrhoea (severity rating of 0.202) lasting 2.4 days in 7.2% of cases • severe diarrhoea (severity rating of 0.281) lasting 7.2 days in 0.6% of cases• death (severity rating of 1) in 0.0008% of elderly cases with an average YLL of 7.1 days The DALY per 1,000 cases then:= (0.061 x 2.1/365 x 922) + (0.202 x 2.4/365 x 72) + (0.281 x 7.2/365 x 6) + (1 x 7.1 x 0.008)= 0.32 + 0.096 + 0.033 + 0.057= 0.5 |

### 3.1.2 Determining DALY for water-related pathogens

DALY for individual pathogens includes considering acute impacts (e.g. diarrhoeal disease or even death) and chronic impacts (e.g. cancer). In terms of waterborne disease, the most commonly recognised illness from pathogens 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, Guillain–Barré syndrome and irritable bowel syndrome associated with *Campylobacter jejuni* (Havelaar et al 2012, Gibney et al 2014)
* haemolytic uraemic syndrome, associated with haemorrhagic *Escherichia coli* (Teunis et al 2004)
* reactive arthritis, associated with *Salmonella* (Rudwaleit et al 2001, Gibney et al 2014).

The DALY metric provides a means of quantifying the burden of public health impacts arising from disease caused by microbial, chemical and physical hazards (although in these guidelines it is only applied to microbial hazards). The metric can be used to:

* define acceptable risk in terms of public health outcomes
* compare impacts from different pathogens; 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 2012, Gibney et al 2014)
* prioritise resources toward controlling pathogens with the greatest potential impact.

### 3.1.3 Health-based targets

Establishing the acceptable risk allows health-based targets (HBT) to be set. The HBT within these guidelines is 1 µDALY. The HBT represents the benchmark to be met by each recycled water scheme to ensure that the systems do not pose an unacceptable health risk. HBT underpin the development of risk management plans (see Chapter 1). HBT can take a number of forms, the most common being guideline values for chemical hazards and treatment requirements for microbial hazards. In the context of this chapter, the HBT refers to the objectives that are set in order to ensure that the risk from pathogens is below the acceptable risk target of 1 additional µDALY per person per year from the use of recycled water.

It is important to note that the acceptable endemic disease burden target is a benchmark and that risk is in fact a continuum rather than a simple pass/fail metric (Walker 2016). Recycled water schemes that are predicted to present risks above 1 µDALY should be improved in order to bring the risk into safer zones. The greater the shortfall between the estimated risk associated with the scheme and the 1 µDALY target, the more urgent and significant the action required to fill that gap (as illustrated in Figure 3.1). For minor discrepancies the response might be a relatively long-term, measured response, such as working towards operational improvements. In contrast, for major gaps a more urgent response is required and that may entail ceasing supply whilst upgrades to treatment systems or exposure control strategies are implemented. While the continuum is a useful tool for establishing improvement requirements it should not be used to justify tolerance of non-compliance with agreed performance criteria. For example, the continuum should not be used as a justification to allow failures to meet agreed critical limits or target criteria to be accepted or allowed to last for extended periods.

It is important to appreciate that Figure 3.1 shows a logarithmic (based 10) scale which may not readily illustrate the diminishing returns at lower risk levels. For instance, dropping risk from a 3 log10 to a 2 log10 shortfall provides ten times the risk reduction associated with dropping risk from 2 log10 to a 1 log10 shortfall.

**Figure 3.1: Water safety continuum for recycled water supplies**

For most recycled water uses and their associated exposures, the acceptable pathogen concentration associated with the 1 µDALY target is not practicably routinely measurable. That is, the acceptable pathogen concentration associated with the 1 µDALY risk is below the detection limits of routine assays. Therefore, in designing and assessing schemes against the HBT it is usual practice to start with an assumed or measured pathogen concentration in untreated source water. The health-based targets are then described in terms of log10 reduction values (LRV). The LRV required can be achieved through the sum of two different control mechanisms:

* hazard reduction: controls that reduce the concentration of hazards, such as wastewater treatment
* exposure reduction: controls that reduce exposure to hazards, such as restricting the use of recycled water.

Hazard reduction is usually achieved via treatment processes that reduce hazard concentrations through removal and/or inactivation. However, it is possible for some sources of wastewater to control or exclude some minor source inputs that have much higher pathogen concentrations than those normally present in the bulk of the source water.

Exposure reduction is typically achieved using barriers aimed at reducing personal exposure to hazards. These barriers can include administrative and engineering exposure reduction measures as well as personal protective equipment.

The required LRV will depend on the hazard concentrations in source water and the likely extent of exposure. Hence, for a given end use, the LRV requirements for sewage will generally be greater than for stormwater or greywater which are in turn higher than for roofwater.

Pathogen control requirements are generally framed in terms of the required LRV for each of three pathogen groups: viruses, protozoa and bacteria. This grouping approach is preferred to evaluating individual microorganisms due to the wide variety of pathogens that may be present in source waters. For schemes that supply water for stock fodder watering and irrigation a fourth category, helminths, is often separately considered.

Monitoring and characterising source waters in order to establish pathogen concentrations takes prolonged periods (typically years) and is costly. However, within Australia, most reasonably similar source waters impacted by comparable inputs will have pathogen concentrations that are statistically similar. Therefore, within Australia, for most water recycling situations, default concentrations of reference pathogens can be adopted. This approach is appropriate where little data is available for reference pathogens in source water, or the cost of obtaining such data is prohibitive.

In developing these guidelines major water utilities have provided detailed data that has enabled the setting of default pathogen concentrations for the most common water sources. For most urban municipal wastewater and for many stormwater, greywater and roofwater schemes, the pathogen concentrations, although highly variable within each matrix, are relatively consistent between such matrices within Australia. Therefore, the default pathogen concentrations given in these guidelines are the most commonly adopted and are applicable to most of the more typical sources of recycled water.

A more tailored approach is to quantify the concentration of reference pathogens in source water to determine the treatment requirements to meet the health-based target. Such an approach is applicable where a source water is highly unusual so that default approaches are likely to be either overly conservative or insufficiently safe. The cost of pathogen testing tends to limit the use of tailored approaches to large volume recycled water schemes that might benefit from reducing treatment requirements by adopting less conservative assumptions than those given as defaults in this guideline or other publications.

## 3.2 Risk assessment

Conducting a risk assessment is the first step in determining treatment requirements to meet health-based targets. The theory of risk assessment is covered in Chapter 2 (Section 2.2.4). A risk assessment using default criteria has been undertaken for these guidelines to determine default treatment requirements. Quantitative assessment of health-based risks typically incorporates the following steps (Figure 3.2):

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

Figure 3.2 Process of quantitative health risk assessment

The remainder of Section 3.2 looks in detail at these four steps in risk assessment. The approach is relevant to both chemical and microbial hazards but this chapter deals with microbial rather than chemical hazards.

Chemical hazards are usually managed using a different paradigm to microbial hazards. For chemical hazards a risk assessment is used to set guideline or trigger values nationally that can be monitored using routine assays. Scheme managers seek to manage sources waters, e.g. through trade waste controls, and confirm those controls through routine audits of potential inputs of chemical hazards and through verification monitoring of recycled water to confirm compliance with those guideline or trigger values. Risk is only assessed in more detail if those guideline values are exceeded. Given the uses of recycled water described in this document, chemical hazards will generally only reach levels of concern in the event of a major contamination event, e.g. due to accidental or inappropriate discharge into source water collection systems. Preventive measures, such as trade waste control, can help to reduce the likelihood that such events will occur. As discussed in the Phase 2 module on augmentation of drinking water supplies (NRMMC et al 2008) chemical hazards require closer consideration and assessment for this use of recycled water.

In contrast, pathogens are expensive and often impractical to monitor at very low concentrations where the required acceptable concentrations are below routine detection limits. Furthermore, compared to chemicals, microbial hazards are typically relatively fast acting (acute) and highly variable in concentration.

### 3.2.1 Hazard identification (Step 1)

This section discusses general issues associated with:

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

#### Microbial hazard identification and reference pathogens

Recycled water sources can contain a wide variety 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 microorganisms (i.e. bacteria, viruses, protozoa and helminths) are required, due to variations in characteristics, behaviours and susceptibilities of each group to treatment processes. However, just four such groups are sufficient to cover the full range of gastrointestinal and most respiratory pathogens of interest in recycled water applications. In some cases (e.g. use in cooling towers), opportunistic pathogens (e.g. *Legionella* bacteria) can become problematic in recycled water and these are discussed in section 3.2.2.

Table 3.1 Microorganisms of concern to humans in sewage

|  |  |  |
| --- | --- | --- |
| Pathogen type | Examples | Illness |
| 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 |
| 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 |
| Helminths | *Taenia*  | Tapeworm (beef measles) |
| *Ascaris* | Roundworm |
| *Trichuris* | Whipworm |
| *Strongyloides* | Threadworm |

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 factors such as:

* high occurrence in the population of hosts discharging pathogens to the source water
* high concentration in source water
* high infectivity (likelihood of infection per ingested pathogen)
* resistant to removal and inactivation in treatment
* resistant to inactivation in the environment (prolonged persistence).

##### Reference pathogens for viral hazards

Of the enteric viruses, there is no single virus that represents an ideal reference pathogen and therefore a combination of viruses is used to provide model reference virus.

In the past rotavirus has been used as a reference pathogen, however, the significance of rotavirus will be reduced over time by the introduction of a vaccine that will change the incidence and severity of disease outcomes from this pathogen (Gibney et al 2014). With respect to occurrence, norovirus is by far the most prevalent cause of viral gastroenteritis in Australia (Gibney et al 2014). Dose–response models have been published for Norovirus (WHO 2016). However, although noroviruses have high infectivity and are likely to be present in high numbers in human waste, until very recently (Jones et al 2015, Ettayebi et al 2016), there was no cell culture method for the virus. The culture methods may lead to future development of a routine assay but currently concentrations of infectious or viable viruses in source waters are yet to be determined.

Reoviruses, enteroviruses and adenoviruses have long been culturable, and there are both Australian and international datasets for numbers of these viruses in sewage. Of these three viruses, adenoviruses have been detected in the highest numbers, and, consistent with their being a naked double-stranded DNA virus, they appear to be the most resistant to many processes used for virus removal or disinfection (Fong et al 2010, WHO 2004, Gerba et al 2002).

Australian adenovirus data were compared to 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 have been found to be similar (Deere and Khan 2016).

In view of these considerations, the virus chosen as a reference pathogen is an amalgam of two viruses: norovirus and adenovirus, using dose–response evidence for norovirus and occurrence and microbial inactivation evidence for adenovirus. Further research to better understand potential infectivity of norovirus in sewage is continuing and efforts to have a suitable assay transferred to Australia are underway through Water Research Australia (White P and Deere D, pers. comm.).

##### Reference pathogens for protozoan hazards

*Cryptosporidium* spp. oocysts are a good candidate for a reference organism for protozoa, because they are highly infective (Medema et al 2009), resistant to chlorination and one of the most important waterborne human pathogens in developed countries. *Giardia lamblia* is another candidate, as it is typically present in sewage at some 10–100 times the concentration of *Cryptosporidium* (Yates and Gerba 1998; Deere and Khan 2016), 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 *Cryptosporidium*. Therefore *Cryptosporidium* is the preferred choice as the reference pathogen for protozoan hazards.

##### Reference pathogens for bacterial hazards

There are several candidates for bacterial reference pathogens, including *E. coli* O157:H7, *Campylobacter, Shigella* and *Salmonella.* Of these, *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 (Gibney et al., 2010), has a relatively high disease burden per case and a relatively high infectivity compared to other bacteria. Therefore, *Campylobacter* has been selected as the bacterial reference pathogen.

##### Reference pathogens for helminthic hazards

Helminthic infections are not endemic in most parts of Australia and there is limited information on helminth occurrence in water and limited human dose–response model (Navarro et al., 2009; Navarro and Jiménez, 2011). However, for protection of human health, the protozoan reference pathogen can be used as a reference for helminths when the concern relates to the direct exposure of humans to recycled water. 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.

For agricultural irrigation schemes helminths may need to be considered separately. Protozoan pathogens may not require significant reduction in order to protect humans from direct contact with recycled water but in such cases helminth reduction may still be an important consideration to protect infection of humans via the food chain since helminths exposure and infection can amplify within the edible tissues of stock animals such as cattle (*T. saginata*) and pigs (*T. solium*).

#### 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 be based on 95th percentile values of data.

##### 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. Australian data consistently shows elevated *Cryptosporidium* concentrations in sewage during mid to late summer, probably related to recreational water exposure (Deere and Khan 2016). Outbreaks of specific illnesses will influence concentrations of pathogens in sewage (Helmer et al 2014, King et al 2015).

Variability in pathogen concentrations 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.

##### Greywater

Concentrations of microbial hazards in greywater 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 and pathogens in greywater can vary widely (Jeppesen and Solley 1994, Dixon et al 1999, Casanova et al 2001, Ottoson and Stenstrom 2003, Deere et al., 2006).

*Stormwater*

The presence of microbial hazards in stormwater is a function of the nature of the catchment that stormwater is collected from. Stormwater that is collected from impervious surfaces and is harvested prior to entry into underground drains will contain limited human-derived faecal contamination. Stormwater that has entered local drains in newly established urban areas, with new infrastructure, may contain low levels of human-derived pathogens, however, in older urban areas, contamination from sewage overflows and cross connections can result in significant pathogen presence. Data on pathogen concentrations in stormwater were reviewed in detail for the Phase 2 guidelines (NRMMC et al 2009) and more recent analyses from the Managed Aquifer Recharge and Stormwater Use Options (MARSUO) research have been consistent with this data (Dillon et al 2014).

### 3.2.2 Exposure assessment (Step 2)

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 (Deere et al 2004) or car washing and the washing of hard surfaces (Sinclair et al 2014; 2016). However, in most cases, occupational exposure can be managed by workplace procedures.

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 (e.g. 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. Other pathways to information include indirect ‘fomite’ transfer (e.g. hand to mouth or via objects that have been contaminated with recycled water) and potentially through the eyes. 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 consider accidental misuse, particularly that caused by third parties. The most commonly described example of this type of exposure is cross-connections introduced into dual-reticulation schemes. Whilst objective evidence in relation to cross-connection rates is lacking since most such events go unreported, there are ongoing reports of such incidents occurring across Australia. An assumed cross-connection rate of approximately 1 in 1,000 properties is a reasonable estimate of the ongoing frequency of such events within the broad population.

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 and largely subjective information. Further research is required in this area. Recent tracer studies using cyanurate have provided objective evidence of exposures (Sinclair et al 2014; 2016). These studies measure excreted cyanurate that has been added to recycled water to help estimate how much recycled water is ingested.

Examples of estimated exposure volumes and frequencies from intended uses of recycled water per person are provided in Table 3.2. In general, the volumes provided are representative and geometric means or averages have been used rather than upper bounds. For some situations, these estimates may be conservative and for others, non-conservative. Whilst these values can be used as defaults where specific or local information is not available, where appropriate local information is available it should be used.

Industrial use of recycled water has not been included in Table 3.2 because exposures will vary widely depending on the use. However, recycled water can be used for purposes such as cooling, process water and washdown water (the latter being an example provided in Table 3.7). In these circumstances, potential occupational and public exposures need to be determined on a case-by-case basis since frequencies of exposure can potentially be very high.

Table 3.2 Exposures associated with uses of 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 ingestionAccidental ingestion | 1 | 90 | Routine exposure results from indirect ingestion via contact with plants, lawns, etc.Infrequent event. |
| 100 | 1 |
| 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) | 7 | 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 |
| 1 (other raw produce) | 50 |
| Food crop consumption (commercial) | Ingestion | 5 (lettuce) | 70 | 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 |
| 1 (other raw produce) | 140 |
| 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. Note that this considers only conventional toilets and not bidets. |
| 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 | 2 | 10 | Median ingestion for firefighters estimated at 2 mL per fire with average number of fires fought within area served by recycled water estimated at 10 per year. e |
| Domestic car washing | Ingestion and inhalation of sprays | 0.1 | 50 | Geometric mean of 0.13 ml per 10 min exposure from car washing simulation with an estimate of 50 weeks per year.f |
| Domestic window washing | Ingestion and inhalation of sprays | 0.4 | 4 | Geometric mean of 0.13 ml per 10 min exposure from car washing simulation extrapolating to 30 min exposure with an estimate of quarterly activity.f |
| Domestic paving washing | Ingestion and inhalation of sprays | 0.4 | 12 | Geometric mean of 0.13 ml per 10 min exposure from car washing simulation extrapolating to 30 min exposure with an estimate of monthly activity.f |
| Occupational hosing down activities | Ingestion and inhalation of sprays | 16 | 50 | Geometric mean of 0.13 ml per 10 min exposure from car washing simulation extrapolated to 0.78 ml per hour with an estimate of 4 hours per day for 5 days per week (15.6 ml per week) for 50 weeks per year.f |

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** Firefighting is an occupational exposure and the exposures were based on Deere et al 2004 and informed by extensive consultation and inputs from the Queensland Department of Emergency Services.

**f** These estimates are based on tracer study simulation evidence from Sinclair *et al*. 2014; 2016.

### 3.2.3 Dose–response (Step 3)

Information on relationships between doses of microorganisms 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 2011). Since an infection can arise from a single pathogen, this makes pathogens non-threshold hazards. What varies between different pathogens is the likelihood of an infection arising per ingested pathogen. For instance, the probability of infection per ingested is higher for viruses and protozoa than for bacteria. However, *Shigella*, typhoid salmonellae and haemorrhagic *E. coli* have having relatively high probabilities of infection per pathogen (Haas et al 1999, Teunis et al 2004, WHO 2004).

Dose–response can be influenced by host factors such as immune status, pre-existing health conditions, health of gut flora (microbiome) and nutrition. However, the influence of these factors is not well understood and the general approach taken in developing water guidelines is to provide guidance 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 the core components of quantitative microbial risk assessments (Haas et al 1999).

### 3.2.4 Risk characterisation (Step 4)

The fourth step in risk assessment is to integrate information from hazard identification, exposure assessment and dose–response 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 the acceptable risk HBT of 1 additional µDALY per person per year. The treatment requirements for microbial hazards represent the reductions required to achieve this acceptable level of risk as described in Appendix 2.

## 3.3 Preventive measures to achieve health-based targets

Unrestricted exposure to hazards contained in untreated sources of recycled water (also termed the maximum, raw, inherent or untreated risk) will inevitably represent unacceptable risks in most cases since most of the water that is intended for recycling is contaminated with hazardous substances. Safe use of recycled water, therefore, requires preventive measures to reduce exposure to hazards by:

* Source water protection - preventing hazards from entering source water.
* Treatment - reducing hazards using treatment processes.
* Exposure control - reducing exposure by using non-treatment barriers or by restricting uses.

This section 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.

In recycled water schemes a combination of multiple preventive measures (often termed controls or barriers) are required to reduce risks to acceptable levels. Consideration should be given to the effectiveness of the preventive measure. In risk management systems (e.g. AS/NZS ISO 31000:2009) the concept of a hierarchy is useful to help classify the effectiveness of preventive measures. For instance, within such a hierarchy, in recycled water schemes, where possible elimination of hazards at the source are the most effective preventive measures. Given the nature of source waters this will not always be possible and engineered treatment measures and onsite measures applied to control exposure will be needed to reduce risk to acceptable levels. On-site measures present monitoring and enforcement challenges.

### 3.3.1 Source water protection

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

* In *sewage*, trade-waste controls can be used to limit the presence of microbial and chemical hazards. Microbial source controls might for instance involve restrictions on agricultural faecal waste.
* In *greywater*,input controls, including changing behaviours of householders/residents can be used to limit concentrations of microbial and chemical hazards.
* In *stormwater* controls on industrial discharges and sewage overflows can be used to limit microbial and chemical hazards

Although the protection of source waters to eliminate hazards would typically be considered the most effective preventive measures, there is only limited scope to eliminate all hazards in sewage and greywater. The Australian Sewage Quality Management Guidelines (WSAA 2012) should be applied for source water protection in recycled water schemes.

### 3.3.2 Treatment

Hazard concentrations can be reduced using various treatment processes, either singly or in combination. After source water protection, these engineered barriers are likely to be the most effective preventive measures in recycled water schemes. Table 3.3 summarises indicative reductions in the concentrations of microbial hazards that can be achieved using identified treatment processes. These values are derived from several studies under different operating conditions. The values represent a planning guide as to what is achievable using different technologies. The achievable ranges of pathogen reduction shown in Table 3.3 are relatively broad because effectiveness will be influenced by design features such as:

* bed depth, hydraulic flows and media characteristics for media filtration
* pore size of membranes (e.g. microfiltration versus ultrafiltration)
* disinfectant doses and detention times
* detention times in lagoons and wetlands.

Whenever treatment options are selected, performance claims need what is defined in these guidelines as ‘validation’ (as discussed in Sections 2.9.1). Validation is achieved be providing evidence of the ability of a specific process to remove or inactivate specific pathogens or suitable indicators under defined operating conditions (see Chapter 5). Standard well-established treatment processes are generally supported by published data, which reduces the requirement for specific testing, and many can be considered pre-validated using that prior art. 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 2009). Nationally, validation frameworks have been developed (Victoria Department of Health 2013, Robillot et al 2016) and protocols have been developed for a number of technologies (WaterSecure a-d, 2017). Internationally protocols have been established for membrane filtration and Ultraviolet disinfection (USEPA 2005, 2006) (See Chapter 2.9 and Chapter 5 for further details).

In practice, to avoid placing too much reliance on any one barrier, and to be consistent with the multiple barrier principle, it is common to avoid allocating too much pathogen reduction credit to any one treatment process. In some jurisdictions a maximum 4 log10 reduction per treatment barrier is considered acceptable (Victoria Department of Health 2013).

The LRV attributed to any treatment or exposure control process should be agreed with the relevant health regulator. Increasingly regulators require pathogen LRV credited to a treatment process to be validated under conditions that are bound by the critical limits that can be assigned to continuously monitored operational monitoring parameters measured using appropriate methods. Over time more and more processes have their pathogen LRV validated based on evidence provided by the vendor for the smaller scale package treatment plants although local in situ validation studies are also used in some cases, particularly for large treatment plants.

Table 3.3 Indicative pathogen LRV potentially attributable to treatment barriers

| **Treatment process** | **Achievable LRVsa** | **Validated LRVsb** | **Basis for validationc** |
| --- | --- | --- | --- |
| **Viruses** | **Protozoa** | **Bacteria** | **Viruses** | **Protozoa** | **Bacteria** |
| **Primary treatment** | 0 | 0 | 0 | 0 | 0 | 0 | Typically primary treatment provides very little pathogen reduction. |
| **Secondary treatment** | 2 | 2 | 2 | 0.5-1 | 0.5-1 | 1-2 | Conservative default values based on reported results1,2,3. These can be increased based on system specific testing for pathogen reductions. In the absence of such studies nominal log reduction values of 0.5 log for protozoa and up to 1 log for bacteria, viruses and helminths have been applied (State of Victoria 2013).  |
| **Coagulation, flocculation and media filtration** | 2 | 4 | 4 | 1-2 | 2.5-4 | 2.5-4 | Performance is very variable and depends on the presence, nature, design and effectiveness of operation and of processes such as coagulation, flocculation, sedimentation, flotation and filtration. |
| **Soil-aquifer treatment** (surface spreading, percolatn detentn) | 6 | 6 | 6 | System-specific | Log reductions dependant on nature of soil, aquifer conditions and detention time in the aquifer. 4,5,6 |
| **Lagoons** | 5 | 5 | 5 | System-specific | Log reductions dependant on design of lagoons and detention time. Where the minimum hydraulic residence time (taking into account short-circuiting) is reliably more than 25 days 4 log10 helminth reduction can be assumed. The LRV for other pathogens is more variable and can be as low as 1 log10. |
| **Membrane Bioreactor (MBR)** | 6 | 6 | 6 | 1.5-4 | 2-4 | 2-4 | In practice the pathogen reduction is largely achieved by the membrane process 3,7, 8 |
| **Micro or ultrafiltration (MF/UF)** | 3 | 6 | 6 | 0**d** | 4 | 4 | membrane filtration LRVs are typically based on supplier warranties with higher LRVs often being achieved for UF rather than MF3,9,10 |
| **Ozone/Biologically active carbon (Ozone/BAC)** | 4 | 3 | 4 | 4 | 0 | 4 | Based on achieving an ozone Ct of 1mg.min/L at ≥10OC 9,11,12. Higher Cts could increase LRVs |
| **Reverse osmosis (RO)** | 6 | 6 | 6 | 1.5-4 | RO systems would routinely achieve very much greater log reduction values in practice than those that can be routinely and readily validated. As a result, LRVs of the order 1 to 2 log are all that can be routinely validated where on on-line operational monitoring of EC or TOC forms the critical limit parameter. LRVs of 2.5-4 can be achieved where on-line or off-line operational monitoring of sulphate or fluorescent dyes forms the critical limit parameter. 3, 5,13 |
| **Ultraviolet light disinfection (UV)** | 6 | 6 | 6 | 4 | A validated low pressure lamp UV dose of 186 mJ/cm2 can provide 4 log inactivation of viruses or of 22 mJ/cm2 can provide 4 log inactivation of protozoa and bacteria. 9,14,15,16,17 |
| **UV/Advanced oxidation process (AOP)** | 6 | 6 | 6 |  4-6 | Major contribution by UV. Oxidant dose also provide inactivation 3,5  |
| **Chlorine (Cl2)** | 6 | 0 | 6 | 4 | 0 | 4 | A concentration x time (Ct) value associated with 4 log virus (and bacteria) inactivation is ≥ 15 mg/L (i.e. 0.5 mgL for 30 mins) at pH ≤ 7.5 and temperature of ≥ 10OC 9,18,19 |
| **Ozone** | 4 | 3 | 4 | 4 | 0 | 4 | Based on achieving an ozone Ct of 1mg.min/L at ≥10OC 9,11. Higher Cts could increase LRVs |

**a** Upper LRVs demonstrated in field investigations and laboratory trials with protozoa LRVs based on *Cryptosporidium* and LRVs for viruses validated on a case by case basis.

**b** LRVs in practice are often limited by practical limitations on the operational monitoring and quality of available evidence.

cSee Chapter 5 for more details of operational monitoring.

**1** WHO (2006); **2** Victorian Department of Health (2013); **3** TWDB (2015) Appendix E; **4** Betancourt et al (2014); **5** NRC (2012); **6** Pang L (2009); **7**WaterSecure (2017a); **8** Branch and LeClech (2015); **9** WHO (2011); **10** USEPA (2005); **11** USEPA (1999); **12**WaterSecure (2017b)**13** Pype et al (2015); **14** USEPA (2006b); **15** Hijnen, WAM et al (2005); **16** Tchobanoglous et al (2015); **17**WaterSecure (2017c), **18** Keegan A et al (2012), **19**WaterSecure (2017d).

### 3.3.3 Preventive measures to manage microbial risk by non-treatment barriers

Hazard reduction to achieve recycled water that is fit for purpose can be achieved by a combination of treatment processes (e.g. filtration and disinfection) and exposure preventive measures. Most existing recycled water guidelines and regulations specify a range of preventive measures that reduce risk by lowering exposure to recycled water. Collectively these preventive measures are known as non-treatment barriers. They differ from treatment barriers as they are applied at the point of use and operational control is based on observational monitoring which often receives limited attention. These non-treatment barriers 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
* 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 3.4. However, there is limited information on the effectiveness of these preventive measures and further research is required on this aspect. Further information on assessments of the performance of on-site measures is provided by O’Toole (2011). Although preventive, measures such as signage, labelling and communication, are important for reducing risks, no numerical hazard reductions are necessarily attributable to these actions. Due to uncertainties, as well as questions about reliability and practicability of monitoring and auditing, upper limits could be established for exposure reductions attributed to on-site controls. For instance, a maximum total allocation of 3 log10 exposure reduction is considered acceptable in non-agricultural recycled water uses within NSW (DPI 2015).

Since non-treatment barriers can be applied at multiple sites and away from the usual focus of operational monitoring at treatment plants, there can be the tendency to lose focus on these preventive measures. If non-treatment barriers are situated on a site that is not under the direct control of the recycled water producer or supplier, the third party must be aware that the safe use of the water is reliant on the effectiveness of the non-treatment barriers.

The effectiveness of any barrier upon which reliance is placed needs to be periodically monitored. It is essential that the application of non-treatment barriers is supported by monitoring and surveillance supported by education of users and auditing. It is important that site specific monitoring schedules for non-treatment barriers are documented, implemented and audited periodically. User agreements between the supplier and recipient of the recycled water can be helpful in clearly delineating the responsibilities for the application, operation and monitoring of the non-treatment barriers to ensure continued safe operations of the scheme.

Any non-treatment barriers should be assessed separately for each potentially exposed cohort (e.g. people or workers exposed through playing or working on a field are to be assessed separately from the public that might be adjacent to the site or consumers of crops).

#### Restricting use

Restricting uses of recycled water can have significant impacts on exposure. For example, using recycled water to irrigate only crops that are cooked or processed before consumption (e.g. potatoes or cereals) will result in lower exposures to infectious microbial hazards than using such water to irrigate salad vegetables. Similarly, using recycled water to irrigate crops with skins that are removed before consumption (e.g. citrus) will result in lower exposures than using the water to irrigate crops where the skin is eaten (e.g. 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 (Hamilton et al 2006).

#### Non-treatment application barriers within use

Methods of application will influence exposure. For above-ground crops it has been estimated that drip irrigation will provide at least 2 log10 lower contamination than spray irrigation while subsurface irrigation reduces the amount of contamination by a further 2 log10 (van Ginneken and Oron 2000). The same authors suggested that subsurface irrigation completely eliminates contamination of higher growing crops such as corn, grapes and orchards. This is supported by experiments with turf-grass that showed 3-5 log10 reductions of contamination when subsurface irrigation was compared to surface drip irrigation (Choi et al 2004). Alum et al (2011) compared contamination of cucumber and tomato plants following subsurface and surface drip irrigation. The results showed that with subsurface irrigation there was little evidence of above ground contamination of any part of the plants. With surface drip irrigation the primary site of contamination was the stem of the plant while only low levels of contamination were detected on the fruit (Alum et al 2011). Other experiments have shown that subsurface irrigation generally produces less contamination of above ground crops than furrow irrigation (Stine et al 2005, Song et al 2006).

#### Setting withholding periods

Setting withholding periods between application of recycled water and use of irrigated produce or lawn areas can reduce exposure. Australian studies have indicated that 1 log10 reduction of bacterial pathogens could occur in 4-6 hours in summer increasing to a day or more in winter while 1 log10 reduction of bacteriophage could take 12 or more hours (Sidhu et al 2008). Under laboratory conditions, reductions were very low (O’Toole et al 2008). Badawy et al (1990) and Choi et al (2004) detected faster rates of decay of bacteriophage in experiments conducted in Arizona but not to the extent of providing consistent 1 log10 reduction within 4 hours. However, as noted by O’Toole et al (2008) a 4 hour withholding period allows for drying of grass thereby reducing the transfer efficiency of micro-organisms from turf grass to playing field users. Drying can lead to rapid inactivation of *Cryptosporidium* oocysts which are particularly susceptible to desiccation (Robertson et al 1992).

Withholding periods for lawn and garden irrigation may reduce exposure further due to 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.

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.

Decay rates of viruses in recycled water on food crops have been estimated at 0.5 log10 per day after irrigation of surface crops (Asano et al 1992). Petterson et al (2001) demonstrated a biphasic inactivation of about 0.5 log per day initially and 2 log over 7 days for viruses. These are considered to be conservative values (Olivieri et al 2014). Similar reductions were estimated for bacterial pathogens and protozoan pathogens albeit at a lower decay rate, e.g. approximately 0.3 log10 per day for protozoa (Olivieri et al 2014).

#### 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; and
* anemometer switching systems.

Table 3.4 Non-treatment barriers

|  |  |
| --- | --- |
| Preventive measure | Estimated log10 reduction in exposure to pathogens |
| Cooking or some types of processing of produce (e.g. cereals that are cooked or wine grapes that are fermented)  | 5 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 (e.g. tomatoes, capsicums) | 3 log |
| Drip irrigation of raised crops with no ground contact (e.g. apples, apricots, grapes) | 5 log |
| Subsurface irrigation of above ground crops  | 4 log |
| Withholding periods for produce (7 days) Delivery period for produce (1.5 days) | 2 log0.5 log |
| Withholding periods for irrigation of parks/sports grounds (1–4 hours) | 1 log |
| Spray drift control (microsprinklers, anemometer systems, inward-throwing sprinklers, etc) | 1 log |
| Drip irrigation of plants/shrubs | 4 log |
| Subsurface irrigation of plants/shrubs or grassed areas | 5–6 logs |
| No public access during irrigation  | 2 log |
| No public access during irrigation and limited contact after (non-grassed areas) (e.g. food crop irrigation) | 3 log |
| Buffer zones (25–30 m) | 1 log |
| Enhanced cross-connection control  | 0.5 -1 log  |

Sources: Asano et al (1992), Cunliffe, D (2011), Tanaka et al (1998), Haas et al (1999), van Ginnekin and Oron (2000), Petterson et al (2001), Mara and Horan (2003), O’Toole (2011) and Olivieri et al (2014). Note that most of the above estimates of pathogen reduction are based on professional judgement and are not necessarily based on objective experimental evidence. Care should be taken to avoid placing excessive reliance (more than 2 to 3 log10 reduction) on such mitigation measures and further data is required.

#### 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 mains water 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*), *WSAA Water Supply Code* (WSAA)and *WSAA Dual Water Supply Systems, Version 1.2* (WSAA). Experience has found that cross-connections can occur at any point, including:

* In the network where the entire drinking water network is charged with recycled water via a cross-connection within the network.
* At the scale of the property, where the entire property received recycled water through its drinking water system via a cross-connection at the meter or connection to the water main.
* Within the property due to cross-connections occurring within properties.
* At a single fitting where a drinking water fitting is connected to a recycled water line.

Cross connections have occurred with recycled water of a range of qualities and in some cases, have gone unnoticed for some time. Multiple examples of cross-connections have been reported throughout Australia and internationally. In some cases the cross-connections resulted in illness. Ongoing measures to prevent, detect and respond to such cross-connection incidents should be proactively implemented by relevant stakeholders to identify and reduce the likelihood of cross-connections.

Table 3.7 incorporates default values for exposure associated with cross-connections. These exposures could be increased or decreased depending on the nature of dual reticulation (i.e. indoor and outdoor use, indoor use only, outdoor use only) and the extent of control measures applied. The examples assume a high grade of water has been cross-connected, a grade suitable for dual reticulation and firefighting. If the grade of water is lower than the risks are higher and this needs to be factored into the risk assessment.

#### 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; and
* communication to users, providing advice on appropriate and inappropriate uses of recycled water.

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

### 3.3.4 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. As part of occupational health and safety management, persons engaged in any operation involving either wastewater source waters or lower quality recycled water that is suitable only for restricted use 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. Advice should be provided on avoiding drinking the water and not using the water for high exposure activities such as in food preparation or for filling swimming pools).

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 (Deere et al., 2004).

## 3.4 Source Water Hazards

This section considers the following aspects of sewage, greywater and stormwater as a source of recycled water for non-drinking water uses:

* microbial hazards
* microbial health-based targets and preventive measures to manage microbial risk
* chemical hazards
* preventive measures to manage chemical risk.

### 3.4.1 Sewage

Sewage will always contain microbial hazards, including large numbers of enteric pathogens that can cause gastro-intestinal illness through ingestion. In addition, sewage contains respiratory viruses that can reach similar concentrations to the enteric viruses. The focus of this chapter is on the enteric pathogens on the basis that control of enteric exposure will mitigate respiratory risks.

Pathogen density in sewage is highly variable as 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 3.5.

### 3.4.2 Greywater

Greywater is used as a source of recycled water, particularly in small schemes or in individual households. A rise in recycling of greywater has occurred as a result of drying conditions, primarily in the southern areas of Australia.

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.

Table 3.5 Indicative concentrations of microorganisms in sewage

|  |  |
| --- | --- |
| Organism | Numbers in sewage (per litre) a,b |
| **Viruses**  |  |
| Somatic coliphages (indicators) | <1–109 |
| F–RNA coliphages (indicators) | <1–107 |
| Noroviruses | <1–106 |
| Enteroviruses | <1–106 |
| Adenoviruses | <1–104 |
| Rotaviruses | <1–105 |
| **Protozoa**  |  |
| *Cryptosporidium* | <1–105 |
| *Giardia* | <1–105 |
| **Bacteria** |  |
| *Escherichia coli* (*E. coli*; indicator)c | 105–1010 |
| *Enterococci* (indicator) | 106–107 |
| *Clostridium perfringens* (indicator) | 104–106 |
| *Shigella* | <1 –104 |
| *Campylobacter* | <1–105 |
| *Salmonella* | <1–105 |
| **Helminths** |  |
| Helminth ova | 0–104 (<102 in Australia)**c** |

**a** Colony-forming units for bacteria, plaque- or focus-forming units for viruses, oocysts for *Cryptosporidium* and cysts for *Giardia* and ova for helminths.

**b** The data shown is indicative and should be used with caution. Reported concentrations are highly variable and rely on different methods. For example, bacteria are usually detected using culture-based methods while virus concentrations can be determined using culture (e.g. adenovirus) or nucleic acid based methods (e.g. norovirus, rotavirus). The relationship between genome concentrations and infectivity is variable.

**c** Some *E. coli* are pathogenic although these are present at much lower concentrations than the indicator *E. coli* which is a benign component of normal gut flora.

**d** Helminth ova concentrations in raw sewage vary considerably due to the rate of infection in the population of the sewer catchment. In countries where the population is not endemic with helminth ova concentrations in raw sewage are usually < 10 ova/L (Navarro and Jiménez, 2011).
Sources: Feacham et al (1983), Geldreich (1990), NRC (1996), Bitton (1999), Soller et al (2015). Deere and Khan (2016).

The perception is that greywater is less hazardous than sewage. However, caution is needed as concentrations of microbial and chemical hazards in greywater vary over a wide range (see Table 3.6). In the worst cases, concentrations of faecal pathogens 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.

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 3.6 Comparison of greywater quality and sewage

|  |  |  |
| --- | --- | --- |
| Parameter | Greywater | Range in sewage |
| Range  | Mean |
| *Escherichia coli*/thermotolerant coliforms (per 100 mL) | 101–107 | No value | 106–108 |
| 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)

### 3.4.3 Stormwater

The increase in popularity of integrated water management has resulted in more focus on stormwater as a potential source for recycled water. This is particularly the case in new urban developments. Stormwater that is captured from overland flow, such as street gutters, or from areas where sewage and stormwater infrastructure is new, can contain fewer pathogens than sewage. In areas with older infrastructure, stormwater can be contaminated by sewage and contain significant concentrations of pathogens. This is discussed further under the Phase 2 Guidelines (EPHC et al 2009).

### 3.4.4 Mixed and blended source waters

In some cases various waters can be blended, including sewage, greywater, drinking water, industrial wastewater and roofwater. In such cases pathogen concentrations will need to be assessed by flow-weighting the estimates from the various sources. Note that the flow-weighting process cannot be based on long-term averages of the blends and must be based on the worst-case instantaneous blend.

## 3.5 Health-based targets and treatment and exposure reduction requirements

This section describes the calculations used to determine the setting of health-based targets (HBT) for achieving microbial quality in recycled water, and the measures that can be applied to meet compliance with the acceptable risk of 1 µDALY per person per year. Treatment and exposure reduction requirements are expressed in terms of log10 reduction values (LRV).

### 3.5.1 Sewage

The two variables are required for calculation of treatment and exposure reduction requirements to meet HBT values:

* exposures associated with identified uses of treated sewage
* pathogen concentrations in the sewage source water.

Indicative exposures associated with particular uses of recycled water are provided in Table 3.2.

As shown in Table 3.5, pathogen concentrations can vary over a wide range. Since pathogens are acute-acting non-threshold hazards, it is important to consider upper bounds in design and consequently 95th percentiles should be used in determining treatment and exposure reduction requirements. This also takes into account variation in concentrations and the impact of increased disease associated with seasonal occurrence of some pathogens and occasional disease outbreaks (Hellmer et al 2014, King et al 2015, Pouillot et al 2015).

Ideally health-based targets and required treatment and on-site controls should be calculated using system specific data. However, this is seldom possible as statistically valid sampling programs are very expensive. The alternative is to use default concentrations derived where possible from Australian data. As discussed in Appendix 2 the following default values have been identified:

* 8000 infectious viruses (based on infectious adenovirus in lieu of an absence of data in infectious norovirus) per L
* 2000 infectious protozoa (based on *Cryptosporidium*) oocysts per L
* 7000 infectious bacteria (based on *Campylobacter*) cells per L
* 5 - 50 human-infectious helminth (based on *Ascaris*) ova per L (for low and high-risk schemes, respectively) (Stevens et al 2017).

These concentrations are consistent with international data and can be used as default values in determining performance targets as shown in Table 3.7. Where system specific data is used care should be taken with the choice of reference pathogens and the methods used for analyses. For example, enteric viruses are often measured using DNA based methods (i.e. polymerase chain reaction (PCR)). These methods typically will provide higher concentrations than culture based tests but do not measure infectivity (Appendix 2). This will need to be considered when using the results to calculate performance targets.

Performance targets represent the reduction in source water concentrations of pathogens to meet the target of 1µDALY for defined uses of recycled water. Performance targets are calculated using the formula:

log reduction = log (concentration in source water × exposure × N ÷ DALYd)

where N is the number of exposures per year and DALYd is the dose equivalent to a DALY of 10–6 which are as follows:

* Norovirus 4.2 × 10-3
* *Cryptosporidium* 4.2 × 10–3
* *Campylobacter* 7.3 × 10–3

Table 3.7 shows that viruses require the greatest pathogen reduction requirements. This reflects the high infectivity of viruses compared to bacteria and the higher disease burden of viruses compared with protozoa. Table 3.7 also shows that the possibility of cross-connections represents a significant proportion of the exposure associated with dual-reticulation systems. This does not indicate a tolerance of cross-connections but recognises the reality that they occur too commonly. Every endeavour should be taken to reduce cross-connections. Experience has shown that poor design requirements, inadequate management systems and governance failures all contribute to cross-connections. Implementation of sound management and governance structures have been shown to reduce the risk of cross-connections. Demonstrated success can result in lower pathogen reduction requirements but this will only be achievable in highly controlled environments. While acute health risks from exposure to enteric pathogens is the primary concern from cross-connections, chemical hazards should also be considered particularly for extended exposure.

Recycled water can be used for purposes such as cooling, process water, washdown water and firefighting. In some case, potential occupational exposures need to be considered in addition to public exposures. Industrial exposures can vary widely depending on both the use and the exposure minimisation approaches and personal protective equipment applied. Firefighting is included in Tables 3.2 and 3.7 but other uses will need to be assessed on a case by case basis.

In addition to showing exposures associated with single types of reuse (i.e. commercial food crops, dual reticulation, municipal irrigation etc) Table 3.7 also shows exposures for combined exposure from municipal irrigation and dual reticulation. This does not lead to substantial changes in required pathogen log reductions particularly involving relatively high exposure uses but should be considered on a case-by-case basis.

Table 3.7 Log10 reduction requirements for uses of recycled water from treated sewage1

|  |  |  |  |
| --- | --- | --- | --- |
| Activity | Route of exposure | Exposure (ml) × freq (per year) | Log reduction2 |
| Viruses(norovirus) | Protozoa(*Crypto-sporidium*) | *Bacteria*(*Campylo-bacter*) |
| **Commercial food crops** | Ingestion – Lettuce – Other produce | 5 × 701 × 140 |  |  |  |
|  | Total | 490 | 6.0 | 5.4 | 5.7 |
| **Dual reticulation** |  |  |  |  |  |
|  | Garden irrigation | Ingestion of spraysIngestion – Low – High | 0.1 × 901 × 90100 × 1 |  |  |  |
|  |  | Total | 199 | 5.6 | 5.0 | 5.3 |
|  | Garden food crops | Ingestion – Lettuce – Other produce | 5 × 71 × 50 |  |  |  |
|  |  | Total | 85 | 5.2 | 4.6 | 4.9 |
|  | Internal uses |  |  |  |  |  |
|  | Toilet flushing  | Ingestion of sprays | 0.01 × 1100 | 4.3 | 3.7 | 4.0 |
|  | Washing machine | Ingestion of sprays | 0.01 × 100 | 3.3 | 2.7 | 3.0 |
|  | Cross-connections | Ingestion | 1,000 × 0.365 | 5.8 | 5.2 | 5.5 |
|  | External uses |  |  |  |  |  |
|  | Car washing  | Ingestion and inhalation of sprays | 0.1 x 50 | 4.0 | 3.4 | 3.7 |
|  | Window washing | Ingestion and inhalation of sprays | 0.4 × 4 | 3.5 | 2.9 | 3.2 |
|  | Washing paving | Ingestion and inhalation of sprays | 0.4 × 12 | 4.0 | 3.3 | 3.6 |
| **Total internal use (no garden use)** |  | 377 | 5.8 | 5.2 | 5.5 |
| **Total residential use (garden + internal + external)** |  | 672 | 6.1 | 5.5 | 5.8 |
| **Municipal irrigation** | Ingestion of sprays  | 1 × 50 | 5.0 | 4.4 | 4.7 |
| **Dual reticulation plus municipal irrigation** | Ingestion water and sprays  | 722 | 6.1 | 5.5 | 5.8 |
| **Occupational washing of hard surfaces** | Ingestion and inhalation of sprays | 15.6 × 50 | 6.2 | 5.6 | 5.9 |
| **Occupational fire fighting** | Ingestion water and sprays | 2 × 10 | 4.6 | 4.0 | 4.3 |

**1** Calculated using default reference pathogens and noting both intentional and unintentional exposure assumptions

**2** Log10 reduction calculations based on comparison to the DALYd as defined in Section 3.2.4:

* Norovirus = Log10 (number of organisms in sewage × exposure (mL) ÷ 1000 × frequency ÷ 4.2 × 10–3)
* *Cryptosporidium* = Log10 (number of organisms in sewage × exposure (mL) ÷ 1000 × frequency ÷ 4.2 × 10–3)
* *Campylobacter* = Log10 (number of organisms in sewage × exposure (mL) ÷ 1000 × frequency ÷ 7.6× 10–3)
* Default values of 8000 Norovirus per litre, 2000 *Cryptosporidium* per litre and 7000 *Campylobacter* per litre used to calculate log reductions

### 3.5.2 Health based targets for greywater

The principles of setting health-based targets are the same for greywater as for other sources of recycled water. 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. Microbial quality depends on the amount of faecal material that enters greywater from activities such as washing nappies or other types of soiled clothing. The variability in individual domestic systems will be greater than that in large systems (e.g. 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 over long enough time periods (at least two years) that site-specific pathogen concentration data can be used. However, 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.

In relation to microbial quality, as a reasonably conservative default, an assumption that greywater is similar to approximately 1% sewage is reasonable (Deere et al 2006) such that pathogen concentrations would be of the order 2 log10 lower than those default values assumed in raw sewage as given in Section 3.5.1. Another practical approach is to use mean *E. coli* concentrations detected in greywater over a reasonably long period (e.g. weekly sampling for three months) to determine the amount of faecal material present in terms of a percentage equivalent of sewage (by comparison with a mean concentration of 107 *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 typical levels of microbial contamination, and the use of medians may underestimate contamination by discounting peak values. Arithmetic means (averages) are considered to provide a balanced assessment of microbial contamination. Using this approach, log10 reductions required for greywater use can be determined by applying a correction factor to those calculated for sewage (see Section 3.5.1). Hence, if greywater quality for a particular scheme is shown to contain 105 *E. coli* per 100 mL (equivalent to 1% sewage), the reductions shown in Table 3.7 could be reduced by 2 log10. The reductions could be determined for each recycling scheme, with the concentrations of *E. coli* verified in precommissioning testing.

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

### 3.6 Implementation of preventive measures for a recycled water scheme

Recycled water guidelines commonly specify combinations of treatment processes (see Table 3.3) together with on-site controls and use restrictions (see Table 3.4) to provide water of acceptable quality for identified uses.

Using treatment (e.g. filtration-based processes) as the primary means of minimising risk from microbial 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 (e.g. 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 and operational expertise
* efficacy, reliability and operability
* availability of land (e.g. if buffer zones are to be used)
* public access (e.g. 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 including treatment processes and on-site controls that can be used to manage microbial risk from various uses of treated sewage. In this table, validated pathogen reductions attributed to treatment processes are used (Table 3.3). In practice pathogen reduction by treatment processes should be validated with reference to objective evidence (as discussed in Sections 3.3.2 and 2.9.1). During operation, advanced treatment will normally be subject to continuous operational monitoring to ensure compliance with critical limits (as discussed in Section 2.3.2). For instance:

* 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 2009).
* Disinfection and membrane filtration associated with advanced treatment will typically need to comply with particular specifications (e.g. UV dose, disinfectant dose (Ct) values for chemical disinfectants such as chlorine, or membrane pressure decay rate values).
* *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 pathogen 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 (e.g. dual reticulation, spray irrigation of salad crops and municipal irrigation with unrestricted access). The required pathogen reductions vary between the different uses.

Trade waste controls are of most relevance to the control of chemical hazards as well as to the control of some agricultural hazards, such as helminths. Further details of such controls can be found in the Australian Sewage Quality Management Guidelines (WSAA 2012) and these should be applied for source water protection in recycled water schemes.

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

| Intended use | LRV required in totala | Examples of LRV achieved by possible controls | Examples of water quality monitoring and objectivesc |
| --- | --- | --- | --- |
| Treatment controls and associated LRV  | Exposure controls and associated LRVb  | Operational monitoring and critical limits | Verification monitoring and water quality objectives |
| Dual reticulation, toilet flushing, washing machines, garden use, fire hydrants | * 6.0virus
* 5.5protozoa
* 6.0 bacteria
 | Advanced treatment required, such as:* secondary, coagulation, filtration and disinfection (UV and chlorine)
* secondary, membrane filtration and disinfection (UV and chlorine)

To achieve LRVs of:* 6.0 virus
* 5.5 protozoa
* 6.0 bacteria
 | Strengthened cross-connection controls required including ongoing education of householders and plumbers | Continuous on line monitoring:* Secondary treatment process flow rate and dissolved oxygen concentrations monitored and reported against agreed target criteria/critical limits.
* Turbidity or pressure decay rate criteria for filtration reported against validated critical limits.
* Disinfectant dose or concentration e e.g. UV dose or chlorine Ct, pH and temperature reported against validated critical limits
 | To be determined on case-by-case basis depending on technologiesWeekly final water testing:* *E. coli* <1 per 100 mL
 |
| Municipal use — open spaces, sports grounds, golf courses, dust suppression, etc or unrestricted access and application | * 5.0 virus
* 4.5protozoa
* 4.5 bacteria
 | Advanced treatment required, such as:* secondary, coagulation, filtration and disinfection (chlorine or UV)
* secondary, membrane filtration and disinfection (chlorine or UV)

To achieve LRVs of:* 5.0 virus
* 4.5 protozoa
* 5.0 bacteria
 | No specific measures | Continuous on line monitoring:* Secondary treatment process flow rate and dissolved oxygen concentrations monitored and reported against agreed target criteria/critical limits.
* Turbidity or pressure decay rate criteria for filtration reported against validated critical limits.
* Disinfectant dose or concentration e e.g. UV dose or chlorine Ct, pH and temperature reported against validated critical limits
 | To be determined on case-by-case basis depending on technologiesWeekly final water testing:* *E. coli* <1 per 100 mL
 |
| Municipal use, with restricted access and application | * 5.0 virus
* 4.5protozoa
* 4.5 bacteria
 | Secondary treatment with disinfection (chlorine or UV)* 2.5-3 virus
* 0.5-1 protozoa (higher LRV with UV)
* 4.0 bacteria
 | LRV attributable to exposure controls: * For all pathogens: 3.0

LRV based on: * Restrict public access during irrigation: LRV for all pathogens: 2.0
* Plus *one* of the following: LRV for all pathogens: 1.0:
	+ no access after irrigation, until dry (1–4 hours);
	+ minimum 25–30 m buffer to nearest point of public access; or
	+ spray drift control; e.g. low-throw sprinklers (180° inward throw), vegetation screening, or anemometer switching.
 | Continuous on line monitoring:* Secondary treatment process flow rate and dissolved oxygen concentrations monitored and reported against agreed target criteria/critical limits.
* Disinfectant dose or concentration e e.g. UV dose or chlorine Ct, pH and temperature reported against validated critical limits.

Oversight and auditing of end use restrictions. | Weekly final water testing:* BOD < 20 mg/Ld
* SS < 30 mg/ Ld
* *E. coli* <100 cfu/100 mL
 |
| Municipal use, with enhanced restrictions on access and application | * 5.0 virus
* 4.5protozoa
* 4.5 bacteria
 | Secondary treatment with >25 days lagoon detention or primary treatment with >50 days lagoon detention* 1.0-2.0 virus
* 1.0-3.0 protozoa
* 3.0-4.0 bacteria

Secondary treatment* 0.5–2.0 virus
* 0.5-1.0 protozoa
* 1.0-3.0 bacteria
 | LRV attributable to exposure controls: * For all pathogens: 4.0

LRV based on: * Restrict public access during irrigation: LRV for all pathogens: 2.0
* Plus *combinations* of the following: LRV for all pathogens:
	+ no access after irrigation, until dry (1–4 hours): 1.0;
	+ minimum 25–30 m buffer to nearest point of public access: 1.0; or
	+ spray drift control; e.g. low-throw sprinklers (180° inward throw), vegetation screening, or anemometer switching: 1.0.
 | Continuous on line monitoring:* Secondary treatment process flow rate and dissolved oxygen concentrations monitored and reported against agreed target criteria/critical limits.
* Lagoon inflow rates, outflow rates and depth.

Oversight and auditing of end use restrictions. | Weekly final water testing:|* BOD < 20 mg/Ld
* SS < 30 mg/ Ld
* *E. coli* <1,000 cfu/100 ml (disinfection may be required to achieve this concentration)
 |
| Landscape irrigation — trees, shrubs, public gardens, etc | * 5.0 virus
* 4.5protozoa
* 4.5 bacteria
 | Secondary treatment or primary treatment with lagoon detention* 0.5–2.0 virus
* 0.5-1.0 protozoa
* 1.0-3.0 bacteria
 | LRV attributable to exposure controls: * For all pathogens: 4.0

LRV based on: * Combinationsof the following: LRV for all pathogens:
	+ Microspray: 2.0
	+ drip irrigation: 4.0
	+ no public access: 3.0
 | Continuous on line monitoring:* Secondary treatment process flow rate and dissolved oxygen concentrations monitored and reported against agreed target criteria/critical limits
* Lagoon inflow rates, outflow rates and depth.

Oversight and auditing of end use restrictions. | Weekly final water testing:* BOD < 20 mg/Ld
* SS < 30 mg/ Ld
* *E. coli* <1,000 cfu/100 ml (if not disinfected)
 |
| Commercial food crops consumed raw or unprocessed | * 6.0 virus
* 5.5protozoa
* 5.5 bacteria
 | Advanced treatment required, such as:* secondary, coagulation, filtration and disinfection (UV and chlorine)
* secondary, membrane filtration and disinfection (UV and chlorine)

To achieve LRVs of:* 6.0 virus
* 5.5 protozoa
* 6.0 bacteria
 | None required, although pathogen reduction may occur between time of last irrigation and sale at 0.5 log10 per 1.5days|The recycled water can be used for all crop applications, including spray irrigation of salad crops | Continuous on line monitoring:* Secondary treatment process flow rate and dissolved oxygen concentrations monitored and reported against agreed target criteria/critical limits.
* Turbidity or pressure decay rate criteria for filtration reported against validated critical limits.
* Disinfectant dose or concentration e e.g. UV dose or chlorine Ct, pH and temperature reported against validated critical limits.
 | To be determined on case-by-case basis depending on technologiesWeekly final water testing:* *E. coli* <1 per 100 mL
 |
| Commercial food crops  | * 6.0 virus
* 5.5protozoa
* 5.5 bacteria
 | Secondary treatment or primary treatment with 25 days lagoon detention and disinfection (chlorine or UV)* 3.0–4.0 virus
* 2.0-4.0 protozoa
* > 4.0 bacteria
 | LRV attributable to exposure controls: *Consumers** Crops with limited or no ground contact and eaten raw (e.g. tomatoes, capsicums) — drip irrigation and no harvest of wet or dropped produce: 3.0
* Crops with ground contact with skins removed before consumption (e.g. watermelons) — if spray irrigation, minimum 2 days between final irrigation and harvest: > 3.0
* Pathogen reduction between time of last irrigation and sale at 0.3 log10 per day for up to 7 days: 2.0

*Public in vicinity of irrigation area*f* No access and drip or subsurface 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: 4.0
 | Continuous on line monitoring:* Secondary treatment process flow rate and dissolved oxygen concentrations monitored and reported against agreed target criteria/critical limits.
* Lagoon inflow rates, outflow rates and depth.
* Disinfectant dose or concentration e e.g. UV dose or chlorine Ct, pH and temperature reported against validated critical limits.

Oversight and auditing of end use restrictions. | Weekly final water testing:* BOD < 20 mg/Ld
* SS < 30 mg/ Ld
* *E. coli* <100 cfu/100 mL
 |
| Commercial food crops | * 6.0 virus
* 5.5protozoa
* 5.5 bacteria
 | Secondary treatment with disinfection (chlorine or UV)* 2.5-3 virus
* 0.5-1 protozoa (higher LRV with UV)
* 4.0 bacteria
 | LRV attributable to exposure controls: *Consumers** Above-ground crops with subsurface irrigation: 4.0
* Crops with no ground contact and skins removed before consumption (e.g. citrus, nuts): 4.0
	+ no harvest of wet or dropped produce
	+ if spray irrigation, minimum 2 days between final irrigation and harvest
* Pathogen reduction between point of last irrigation and sale at 0.3 log10 per day for up to 7 days: 2.0

*Public in vicinity of irrigation area*f* No access and drip or subsurface 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: 4.0
 | Continuous on line monitoring:* Secondary treatment process flow rate and dissolved oxygen concentrations monitored and reported against agreed target criteria/critical limits.
* Disinfectant dose or concentration e e.g. UV dose or chlorine Ct, pH and temperature reported against validated critical limits.

Oversight and auditing of end use restrictions. | Weekly final water testing:* BOD < 20 mg/Ld
* SS < 30 mg/ Ld
* *E. coli* <100 cfu/100 ml
 |
| Commercial food crops | * 6.0 virus
* 5.5protozoa
* 5.5 bacteria
 | Secondary treatment or primary treatment with lagoon detentionTo achieve LRVs of:* 0.5-1.0 virus
* 0.5-2.0 protozoa
* 1.0-3.0 bacteria
 | LRV attributable to exposure controls: *Consumers** Crops with no ground contact and heavily processed (e.g. grapes for wine production, cereals)
* Crops cooked/processed before consumption (e.g. potatoes, beetroot): > 5.0
* No harvest of wet or dropped produce consumption (e.g. citrus, nuts) with no spray irrigation (e.g. drip irrigation and no harvest of wet, dropped produce): > 5.0
* Crops with no ground contact and skin removed before consumption: 6.0
* Raised crops (e.g. apples, apricots, grapes) with no spray irrigation (e.g. drip irrigation and no harvest of wet, dropped produce): 5.0
* Pathogen reduction between point of last irrigation and sale at 0.3 log10 per day for up to 7 days: 2.0

*Public in vicinity of irrigation area*f* No access and drip or subsurface irrigation: 6.0
* No access during irrigation and, if spray irrigation: 5.0
	+ minimum 25–30 m buffer distance between irrigation area and nearest point of public access, and spray drift control (e.g. through part cycle sprinklers with 180° inward throw, vegetation screening, or anemometer switching)
* or
	+ extended buffer distances to >50 m
 | Continuous on line monitoring:* Secondary treatment process flow rate and dissolved oxygen concentrations monitored and reported against agreed critical limits considered to achieve conditions associated with the LRV attributed to the process.
* Lagoon inflow rates, outflow rates and depth.

Oversight and auditing of end use restrictions. | Weekly final water testing:* BOD < 20 mg/Ld
* SS < 30 mg/ Ld
* *E. coli* <1,000 cfu/100 ml
 |
| Nonfood crops — trees, turf, woodlots, flowers | * 5.0 virus
* 4.5protozoa
* 5.0 bacteria
 | Secondary treatment or primary treatment with lagoon detention* 0.5-1.0 virus
* 0.5-2.0 protozoa
* 1.0-3.0 bacteria
 | *Public in vicinity of irrigation area*f* No access and drip or subsurface irrigation: 6.0
* No access during irrigation and, if spray irrigation: 5.0
	+ minimum 25–30 m buffer distance between irrigation area and nearest point of public access, and spray drift control (e.g. through part cycle sprinklers with 180° inward throw, vegetation screening, or anemometer switching)
* or
	+ extended buffer distances to >50 m
 | Continuous on line monitoring:* Secondary treatment process flow rate and dissolved oxygen concentrations monitored and reported against agreed critical limits considered to achieve conditions associated with the LRV attributed to the process.
* Lagoon inflow rates, outflow rates and depth.

Oversight and auditing of end use restrictions. | Weekly final water testing:* *E. coli* <10,000 cfu/100 ml
 |

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 3.2.

**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** This may include chlorine CT or UV dose validated for adequate inactivation of target pathogens. The aim is to demonstrate reliability of disinfection and ability to consistently achieve microbial quality.

**f** Log10 reductions for public in the vicinity of commercial food crop irrigation areas should comply with total log reductions required for municipal use.

### 3.6.1 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 (e.g. Jeppesen and Solley 1994, NSW Health 2000, Queensland DLGPSR 2002, State of Western Australia 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 for instance NSW Health 2000, Queensland DLGPSR 2002 and State of Western Australia 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 3.4, 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.

***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 as a guide for operational and verification monitoring.

As described in Section 3.3.2, 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.

### 3.5.5 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 by-products. Processes used to treat sewage before recycling can reduce the concentration of chemical contaminants. The 2011 *Australian Drinking Water Guidelines* (NHMRC–NRMMC 2004) (ADWG) and Phase 2 drinking water augmentation guidelines (NRMMC et al. 1998) can be used to assess potential health risks associated with a broad range of inorganic and organic substances.

The health-related guideline values for drinking water uses 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 non-drinking uses of recycled water discussed in this chapter (see Table 3.2). 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 by-products (NRC 1996, NRC 1998, USEPA 2004).

### 3.6.2 Preventive measures to manage chemical risk

The risk to human health from chemicals in treated sewage from largely domestic sources is low for non-drinking uses, providing that preventive measures (e.g. trade-waste programs) are established and maintained to ensure that industrial discharges do not lead to elevated chemical concentrations in recycled water. In summary, it’s largely most appropriate to manage chemical risk at source.

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.

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

These guidelines provide an overview of the hazards and risks associated with using recycled water for livestock. It is important to adopt local legislation, as set by the food and primary industry customers and regulators, in relation to managing risks to 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 there is only very limited dose–response data 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.

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 (e.g. > 25 days of lagoon detention or equivalent process**b** to achieve the pathogen reduction required) 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 (e.g. abattoir or saleyard) waste
 | * Soluble BOD5 <20 mg/L
* SS <30 mg/L
* Disinfectant residual (e.g. minimum chlorine residual) or UV dosea
* *E. coli* <100 per 100mL
 |
| Dairy shed wash down | * Secondary treatment with helminth reduction (e.g. 25 days of lagoon detention or equivalent process**b** to achieve the pathogen reduction required) 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 BOD5 <20 mg/L
* SS <30 mg/L
* Disinfectant residual (e.g. minimum chlorine residual) or UV dosea
* *E. coli* <100 per 100 mL
 |
| Pasture or fodder crop irrigation (including hay, silage and commercial fodder production). Limited withholding period(not to be drunk by livestock) | * Secondary treatment with helminth reduction (e.g. > 25 days of lagoon detention or equivalent process**b** to achieve the pathogen reduction required) 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, e.g. through low-throw sprinklers, microsprinklers, drippers, part circle sprinklers (180º inward throw), vegetation screening, or anemometer switching
 | * Soluble BOD5 <20 mg/L
* SS <30 mg/L
* Disinfectant residual (e.g. minimum chlorine residual) or UV dosea
* *E. coli* <100 per 100 mL
 |
| Pasture or fodder crop irrigation (including hay, silage and commercial fodder production). With withholding period.(not to be drunk by livestock) | * Secondary treatment with helminth reduction (e.g. > 25 days of lagoon detention or equivalent process**b** to achieve the pathogen reduction required)

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, e.g. through low-throw sprinklers, microsprinklers, drippers, part circle sprinklers (180º inward throw), vegetation screening, or anemometer switching
 | * Soluble BOD5 <20 mg/L
* SS <30 mg/L
* *E. coli* <1000 per 100 mL
 |

BOD5 = biochemical oxygen demand over 5 days; SS =suspended solid; UV = ultraviolet

**Table 3.9 (continued)**

**a**Aim is to demonstrate reliability of disinfection and ability to consistently achieve microbial quality,
**b** e.g.Sand filtration can provide 2 to 4 log10 reduction and activated sludge plants 0-1 log10 reduction.

### 3.7.1 *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.

There are several preventive measures in place that limit the risk of *T. saginata* to humans and stock: meat inspection, cooking of meat and sanitation practises in Australia. However, the definitive preventive measure is achieved by breaking the life-cycle by preventing the exposure of helminth ova (released from the definitive host humans) to the intermediate hosts (cattle). 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’, other than some state authorities that recommend sand filtration noting that such treatment can potentially be equivalent to approximately 3 log10 reduction of helminth eggs. Advanced filtration methods, such as full conventional coagulation-flocculation-sedimentation-filtration or membrane filtration would be expected to achieve similar log10 reduction values for helminth eggs as they would for protozoan pathogens, which is typically in the range of 2 to 4 log10 reduction.

The guidelines have used the empirical model described by Ayres et al (1992)[[2]](#footnote-2) to determine the mean hydraulic retention required (25 days) to achieve approximately 4 log10 reduction of helminth ova. Recent research has supported this empirical model by showing that 23 days lagoon retention equates to 4 log10 reduction of helminth ova and 18 days equates to 3 log10 reduction of helminth ova[[3]](#footnote-3) (Stevens et al 2017).

To achieve these helminth log10 reduction values lagoons must be properly designed as treatment lagoons and must be functioning appropriately as sedimentation basins. The lagoons must not be mixed in ways that lead to ova potentially remaining in suspension. Consideration should be given to both water levels in lagoons and to sedimentation build up to ensure that adequate effective hydraulic lagoon volumes remain. Short-circuiting must be prevented through the use of appropriate baffles, inlet and outlet locations, angles, flow rates and structures, placing ponds in series and avoiding strong stratification. Those conditions must be maintained and monitored.

### 3.7.2 *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. This has implications for the quality of the meat. Humans can also autoinfect (via faeces) and this can lead to a *T. solium* infection that can cause a severe neurological disease in humans — neurocysticercosis — which is particularly significant in developing countries. Good sanitary practice in Australia is one of the many control measures for mitigating this risk, as is meat inspection and cooking.

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. Methods such as contractual specifications, user agreements and labelling and should be employed to help prevent fodder or crops irrigated with recycled water being supplied to pigs.

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.

### 3.7.3 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).

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.

### 3.7.4 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.

## 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 (e.g. 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.

# 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 are established/constructed/built correctly and will be safe and thus 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 continues to operate 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 design 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 – where are we now?
* validation monitoring – will it work?
* operational monitoring – is it working now?
* verification monitoring – 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 under predetermined parameters |
| 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

### 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 and also include examining the individual components of the scheme, not just the treatment efficiency.

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, re- validation maybe required when major impacts occur on a treatment system (e.g. change in source water), and when individual treatment components are repaired or upgraded. These additional validations must reconfirm that a modified or repaired recycled water system achieves the required results.

Validation monitoring, for example challenge testing, should be performed, or at least overseen in detail, by an independent and appropriately qualified professional or group of professionals. 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 any necessary microbial validation testing. Such oversight provides independent assurance that both the system being validated, and the sampling strategies and laboratory techniques being applied are sound.

It is important to note that the operational monitoring must be included as a part of the validation monitoring to demonstrate that usage controls ensure the system delivers the expected water quality.

### 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 timely 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 where the critical limits may be breached. This enables 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. For high risk schemes online monitoring is often required. In general, 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 or redesigned 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 (e.g. 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 (e.g. checking that the barriers to birds and vermin nesting in recycled water tanks are intact). These are used for monitoring points where on-line instrumentation is not practical or available. This requires a rigorous monitoring and reporting protocol to be established to ensure that timely monitoring continues and does not become overlooked.

### 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 continual 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 is undertaken at set frequencies to demonstrate that the final recycled water continues to meet the required health-based targets. 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 continuing quality of the water supplied and the functionality of the system as a whole
* confidence that environmental targets are being achieved
* along with operational monitoring, provide an additional indication of problems and a trigger for any 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
* exceedances of relevant target criteria or critical limits for environmental protection.

Such changes need to be assessed relative to baselines determined before recycled water use. 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 (e.g. a 20% increase above the baseline) can be set as target criteria or critical limits.

***Auditing***

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 (e.g. 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 independent 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. The auditing outcomes should be used to support continuous improvement and to respond to specific issues or concerns that are identified.

## 5.3 Monitoring for management of health risks

### 5.3.1 Validation monitoring

Validation is important to ensure that a specific treatment process is able to meet a predetermined or desired log reduction of specific pathogens. 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, need to be validated through objective empirical evidence. The precise nature of this evidence depends on the nature of the barriers. Tasks that should be included in a validation protocol are summarised in Table 5.2 (Victorian Department of Health 2013, Robillot et al 2016).

Validation protocols have been identified internationally for membrane filtration (USEPA 2006) and UV Light disinfection (USEPA 2005) and in Australia for chlorine, membrane bioreactors, UV light disinfection and reverse osmosis.

**Table 5.2. Validation Protocol**

|  |  |
| --- | --- |
| **Task**  | **Actions** |
| Task 1 | Identify the mechanisms of pathogen removal by the treatment process unit |
| Task 2 | Identify the target pathogens, or appropriate surrogates, that are the subject of the validation study. |
| Task 3 | Identify the influencing factors that affect the efficacy of the treatment process unit to reduce the target pathogen |
| Task 4 | Identify the operational monitoring parameters that can be measured continually and relate to the reduction of the target pathogen |
| Task 5 | Identify the validation methodology to demonstrate the capability of the treatment process unit |
| Task 6 | Describe a method to collect and analyse data to formulate evidence-based conclusions |
| Task 7 | Describe a method to determine the critical limits as well as an operational monitoring and control strategy |
| Task 8 | Describe a method to determine the LRV for each pathogen group (protozoa, virus or bacteria) in each specific treatment process unit performing within defined critical limits |
| Task 9 | Provide a means for re-validation or additional onsite validation where proposed modifications are inconsistent with the previous validation test conditions |

#### 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 ideally twenty samples for each condition validated to enable appropriate statistical analysis (e.g. assessment of 95% percentile) and to account for sample losses.

A range of conditions should generally be tested where possible (e.g. high, low and intermediate conditions of flow rate). Interpolation between conditions tested is often acceptable, but extrapolation is not acceptable, because unpredictable and unknown outcomes 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, the presence of high numbers in sewage, and the relative ease in detecting via both culture and molecular methods
* *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. Microbial indicators can include general faecal indicators such as *E. coli*, thermotolerant coliforms and enterococci, coliphage (for viruses) and *Clostridium* spp (for protozoa). The choice of microbial indicators will depend on the characteristics of the validation process being validated and mechanisms for achieving pathogen removal. For example, while physical characteristics of coliphage and *Clostridium* spp are similar to viruses and protozoa their sensitivity to disinfection and biological processes can be very different.

5.3.2 Operational monitoring for health risks

Operational monitoring is the continual assessment of the operation of significant parts of a treatment system and/or the performance of the treatment system as a whole. Operational monitoring should be commenced during the initial validation process to obtain suitable baselines of performance then then continue at pre-determined intervals. Appropriately designed operational monitoring is used to significantly reduce any residual unacceptable risks from microbial infections arising from even very brief, single exposures due to failures in the treatment system. 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. Examples of operational monitoring requirements are provided in Table 5.3.

### 5.3.3 Verification monitoring for health risks

Verification includes two components, monitoring of water quality to demonstrate compliance with requirements for identified end-uses and auditing of the design and performance of recycled water quality management plan. Key characteristics that should be considered for inclusion in verification monitoring plans include:

* microbial indicator organisms
* any health or environment-related chemical, physical or radiological 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.

Verification monitoring is normally conducted by testing of water after treatment and at the point of supply to recycled water distribution systems. The rationale is that concentrations of enteric pathogens, microbial indicators and health related chemical hazards will not increase in distribution systems. Exposures associated with end-uses described in this document are 1000 fold or more below those used in calculating drinking water guidelines (730L per year) and in the absence of chemical spills or accidents the likelihood that concentrations of chemical hazards will exceed 1000 times drinking water guideline values is extremely low.

Verification monitoring for health risks typically focusses on testing for microbial indicators with *E. coli* (or alternatively thermotolerant coliforms) being the usual choice. Other indicators such as coliphage, *Clostridium* spp and enterococci have been suggested as alternatives but there is limited evidence that they provide substantial advantages and they are not used as commonly as *E. coli* (or alternatively thermotolerant coliforms). The frequency of monitoring should take account of the size of the scheme, expected quality of the recycled water and intended uses and can vary from several times a week for large schemes providing recycled water for dual reticulation to monthly for small schemes providing recycled water for highly restricted uses.

**Table 5.3 Examples of operational monitoring parameters for pathogen removal by indicative treatment processes**

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatment process** | **Operational monitoring parameters** | **Frequency** | **Notes** |
| **Secondary treatment** | Ammonia, nitrate/nitrite, BOD, suspended solids, DO, mixed liquor suspended solids, hydraulic retention time, solids retention time, flow  | On line for DO, ammonia, flowWeekly for other parameters | Achieves LRVs but no quantitative correlation with individual operational parameters. Default LRVs based on achieving good operating characteristics |
| **Membrane Bioreactor (MBR)** | pH, bioreactor dissolved oxygen, solids retention time hydraulic retention time, mixed liquor suspended solids transmembrane pressureflux, turbidity | Online for parameters such as pH, turbidity, DO, transmembrane pressureWeekly for other parameters | Achieves LRVs but no quantitative correlation with individual operational parameters. Default LRVs based on achieving good operating characteristics |
| **Micro or ultrafiltration (MF/UF)** | Turbidity,PDT | OnlineDaily | Can achieve <0.1NTU |
| **Media filtration** | Turbidity | Online | Can achieve <0.15NTU Monitoring of individual filters improves control  |
| **Ozone/Biologically active carbon (Ozone/BAC)** | Ozone CtTemperature  | Online | LRVs based on ozone Ct |
| **Reverse osmosis (RO)** | Electrical conductivity EC or TOC.Sulphate or fluorescent dyes | Online Daily | Lower LRVs based on TOC/ECHigher LRVs if daily off-line measurements of sulfate or fluorescent dyes used as well as TOC/EC |
| **Ultraviolet light disinfection (UV)** | UV intensity, UV transmissionFlow | Online | Monitoring used to determine dose received by waterborne microorganisms |
| **UV/Advanced oxidation process (AOP)** | UV intensity, UV transmissionFlow | Online | LRVs based on UV dose.Monitoring used to determine UV dose received by waterborne microorganisms |
| **Chlorination (Cl2)** | Free chlorine residual and contact time pHTemperature | Online or frequent grab samples  | LRVs for bacteria and viruses based on chlorine Ct |

## 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 (i.e. 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 (e.g. ~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 (i.e. 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 (i.e. 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 5.4). 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 5.4 Examples of how maximal risk assessment relates to monitoring requirements

|  |  |  |
| --- | --- | --- |
|  |  | Sampling frequency |
| Maximal risk | Monitoring | Concerned with reliability of preventive measure | High confidence in preventive measure |
| Low | Low level of monitoring required (i.e. limited monitoring required at catchment level) | No sampling Risk assessment reviewed in 2–5 years | No samplingRisk assessment reviewed in 5–10 years |
| Moderate | Moderate level of monitoring required (i.e. 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 (i.e. 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 (e.g. 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 (i.e. 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 (e.g. chloride toxicity to foliage), continuous or frequent monitoring may be required (daily, weekly or monthly). Where the effects are chronic (e.g. 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 5.5, 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 (e.g. 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 5.5 Typical sampling program for verification monitoring of environmental water quality targets for assessment of environmental allocation of recycled water

|  |  |
| --- | --- |
|  | Sampling frequencya |
| Hazard | Continuous | Weekly | Monthly |
| 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 5.6. It may also be useful for assessing the suitability of the soils for the crops or plants to be grown.

Table 5.6 Typical sampling program for verification monitoring of environmental hazards in soil

|  |  |  |
| --- | --- | --- |
|  |  | Sampling frequencya |
| Hazard | Depth (cm) | Annually | Biennially |
| pH | 0–10b | √ |  |
| 30–50c |  |  |
| 90–100d |  |  |
| Salinity (electrical conductivity) | 0–10b | √ |  |
| 30–50c |  | √ |
| 90–100d |  | √ |
| Sodium adsorption ratio (SAR)(or exchange sodium percentage)  | 0–10b | √ |  |
| 30–50c | √ |  |
| 90–100d | √ |  |
| Cadmium | 0–10b | √ |  |
| 30–50c |  |  |
| 90–100d |  |  |
| Nitrogen (total) | 0–10b | √ |  |
| 30–50c |  | √ |
| 90–100d |  | √ |
| Phosphorus (available) | 0–10b | √ |  |
| 30–50c |  | √ |
| 90–100d |  | √ |
| Boron | 0–10b | √ |  |
| 30–50c |  | √ |
| 90–100d |  |  |

**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 (e.g. 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 (i.e. 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 (i.e. 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 5.7.

Table 5.7 Typical sampling program for verification monitoring of environmental hazards in groundwater

|  |  |
| --- | --- |
|  | Sampling and analysis frequencya |
| Hazard | Quarterly | Annually |
| 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 (i.e. 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 (e.g. monthly, yearly), surface water may require monitoring in response to climatic events (e.g. rainfall, or warm, still conditions conducive to algae growth). With the improvements in online water quality monitoring, if deemed necessary or appropriate, selected water quality parameters can be monitored on a real time basis to assist protecting environmental waterways.

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 5.8 shows a typical surface water monitoring program designed to assess the environmental impact of recycled water.

Table 5.8 Typical sampling program for verification monitoring of environmental hazards in surface water

|  |  |
| --- | --- |
|  | Sampling and analysis frequencya |
| Hazard | Quarterly | Annually | 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 (e.g. 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, transfer, 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 5.9.

Table 5.9 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 (chain of custody)
* 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.[[4]](#footnote-4) 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. Assurances must be sought that all sampling and analysis will be undertaken with the appropriate quality controls.

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 (e.g. 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, potential impacts of matrix effects, and the cost.

Information on accepted methods can be found in publications such as *Standard Methods for the Examination of Water and Wastewater* (APHA, AWWA and WEF 2012), *Australian Laboratory Handbook of Soil and Water Chemical Methods* (Rayment and Higginson 1992) and *Plant Analysis and Interpretation Manual* (Reuter and Robinson 1997). Note that these publications are updated from time to time

## 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:

* 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 (e.g. 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 documented, and regular independent audits of the program should be conducted by appropriately qualified personnel. Refer to Section 2.11 and 2.12 for further discussion of review and improvement programs.

# Appendix 2 Calculation of microbial health-based performance targets

Initial

As described in Chapter 3, Performance targets are the reductions in source water concentrations of reference pathogens required to ensure that uses of recycled water meet the definition of tolerable risk, that is, 10-6DALYs per person per year. In these guidelines the reference pathogens are *Cryptosporidium*, norovirus and *Campylobacter.*

Performance targets are calculated using the formula:

Required log reduction = log ($\frac{concentration of the pathogen in source water x exposure \left(L\right)to recycled water}{pathogen concentrations equivalent to 10^{-6 } DALYs pppy (DALYd)}$)

This formula has three inputs; the concentration of pathogens in source water, pathogen concentrations equivalent to 10-6 DALYs pppy and exposures associated with specific uses of recycled water.

##  Concentrations of pathogens in source water

Concentrations of pathogens in sewage are influenced by the prevalence of disease in communities and are generally subject to seasonal and yearly variations. The ideal approach for assessing risk associated with recycled water schemes is to start with source water pathogen concentrations provided by monitoring programs taking into account seasonal and yearly variations. This is an expensive and time consuming process. An alternative is to use default concentrations based on data collected by Australian water utilities and associated research organizations. The 2006 edition of these guidelines included default 95th%ile concentrations of 2000 *Cryptosporidium*, 8000 enteric viruses and 7000 *Campylobacter* per Litre of raw sewage. This was based on data from two major urban utilities.

The default concentrations for *Cryptosporidium* and *Campylobacter* were based on direct analyses for these organisms. However, the default concentrations of enteric viruses involved testing for a surrogate virus. Although norovirus has been identified as the most appropriate reference pathogen for enteric viruses there is currently no method for monitoring infective particles. Published concentrations are derived using PCR based methods. of published data from inlets to 42 WWTPs calculated a mean concentration of 3.9 log PCR detectable units (PDU) per litre with a 95th%ile credible interval of 3.5-4.3 log (3000-20000) PDU per litre by Pouillot et al (2015). However, the lack of a consistent relationship between PCR detected genome numbers and infectious virus particles (Jofre and Branch 2009, Rodriguez et al 2009) represents a significant limitation in using PCR based data to determine log reductions. Genome concentrations can be much higher than concentrations of infectious particles in sewage and drinking water sources (Lodder and de Roda Husman 2005, Lodder et al 2010). Results from other RNA viruses such as enteroviruses, rotavirus, poliovirus and coxsackie B5 have shown that genome concentrations can be much higher than concentrations of infectious particles in sewage (Lodder and de Roda Husman 2005, de Roda Husman et al 2009, Rutjes et al 2009, Lodder et al 2010). Using PCR based results is likely to over-estimate the risk from viruses in wastewater.

An alternative approach to estimating concentrations of norovirus is to use culture based methods to measure an abundant virus species as a surrogate for norovirus. Australian and international data supports the use of adenoviruses for this purpose. Adenoviruses are environmentally robust, can be measured using culture based methods and are abundant in sewage (Fong et al 2010, Deere and Khan 2016). The default value for enteric viruses published in the 2006 edition of the guidelines was based on culture-based analyses for adenovirus. Since the publication of the 2006 edition of the guidelines more data has become available from 7 WWTP (Deere and Khan 2016). The 95th%ile concentration was 8000 infectious units per litre which is the same as the 2006 default. This is concentration is almost certainly more conservative than the 20000 PDU per litre upper limit of the Norovirus PCR data and has been adopted in this guideline.

Recent data from 8 Australian WWTP showed that sewage contained 3500 viable oocysts per litre (95th%ile) (Deere and Khan 2016). This is higher than the default adopted in 2006 of 2000 viable oocysts per litre (95th%ile). Both sets of results were determined using the same method incorporating immunofluorescence, DAPI confirmation and were recovery adjusted (USEPA 2012). However, it should be noted that DAPI confirmation while providing a useful indication of potential viability of *Cryptosporidium* oocysts does not provide any evidence of human infectivity (King et al 2015).

A second smaller study of 5 wastewater treatment plants conducted in South Australia and Victoria detected an average of 2300 Cryptosporidium oocysts/L with a 95th%ile of 5000 oocysts/L (King et al 2015). The higher numbers in this survey were due to several samples being collected during an outbreak of cryptosporidiosis in Victoria. This study measured infectivity of DAPI confirmed *Cryptosporidium* oocysts and found that it varied from 7% to 44%. If a conservative value of 50% infectivity is applied to the earlier data the default concentration would be reduced to 1000 oocysts per litre for the 2006 data and for the more recent data to 1750 oocysts per litre. The latter concentration rounded to 2000 oocysts per litre has been adopted as a default value.

There is no new data on *Campylobacter*. Although recent data for *Salmonella* indicated that it is present in higher concentrations than the default value used for *Campylobacter* (Deere and Khan 2016) there 10 fold more cases of campylobacteriosis than salmonellosis in Australia each year, the disease burden from *Campylobacter* is 5 fold higher (Gibney et al 2014) and the dose response models for Salmonella indicate it is far less infective than Campylobacter (Haas et al 1999). *Campylobacter* is one of the most significant causes of gastro-intestinal disease worldwide with evidence of increasing prevalence (Kaakoush et al 2015). The default value of 7000 *Campylobacter* per L has been retained.

##  Pathogen concentrations equivalent to 10-6 DALYs pppy

The concentrations of reference pathogens equivalent to 10-6 DALYs pppy (DALYd) can be calculated using:

* QMRA to determine the likelihood of disease arising from exposure to reference pathogens.
* the disease burden from single cases of disease

Table A2.1 provides dose–response information for the reference pathogens which forms the basis of determining probabilities of illness following exposure to the pathogens while Table A2.2 shows the probability of illness developing from those infections and the disease burdens arising from illnesses. This information is used in Table A2.3.

Table A2.1 Human infection dose–response relationships for reference pathogens

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Organism type | Distribution | Model | Parameters | Derivation |
| Viruses(norovirus) | Exact beta‑Poisson | Pinf =$\frac{α}{α+ β}.d$ | α = 0.0044β = 0.002 | Messner et al. 2014and Van Abel et al. 2016. |
| Protozoa(*Cryptosporidium*) | Exponential | Pinf = r.d | r = 0.2 | Medema et al. 2009 |
| Bacteria(*Campylobacter*) | Approximate beta‑poisson | Pinf =$\frac{α}{β}.d$ |  = 0.145ß = 7.58 | Medema et al. 1996 |

 and r are parameters describing probability of infection; d = dose; ß = median infective dose (N50) ÷ (21/α–1); Pinf = probability of infection; for helminths the dose-response model is based on the 95th percentile of a sensitivity analysis for what is an uncertain relationship

Table A2.2 Probability of illness and disease burden associated with reference pathogens

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Organism type | Probability of illness per infection  | Derivation | Disease burden per case of illness (DALYs) | Derivation |
| Viruses(norovirus) | 0.7 | Messner *et al.* 2014 | 5 x 10-4 | Gibney *et al.* 2014 |
| Protozoa(*Cryptosporidium*) | 0.7 | Teunis *et al.* 2002  | 1.7 x 10-3 | Gibney *et al.* 2014 |
| Bacteria(*Campylobacter*) | 0.3 | Medema *et al.* 1996 | 2.4 x 10-2 | Gibney *et al.* 2014 |

**Table A2.3 Calculating concentrations of reference pathogens equivalent to 10-6 DALYs pppy (DALYds)**

|  |  |
| --- | --- |
|  | **Reference pathogen** |
| ***Cryptosporidium*** | ***Campylobacter*** | **Norovirus** |
| **Dose response parameters** | r= 0.2**a** | α = 0.145, β = 7.58**a**Approx Beta Poisson | α = 0.0044, β = 0.002**b**Exact Beta Poisson |
| **Low dose formulac** | Pinf = r.d | Pinf =$\frac{α}{β}.d$$\frac{α}{β}.d$ | Pinf =$\frac{α}{α+β}.d$ |
| **Probability of infection per organism (Pinf)** | 0.2 | 0.019 | 0.69 |
| **Probability of illness per infection (Pill/inf)** | 0.7**a** | 0.3**a** | 0.7**b** |
| **Probability of illness per organism (P*i =* Pinf x Pill/inf)** | 0.14 | 0.0057 | 0.48 |
| **Disease Burden (DB)d (DALYs per case)** | 1.7 x 10-3 | 2.4 x 10-2 | 5 x 10-4 |
| **DALYd** **= (**$\frac{10^{-6}}{P\_{i } x DB }$**) organisms** | 4.2 x 10-3 | 7.3 x 10-3 | 4.2 x 10-3 |

**a** GDWQ (WHO 2011)*.*

**b** from Messner *et al* 2014 with correction as noted in Van Abel et al (2016)

**c** low dose approximations from FAO/WHO (2003) and Petterson *et al* (2006)

**d** disease burdens from Gibney *et al* (2014).

## Performance targets as a function of exposures to recycled water

Once pathogen concentrations in source water have been determined, performance targets can be calculated as a function of estimated exposures to recycled water as shown in Figure A2.1. Alternatively the exposures shown in Tables 3.3 and 3.7 can be used to calculate required pathogen reductions for specific uses of recycled water (e.g. residential use, municipal irrigation). Box 2.1 presents a case study to illustrate application of this approach using the default values as discussed above.



**Figure A2.1 Required log reductions as a function of exposure to recycled water.**
Calculations were based on use of the default values of 2000 *Cryptosporidium*, 8000 Norovirus and 7000 *Campylobacter* per Litre (Section A2.1) and DALYds as calculated in Table A2.1

**Box A2.1 Case Study: Calculation of log reductions required to ensure that residential use of recycled water is within tolerable limits**

Potential exposures to recycled water associated with residential use of recycled water are summarised below (taken from Table 3.7)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Activity**  | **Route of Exposure** | **Volume (mL)**  | **Frequency per year** | **Exposure (mL)** |
| **Garden irrigation** | Ingestion of spraysIngestion – Low – High | 0.1 1100  | 9090 1 | 990100 |
| **Garden food crops** | Ingestion – Lettuce – Other produce | 5 1  | 750 | 3550 |
| **Toilet flushing**  | Ingestion of sprays | 0.01  | 1100 | 11 |
| **Washing machine** | Ingestion of sprays | 0.01  | 100 | 1 |
| **Cross-connections** | Ingestion | 1000  |  0.365 (1 cross-connection per 1000 houses) | 365 |
| **Car washing** | Ingestion of sprays | 0.1 | 50 | 5 |
| **Window washing** | Ingestion of sprays | 0.4 | 4 | 1.6 |
| **Washing paving** | Ingestion of sprays | 0.4 | 12 | 4.8 |
| **Total** |  |  |  | **672** |

The total exposure of 0.672 L per person per year can be used to calculate required log reductions from source water containing the default concentrations of 2000 *Cryptosporidium* oocysts, 8000 Norovirus and 7000 *Campylobacter* per Litre:

1. **Protozoa (Cryptosporidium)**

Required log reduction = log (2000 x 672÷ 1000÷4.2x10-3)$\frac{ 2000 x 0.66}{ 4. 2 x 10^{-3 }} $) = 5.5

1. **Viruses (Norovirus/Adenovirus)**

Required log reduction = log (8000 x 672÷ 1000÷4.2x10-3) = 6.1

1. **Bacteria (Campylobacter)**

Required log reduction = log (7000 x 672÷ 1000÷7.6x10-3) = 5.8

Appendix 3

Additional guidance on elements 2 to 4 of the framework for management of recycled water quality and use

Assuring the safety of recycled water schemes requires appropriate attention to detailed system assessment and management. This appendix provides additional guidance on *Assessment of the recycled water system* (Element 2), *Preventive measures for recycled water management* (Element 3) and *Operational procedures and process control* (Element 4). In particular, additional details are provided on system characteristics, sources of hazards and hazardous events, process controls and corrective actions.

A3.1 Assessment of the recycled water system (Element 2)

Understanding the characteristics of recycled water systems is an essential component of developing comprehensive risk management plans. All components of the system from source to end-use need to be identified. Table A3.1 includes examples of characteristics that may need to be considered.

**Table A3.1 Characteristics of recycled water systems**

|  |
| --- |
| **Recycled water sources (catchment and collection systems)** |
| Development and planning restrictionsFuture planning activitiesIndustrial developmentsInput controls, such as:* household chemical regulation, labelling and education
* livestock yards and abattoirs
* trade waste programs (for sewerage systems)
 | * management of contaminated sites (for stormwater systems)
* regulation of household plumbing configuration (for greywater systems)

Meteorology and weather patterns (climatic and seasonal variations)Residential developmentsTopography and drainage patterns (hydrology) |
| **Source water characteristics** |
| Flow and reliability of source waterGeneral and unique constituents (physical, chemical, microbial):* bacteria, viruses, protozoa and helminths
* detergents (greywater)
* industrial chemicals
* major ions, salinity, hardness and pH
* metals and radionuclides
 | * nutrients (nitrogen and phosphorus)
* organic chemicals
* disinfection byproducts
* biologically active compounds including endocrine disruptors, pharmaceuticals

Seasonal and event changes (including infrequent events such as droughts or floods)Spatial variations and identifying contamination sources |
| **Treatment systems** |
| Disinfection residual and contact period Equipment design:* size
* materials
* peak flow rates
* process change control
* backup systems
* bypass provisions

Monitoring equipment and automation | Nature of treatment processes including primary, secondary and tertiary treatment, on-site treatment, nutrient reduction, disinfection, etcRecycled water treatment chemicals used:* coagulant
* filtration aids
* disinfectant

Stability and reliability of processesTreatment configuration and efficiencies |
| **Storages (including lagoons and wetlands)** |
| Algae, macrophytes, zooplankton–plant dynamicsAquatic community characteristics and any protection statusDetention times Protection (e.g. covers, enclosures, access)Recreational or human activitySeasonal variations:* stratification
* algal blooms
 | Storage design:* depth
* materials
* size
* storage capacity

Intake location and operationTreatment efficiencies (microbial removal)Use of the site by birds |
| **Distribution systems, application and receiving environments** |
| Access controls (e.g. fencing)Application controls including methods (e.g. spray, drip, subsurface irrigation), design of irrigation system and scheduling (e.g. night-time only)Application ratesConservation status/protected areasCross-connection controls and audit systemsGroundwater characteristics including nature of existing aquifers, current uses, depth and quality | Local vegetation (on-site and off-site)Physical barriers (e.g. buffer zones, trees and shrubs)Plumbing standards and requirements (e.g. location of piping, colour coding, labelling)Permitted usesReceiving water characteristics including their nature (marine or freshwater, flows, volume, tidal movement, current uses and environmental values)Soil characteristics |
| **Uses of recycled water**  |
| Residential and commercial use of water for toilet flushing, car washing, garden watering, clothes washingEnvironmental flow (intentional discharge)Fire control | Water features (e.g. ponds and fountains)Agriculture and horticultureIndustrial usesIrrigation 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 (e.g. fire control officers, road workers, irrigation officers, farmers)Local plumbers who may gain access to distribution systems |
| **Receiving environments and endpoints** |
| AirBiota GroundwaterHumans | Infrastructure PlantsSoilsSurface water |
| **Other** |
| Extreme and infrequent events (e.g. droughts or floods)  | Seasonal characteristics |

Once all the characteristics have been identified the next step is to identify all of the potential sources of hazards and hazardous events. Table A3.2 provides examples of potential hazards and their sources while Table A3.3 provides examples of hazardous events that may lead to the introduction of hazards into recycled water schemes.

Table A3.2 Examples of sources and potential hazards

|  |  |
| --- | --- |
| Sources  | Potential hazards  |
| Stormwater |
| Animal husbandry | Pathogens, antibiotic-resistant bacteria, 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 (e.g. 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 (e.g. copper from domestic pipes), domestic chemicals (e.g. inappropriate disposal of garden chemicals, paint, solvents, petrochemicals) |
| Industry | Heavy metals, organic chemicals, specific industries can be associated with specific types of contaminants (e.g. 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, antibiotic resistant bacteria, ammonia, pharmaceuticals, personal care products |
| Greywater |
| Domestic/household chemicals | Detergents (including boron, phosphates), personal care products, sunscreens, domestic chemicals (e.g. 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 A3.3 Examples of potential hazardous events

|  |
| --- |
| Stormwater catchments |
| * Chemical use in catchment areas (e.g. use of fertilisers and agricultural pesticides)
* Climatic and seasonal variations (e.g. 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 leakages, overflows and septic system discharges
* Unrestricted livestock
 |
| 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 (e.g. heavy rainfalls, droughts)
* Cyanobacterial blooms
* Leakage from storage to groundwater
* Livestock access
 | * Inadequate buffer zones and vegetation
* Inadequate storage (e.g. 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 (e.g. 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 (e.g. 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 (e.g. 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
 |

**A3.2 Preventive measures for recycled water management (Element 3)**

Following identification of hazards and hazardous events, preventive measures can be identified to control those hazards and hazardous events that represent unacceptable risks. The most effective preventive measure is minimise contamination through source water protection but given the nature of sources waters this is only possible for some contaminants (e.g. industrial chemicals). Other preventive measures include water treatment and end-use and on-site restrictions.

**A3.2.1 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 (e.g. discarding kitchen waste or nappy-wash water), and controlling the types of detergents and other household chemicals used in water collected by greywater systems.

**A3.2.2 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.

***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’).

***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.

**A3.2.3 Specific treatment processes**

***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.

***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 A3.4 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 A3.4 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 | 0.1–0.5a |
| 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 (e.g. FeCl3) 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 BOD5; 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, PO4–3) 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.

***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 (e.g. 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 A3.5 shows the chemical qualities that can be achieved by advanced processes.

**Table A3.5 Effect of some advanced processes on the chemical quality of sewage effluents**

|  |  |
| --- | --- |
| **Treatment process** | **Typical effluent quality, mg/L (except turbidity, NTU)** |
| **TSS** | **BOD5** | **Total N** | **NH3-N** | **PO4-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 |

BOD5 = 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.

***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.

***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.

**A3.2.4 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.

Growth of opportunistic pathogens such as *Legionella* can occur in distribution systems but significance of these organisms in recycled water has not been established. Where possible conditions that favour growth of these organisms (e.g. water temperatures between 25 and 50OC) should be avoided.

**A3.2.5 End-use and on-site restrictions**

***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.

***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 (e.g. ‘Recycled water — do not drink’) should be installed wherever recycled water is used. Alternative signs may be required for other uses (e.g. ‘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 (e.g. 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 (e.g. 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 (e.g. ‘Warning — recycled water — not for drinking’). Outlets and taps should also be clearly marked.

**A3.2.6 Identifying critical control points and establishing limits for operational control**

Critical control points (CCPs) are preventive measures that are:

* essential for controlling or removing hazards that represent high risks
* amenable to operational monitoring using parameters for which critical limits can be set and
* amenable to implementation of corrective actions to restore acceptable performance

Table A3.6 provides examples of possible critical control points, operational criteria and corrective actions. These examples are illustrative and are not intended to be definitive. The identification of CCPs and criteria for individual schemes will depend on a risk assessment and on consideration of specific targets associated with required end uses.

**Table A3.6 Examples of potential CCPs and operational criteria**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Potential CCP** | **Hazard(s) controlled** | **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 (e.g. increase coagulant dose, increase filter backwashing frequency) |
| 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 (e.g. stormwater intakes), if necessary increase performance of other barriers) |
| Lagoon detention of recycled water | Helminths | Minimum detention 25 days (target criterion 30 days)  | Continuous flow monitoring | Identify cause of problem (e.g. 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 | Increase dose |
| 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 | Disable illegal connection |
| 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 (e.g. 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

**A3.3 Operational procedures and process control (Element 4)**

Operational procedures and process control formalise activities essential to ensuring that management systems function effectively. Process controls describe how processes and activities should be performed. Examples are provided in Table A3.7

**Table  A3.7 Examples of process-control programs**

|  |
| --- |
| **Process-control programs** |
| * 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).
 |

As discussed in Table A3.6 corrective actions should be identified to restore performance of preventive measures when they do not meet operational requirements. This is particularly important for CCPs. Examples of corrective actions are shown In Table A3.8.

**Table A3.8 Examples of corrective actions**

|  |
| --- |
| **Possible corrective actions** |
| * identifying sources of chemical contaminants and reinforcing trade waste controls
* altering the plant flow rate (e.g. 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
 |

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1. 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. [↑](#footnote-ref-1)
2. R=100[1-0.41exp(-0.49θ+0.0085 θ 2)], where R equals the percentage removal of helminth eggs and θ equals the detention time, in days. [↑](#footnote-ref-2)
3. LRV=0.224HRT-1.038, where LRV= Log Removal and HRT = Hydraulic retention time in a lagoon (days). [↑](#footnote-ref-3)
4. Available online at http://www.nata.asn.au [↑](#footnote-ref-4)