A review of international wastewater reuse standards and guidelines

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EXECUTIVE SUMMARY

Water scarcity is an emerging issue in New Zealand and reducing water use is the first step in the "Reduce, Reuse and Recycle" hierarchy of water conservation. Wastewater can be treated and reused to reduce the use of potable water and freshwater resources, providing an alternative source of water for agriculture, urban activities and use by industry. However, while wastewater reuse provides benefits as an alternative source of water and nutrients, it also presents potential risks to human health and the environment.

Guidelines have been developed internationally to manage the risks associated with wastewater reuse. The World Health Organization (WHO), the Food Agriculture Organization of the United Nations (FAO), the International Organization for Standardization (ISO) and the European Union (EU) have developed international guidelines. Whilst New Zealand has national guidelines for the application of sewage effluents, sludges and biosolids to land and regional guidance for the reuse of wastewater from small, onsite wastewater systems, there are no appropriate guidelines for reuse from municipal wastewater treatment facilities, or for reuse of wastewater in agricultural, urban or industry applications. In the absence of New Zealand guidelines for wastewater reuse, there is the potential for inconsistent and/or inappropriate regulatory decisions. It is important to highlight that Māori have established cultural traditions and associated customary practices for managing human waste, particularly to relation to keeping it separate from food (Pauling, Araria 2010).

The greatest risk to human health is associated with pathogens in the wastewater (WHO 2006) and this review focuses on how the risks can be managed to meet health-based targets. The guidelines produced by the WHO (2006) and the Australian Wastewater Reuse Guidelines (AWRG) (NRMMC et al 2006) provide a detailed risk management framework. An overview of the risk management approach is also given in ISO 20426 (ISO 2018a) which refers to the AWRG (NRMMC et al 2006) for quantitative risk assessment methodology. This methodology uses a risk management plan to identify the critical control points in the system, the processes that are implemented to control risks (ie preventive control measures), how the system will be operated, monitored, managed, reviewed and emergency management. Commissioning and operational monitoring ensures safe water is supplied and verification monitoring provides evidence that regulatory compliance requirements are met. The WHO (2006), AWRG (NRMMC et al 2006) and ISO 16075-2 (ISO 2020b) guidelines show how preventive control measures (or barriers) can be applied in an additive way. Wastewater treatment to reduce pathogen concentrations can be used in conjunction with other preventive control measures, such as restrictions on irrigation methods, the crops selected or access to sites where wastewater is reused, to achieve a set health-based target.

Comparison of the microbiological guidelines shows key differences between the WHO (2006) and Australian risk assessments (NRMMC et al 2006). The WHO guidelines (WHO 2006) focus on low- and middle-income countries, arid and semi-arid climates, where there may be multiple exposure routes for disease and/or significant benefits from food production. In New Zealand wastewater reuse for food production is likely to be incompatible with Māori values.

Where wastewater reuse is being used to for food grown in direct contact with the soil, or wastewater the AWRG (NRMMC et al 2006), US EPA (US EPA 2012) and EU guidelines (EU 2020) rely on a high level of wastewater treatment with faecal indicator bacteria (FIB) criteria of <1/100 mL and ≤10/100 mL. These criteria differ from the higher FAO (1992) and

WHO (2006) FIB criteria. The WHO (2006) guidelines rely heavily on the end user implementing preventive control measures, which are impractical to verify, and the guidelines apply a very high pathogen die-off rate unlikely to be achieved in the temperate New Zealand climate. The more precautionary approach by Australia, EU, ISO and the US gives greater confidence that the health risk is appropriately managed. For activities such as growing trees, where there is low potential for human exposure, criteria for FIB may be ≤10,000/100 mL with specific preventive control measures. For irrigation of pasture FIB criteria may range between ≤100 and ≤1,000/100 mL, depending on the other preventive controls in place to achieve the pathogen log reduction. Where an activity is part of the human food chain eg milk production, the AWRG guidelines set FIB criteria at the lower criterion of <100 /100 mL in (NRMMC et al 2006).

Where wastewater treatment is the main preventive control for urban reuse, guidelines specify FIB criterion of <1/100 mL. In other settings such as irrigation of public spaces, FIB criteria may be higher when combined with other preventive controls such as controlling access to the area, buffer zones, or withholding periods. There is limited guidance for industrial reuse with a mostly case by case assessment of risk proposed.

As FIB criteria increase the importance of the preventive control measures being implemented and being effective is critical.

The AWRG risk management framework (NRMMC et al 2006) provides a useful tool for managing health risks from wastewater reuse. It is promoted by ISO 20426 2018a and the preventive control measures are more precautionary than the WHO (2006). There are two aspects which need to be adapted to New Zealand conditions:

- a site-specific approach to buffer zones suggested by the EU (2020) would take into account local conditions that affect spray drift such as wind and the presence of vegetation barriers.
- longer die-off periods in New Zealand may be longer due to the more temperate cooler climate.

The risk from pathogens is considered the greatest human health risk associated with wastewater reuse (WHO 2006, ISO 20426 2018a). The studies used in the WHO (2006) and NRMMC et al (2006) guidelines to derive FIB criteria are dated and new research may provide better information on the human health risks. There was little information available on the environmental fate of emerging organic chemicals or antimicrobial resistance in guidelines. ISO 16075-1 (ISO 2020a) does not include guideline values due to a lack of evidence that emerging contaminants cause health, environmental or crop issues in wastewater reuse. ISO 20760-1 (ISO 2018b) proposes source control to avoid toxic chemicals. The US EPA (2012) has funded some research on anti-microbial resistance. A review of recent literature could ensure that the most recent data is available to manage public health risks in decision making on wastewater reuse in New Zealand.

1. INTRODUCTION

1.1 BACKGROUND

Water scarcity is an emerging issue in New Zealand. Reducing water use is the first priority in the “Reduce, Reuse and Recycle” hierarchy of water conservation. Wastewater can be treated and reused to reduce the use of potable water and freshwater resources. As well as agricultural reuse, wastewater has been increasingly used internationally in an urban setting for irrigation of public parks, sports fields and golf courses, for dust suppression, street cleaning, toilet flushing, irrigation of domestic gardens and by industry. As well as the benefits as an alternative source of water and nutrients, reuse of wastewater also presents potential risks to human health and the environment. Adverse environmental impacts may occur from contamination of surface water or groundwater. These environmental impacts may also have health impacts if the water bodies are used for drinking water (directly or indirectly) or recreation.

Regulations and guidelines have been developed by various authorities or international organisations to manage the health and environmental risks from wastewater reuse. California first developed guidelines for wastewater irrigation in 1918 and the US EPA in 1980. International organisations such as the World Health Organization (WHO) developed guidelines in 1973, the Food and Agriculture Organization of the United Nations (FAO) in 1987 and the International Organization for Standardization (ISO) in 2010. Between,1990 and 2017, 56 other countries and states also developed guidelines (Shoushtarian and Negahban-Azar 2020). Current guidelines from the WHO (2006), US EPA (2012), European Union (EU) (2020) and ISO (2018a, 2020b) are based on a risk management framework. The advantage of this framework is that it is flexible and can be tailored to local conditions to give a more dynamic approach to managing risk. In contrast, the FAO guidelines are based on information available in scientific literature which is used to determine criteria to protect health. The FAO and WHO guidelines focus on irrigation for agriculture in arid and semi-arid areas and low- and middle-income countries (LMIC) where resources are limited and significant health benefits can be achieved through food security. The ISO, US, Australia and EU have developed guidelines due to water scarcity and include urban reuses.

1.2 NEW ZEALAND CONTEXT FOR MUNICIPAL WASTEWATER REUSE

Wastewater reuse for agriculture and public amenity irrigation has not been commonly practiced in New Zealand. The key driver for land irrigation of municipal wastewater has been in response to the cultural inappropriateness of discharging human sewage directly to water bodies. However, other drivers for wastewater reuse are emerging and interest in other forms of wastewater reuse has increased. In particular, water scarcity and climate change are potential drivers, with increased interest in wastewater as an alternative water source. Emerging design philosophies such as circular economy and sustainable design are also potential drivers. These drivers may be reflected in council decision making and planning. For example, urban reuse is proposed in Akaroa and the Christchurch City Council’s decision identifies dual reticulation and non-potable water reuse as potential options for the town which suffers from water scarcity issues and a lack of suitable land for municipal wastewater disposal (Christchurch City Council). In the decision Council Officers are requested to work with

> “Ministry of Health, the Canterbury District Health Board, Ngāi Tahu and water suppliers…. To develop non-potable re-use guidelines or standards for New Zealand”.

New Zealand has guidelines for the disposal of wastewater to land. The Department of Health developed guidelines for the use of sewage effluent and sludge in 1992 (Department of Health 1992) based on criteria in the WHO 1987 guidelines. As more councils chose discharge of wastewater to land to address iwi concerns regarding discharge of human sewage to water, new guidelines for sewage effluent disposal to land were developed in 2000 (NZLTC 2000). A key difference between the New Zealand guidelines and international guidelines for wastewater reuse is that the New Zealand guidelines focus on the application of wastewater to land as a means of disposal. The system must operate throughout the year, irrespective of weather conditions or soil moisture deficit, rather than as an alternative source of water.

Guidelines have also been developed for wastewater reuse as part of the on-site management of wastewater for small domestic systems by councils. For example, Auckland Council's guidelines for on-site wastewater management (TP 58 2004) and their current draft guidance document *On-site wastewater management in the Auckland Region* 2021/GD006 (Chen & Roberts 2021) contain guidance on urban wastewater reuse for certain applications, including toilet flushing and irrigation of gardens. The guidance is intended for households and small facilities, with a flow limitation of 2,000 L/day (TP 58 2004) increased to 3,000 L/day proposed in the draft guidance document, GD006 (Chen & Roberts 2021).

In the absence of New Zealand guidelines for wastewater reuse, there is the potential that on-site guidelines for the management of small domestic wastewater systems may be applied at a larger scale, such as the reuse of wastewater from larger wastewater treatment systems, or is used for larger activities, which increases risk due to the larger number of people potentially affected. Alternatively, international guidelines could be applied, but New Zealand has no guidance on which international guidelines would be most appropriate. For example, international guidelines such as WHO (2000) and FAO (1992) are developed for LMIC countries which may have high burdens of disease and different climatic conditions to New Zealand. The absence of New Zealand guidelines for wastewater reuse, or agreement on the best international guidelines to apply, potentially leads to inconsistency in how wastewater reuse is regulated in New Zealand. While not discussed in this review, the appropriateness of reusing wastewater also needs to be considered in terms of Māori traditional culture and practices.

1.3 SCOPE OF REVIEW

This review compares international guidelines on wastewater reuse, in particular how health risk is managed. The review can be a resource to support Public Health Officials making submissions on resource consent applications, plans and policies relating to wastewater reuse. It also provides a resource to support consistency in regulatory decision making on resource consents and in regional plans.

The focus of the review is on the risk to human health from agricultural irrigation, urban and industry wastewater reuse. The key international guidelines reviewed listed below are summarised in Appendix A and discussed in this review:

- WHO Guidelines for The Safe Use of Wastewater, Excreta and Greywater
    - Volume 1 Policy and Regulatory Aspects
    - Volume II Wastewater Use in Agriculture (WHO 2006)
- FAO Wastewater Quality Guidelines for Agricultural Use (FAO 1992)
- Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on Minimum Requirements for Water Reuse (EU 2020)
- US EPA and US Aid Guidelines for Water Reuse (US EPA 2012)

- Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1) (AWRG) (NRMMC et al 2006)
- ISO 20426 Guidelines for Health Risk Assessment and Management for Non-Potable Water Reuse (ISO 2018a)
- ISO 20760 Parts 1 and 2 Water Reuse in Urban Areas- Guidelines for Centralised Water Reuse System (ISO 2017, ISO 2018b)
- ISO 20761 Water Reuse in Urban Areas – Guidelines for Water Reuse Safety Evaluation – Assessment Parameters and Methods (ISO 2018c).
- ISO 16075 2020 and 2021 Guidelines for treated wastewater use for irrigation projects. Parts 1-4. Part 5 is about wastewater treatment and is not included in this review. (ISO 2020a, b, ISO 2021a, b).

WHO (2006) and FAO (1992) do not have guidelines for urban reuse. The EU (2020) guidelines are focused on agriculture but suggest that the irrigation guidelines could be applied to urban irrigation with consideration of the potential impacts of spray irrigation on workers and bystanders.

Other forms of reuse (eg aquifer recharge, direct and indirect potable water use and environmental augmentation) have recreational, environmental and drinking water guidelines and are not included in this review, but the following guidelines are summarised in Appendix A:

- WHO Potable reuse: Guidance for Producing Safe Drinking Water (WHO 2017)
- Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2). Augmentation of Drinking Water Supplies. (NRMMC et al 2008)
- Australian Guidelines for Water Recycling: Managing Health and Environmental Risks. Managed Aquifer Recharge (Phase 2) (NRMMC 2009).

The review also does not cover aquaculture, wastewater treatment systems, irrigation systems, site or crop selection.

Since 2006, guidelines on wastewater reuse have incorporated a risk management framework to identify hazards, assess the human health and environmental risks and identify appropriate control measures to manage risk to achieve health goals. As this is the dominant approach to the guidelines, the key elements of the risk assessment approach are presented in section 2. Comparison of the different international guidelines for agriculture, urban reuse and industrial reuse are given in sections 3 to 5, respectively, with key criteria and values presented. It is noted that Australian states generally follow the AWRG guidelines (NRMMC 2006) but the US states can vary widely from the US EPA criteria (REUSExplorer 2023) and the basis for these different criteria is not clear. This review focuses on national guidelines or guidelines from international organisations. A summary is presented in section 6.

2. RISK BASED FRAMEWORK

Wastewater reuse guidelines from Australia (NRMMC et al 2006), WHO (2006), ISO (2018a, b, c), ISO (2020a, b), and EU (2020) use a risk-based framework rather than the older, more prescriptive approach of the FAO (1992) (Appendix A). Risk-based frameworks to manage water quality were developed in the early 2000s, and since then the framework has been widely applied to drinking water and water reuse guidelines to manage health risks. Examples of wastewater reuse guidelines based on a risk framework are:

- Guidelines for the Safe Use of Wastewater, Excreta and Greywater in Agriculture and Aquaculture (WHO 2006) uses the Stockholm framework
- Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1) (AWRG) (NRMMC et al 2006) uses a Quantitative Microbial Risk Assessment (QMRA)
- ISO 20426 Guidelines for Health Risk Assessment and Management for Non-potable Water Reuse (ISO 2018a), presents a quantitative risk approach, where there is likely to be human contract, and a qualitative approach.

A risk-based framework broadens the scope of the guidelines compared to earlier guidelines such as FAO (1992). Elements which increase the success of the project such as legislative frameworks, public consultation, operation, risk management plans and emergency plans are included. As well as risk assessment, these frameworks also include quality assurance practices. The key components for managing a wastewater reuse system are:

- setting health based targets
- identifying health risks from potential hazards and exposure routes
- risk management planning which identifies preventive control measures to reduce the risk to a level where the health based targets can be achieved
- monitoring to ensure the preventive control measures are effective and highlight data trends
- regular review of the system, reporting and emergency planning.

The risk-based framework can be applied to risks to human health from pathogens or chemicals. As the greatest risk is from pathogens, this review focuses on microbial risk assessment, with the health risks due to chemicals summarised. The aspects which are covered in the different guidelines are described below.

2.1 HEALTH-BASED TARGETS

The risk framework sets health-based targets based on what is considered a tolerable risk for the community. Tolerable risk per person year (ppy) can be expressed using the Disability Adjusted Life Year (DALY), which is a measure of disease burden per person per year (pppy). The DALY is made up of two components; years of life lost (YLL), a measure of the burden due to mortality, and years of life lived with disability (YLD), a measure of the burden due to morbidity.

Health impacts are weighted in terms of severity, for example, from a minor inconvenience to death, with disability/severity weights in the range 0-1. For YLD, this weighting is then multiplied by the duration of the effect, while for YLL the disability weight is one and the duration is the years of expected life lost due to untimely death. The AWRG (NRMMC et al 2006) guidelines use the example that mild diarrhoea lasting for seven days has a DALY of

0.002, but the death of a 1-year-old child from rotavirus infection has a DALY of 80, due to the reduction in life expectancy.

Comparing the calculated DALY for different microbial or chemical hazards allows the highest risks to be identified. The reference health-based target is 10^{-6} DALY pppy and is used by the WHO (2006) and AWRG (NRMMC et al 2006). This target is considered to represent a tolerable level of risk. However, the WHO (2006) guidelines also recognise that a higher DALY may be more appropriate in LMIC where there may be multiple pathways for exposure and cost-benefit analysis of health improvement programmes and food security within other sectors may provide higher overall health benefits (eg provision of safe drinking water). The WHO (2006) guidelines emphasise the multisector approach as goals of different sectors may overlap.

2.2 QUANTITATIVE MICROBIAL RISK ASSESSMENT (QMRA)

To achieve health-based targets it is necessary to understand what constitutes the greatest risks and implement control measures to reduce risk. The WHO (2006) and AWRG (NRMMC et al 2006) use a QMRA where microbial exposure doses are simulated using variable inputs for the concentration of hazard in media and the amount of the media that is ingested. Dose-response relationships from the literature are used to estimate the risk of infection or illness. This dynamic modelling provides a better understanding of risk compared to static (deterministic) calculations based on an average and 95th percentile. A QMRA can also compare how different interventions would affect the overall risk.

The key steps to a health risk assessment, including QMRA, are shown in Figure 1:

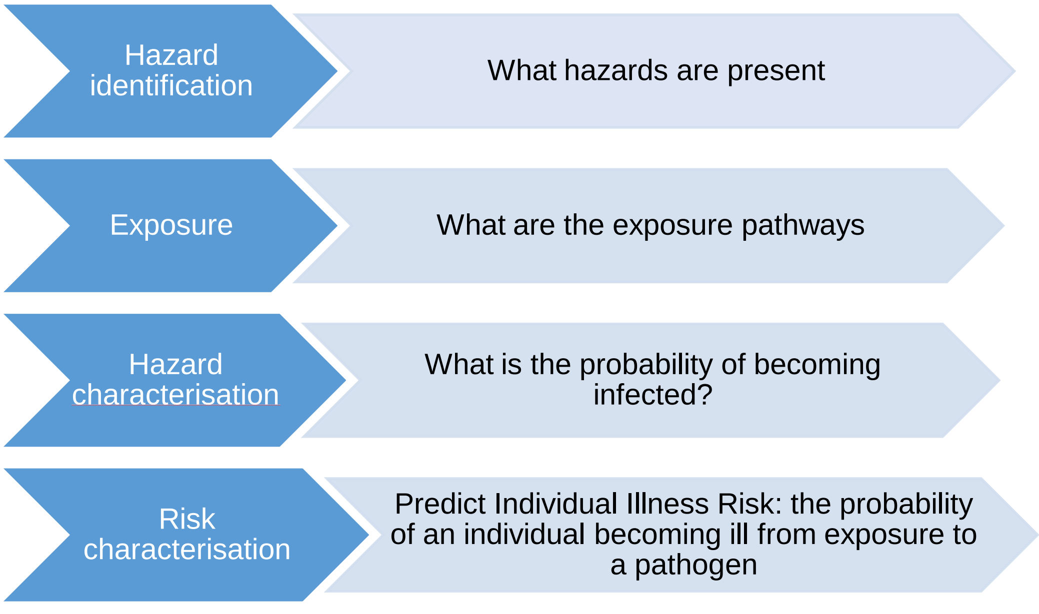

Figure 1 Overview of steps of risk characterisation

2.3 HAZARD IDENTIFICATON

Hazards may be microbiological, chemical or physical agents with the potential to cause adverse effects. Hazards can be geographically specific and their presence may depend on patterns of diseases prevalent in the community, sanitation practices, availability of safe drinking water and cultural practices. Wastewater can be used to grow food directly, or indirectly as fodder crops or pasture, grow plants in nurseries or silviculture, and irrigate private, public and residential spaces. It can be a water source for toilet flushing or industry (not food production). Different uses present different risks due to the composition of the wastewater and the potential human exposure routes.

2.3.1 Microbial hazards

Microbial pathogens present in wastewater include bacteria, viruses, protozoa and helminths, and pose the greatest to public health (WHO 2006). They can cause gastroenteric illnesses (GI), skin diseases and enteric parasitic diseases. While helminths may be a health risk in countries where they are endemic, the risk in New Zealand is very low (Department of Health, 1992) and they are not discussed in detail in this review. Consumers, workers and local community may be exposed either directly or indirectly. Exposure routes assessed by the WHO are:

- ingestion of soil associated with raw food grown at the soil surface
- ingestion of root vegetables food with pathogens on the surface of the food.

The AWRG (NRMMC et al 2006) consider a wider range of activities, including:

- aerosol inhalation from municipal or home spray irrigation or firefighting
- water retained on food which is consumed raw (eg lettuce)
- cross connections in dual water systems between reuse water and drinking water.

NRMMC et al (2006) and ISO 20426 (ISO 2018a) also present a qualitative framework to assess risk using likelihood and consequence. ISO 20426 (ISO 2018a) specifies that if there is likely to be human contact the quantitative approach is required.

Indicators used in Guidelines

Waterborne pathogens that cause GI are excreted in faecal material. As it is not possible to test for all the potential pathogens that may be present in wastewater, a surrogate is used that is indictive of the presence of faecal contamination from warm blooded animals – faecal indicator bacteria (FIB). For over 100 years, faecal coliforms were used as the FIB (Korajkic et al 2018), however, many of the more recent guidelines use *E. coli* as these have been found to be better associated with the risk of GI (eg in recreational water (WHO 2021))). While other indicators have been proposed, their association with GI has not been robustly established (WHO 2021). *Clostridium perfringens* spores, for example, are very hardy and therefore may not be related to a current faecal contamination risk.

Various wastewater reuse guidelines use a variety of FIB.

- Total coliforms are a diverse group of bacteria, including species of the genera *Citrobacter, Enterobacter, Escherichia* and *Klebsiella*. Different species can live in a range of habitats, including soil, surface water, vegetation, and the intestines of warm-blooded animals. Total coliforms are therefore not solely of faecal origin. Their optimum growth temperature is 35°C. Total coliforms are used as FIB in wastewater reuse guidelines by China.
- Faecal coliforms (also known as thermotolerant coliforms) are a subset of total coliforms with optimum growth temperatures of 44.5°C. They are more specific to the intestinal environment than total coliforms, although they are not exclusively of faecal

origin, and can be isolated from the environment in the absence of faecal pollution. Faecal coliforms are used as the FIB in US EPA (2012), ISO 16075-2 (ISO 2020b) and Israel (Ministry of Health Israel (nd)) .

- *E. coli* is a single species from the faecal coliform group, and is reasonably specific to the intestinal environment, where it accounts for up to 97% of all total coliforms present. The optimum growth temperature is 35°C. *E. coli* is used as the reference FIB in WHO (2006), AWRG (NRMMC et al 2006) and EU (2020) guidelines. In human sewage most faecal coliforms are *E. coli*. However, this could not be assumed if there were significant animal contributions (eg meat works processing wastewater).

Pathogens used in QMRA

While local disease burden will determine what pathogens are present in sewage and in what concentrations, the same representative target pathogens have been used in QMRA by the WHO (2006) and AWRG (NRMMC 2006):

- *Campylobacter* (bacteria)
- rotavirus (virus)
- *Cryptosporidium* (protozoa).

Viruses are identified as the most significant source of human infections in all the risk assessment approaches (WHO 2006, EU 2020, NRMMC et al 2006). The WHO (2006) and FAO (1992) also provide treated wastewater criteria for helminths as they present a significant risk in LMIC, particularly to workers in bare feet. The health risk from rotavirus in New Zealand may have been reduced through vaccination of children 5 years old and under. However, a revised risk assessment using norovirus showed a similar risk to rotavirus in LMIC (Duncan and Sleigh 2010). Norovirus is a common viral GI pathogen in New Zealand with a very low infectious dose (Teunis et al 2008).

While this review is focussed on human sewage, animal processing wastewater will contain zoonotic pathogens. Although animal wastewater does not contain human viruses, application of the risk framework would be appropriate to assess risks from zoonotic bacteria, such as *Campylobacter, Salmonella* and shiga toxin-producing *E. coli* (STEC), and protozoa such as *Cryptosporidium* and *Giardia*.

2.3.2 Chemical hazards

Chemicals present in the wastewater are most likely to constitute environmental hazards but may also be hazardous to human health if ingested in sufficiently high amounts (dose). Public health hazards from chemicals include:

- nitrate concentrations in water sources above the drinking water standard
- eutrophication leading to toxins from cyanobacteria blooms
- accumulation of heavy metals in soils and plants which may be ingested with food.

The types and concentrations of chemical contaminants in wastewater will depend on the contributing wastewater streams. In many towns and cities, industrial wastewater is also discharged to the sewer. The key chemicals of concern with regards to wastewater reuse are heavy metals, toxic organic chemicals, including emerging organic chemicals. Wastewater with no industrial input is considered unlikely to cause direct adverse health effects from chemical hazards (WHO 2006). The WHO (2006), AWRG (NRMMC et al 2006) and ISO 20760-1 (ISO 2018b) guidelines propose that industrial wastewater be excluded from wastewater streams or be controlled at source to avoid toxic concentrations of contaminants. This can be achieved through local regulations that manage the discharge of industrial chemical contaminants to the sewer.

New and emerging contaminants are briefly discussed in the AWRG (NRMMC et al 2006) and WHO (2006) guidelines. Pharmaceuticals and endocrine disrupters are identified as potential concerns, but a lack of information on their environmental fate was identified as an issue (WHO 2006). ISO 20760-1 (ISO 2018b) proposes management of source water so it does not include toxic chemicals or excessive pathogens concentrations from industrial or medical wastewater. None of the guidelines discuss anti-microbial resistance, but the US EPA (2012) has funded some research on anti-microbial resistance.

Site selection, irrigation, crop selection and hydraulic loading of soils is addressed in the FAO guidelines (FAO 1992) and ISO 16075-1 (ISO 2020a).

WHO (2006), FAO (1992), AWRG (NRMMC et al 2006) and ISO 16075-1 (2020a) provide details on the potential environmental risks from chemicals on aquatic environments, soil and plant health.

- Nutrients (nitrogen and phosphorous) can cause eutrophication in receiving waters, cyanobacteria blooms and biological growth in reservoirs or irrigation equipment.
- Ions, such as sodium, can disrupt soil structure.
- Salts can cause salinisation which reduces soil productivity.
- The pH affects bioavailability of metals which bond to the soil above pH 6.5 becoming unavailable for plant uptake.
- Crop growth may be affected by chemicals such as boron.
- Heavy metals such as cadmium and nickel are potentially the most harmful.
- Toxic organic compounds from sources such as agricultural runoff and hospital wastewater may contain pharmaceuticals, pesticides and herbicides. Organic compounds tend to be hydrophobic and partition into the sludge phase and their reuse is covered in the New Zealand Biosolids Guidelines (MfE, NZWWA 2003). Metals also partition into the sludge (ISO 16075-1 2020a)

2.4 RISK MANAGEMENT PLANNING

Risk management planning manages the risks identified by the risk assessment. The AWRG (NRMMC 2006) identify the key features of a risk management framework.

- Organisational commitment to responsibly reuse wastewater using a preventive risk management approach.
- Systems analysis and management to identify and manage the risks and operational control to ensure safe, reliable reuse of wastewater.
- Evaluation and auditing processes to ensure the system is working and provide opportunities for continuous improvement.

ISO 20246 (ISO 2018a) describes the framework as responsibility, regulation, partnership and policy. The framework is used to develop a risk management plan which will identify the processes to be implemented to control risk (ie preventive control measures), how they will be operated and monitored and managed. The plan includes review and emergency management.

This review focuses on the preventive control measures and monitoring in the various guidelines.

2.4.1 Preventive control measures

Having identified the most significant risks, the entire process is assessed to determine where control measures could be implemented to reduce the risk(s). Preventive control measures are identified in the guidelines and their effectiveness at reducing exposure to pathogens is given. Control points can occur across the entire process, ranging from limiting industrial inputs to the wastewater stream to manage chemicals, to managing food preparation by washing and peeling food before it is eaten. Use of multiple preventive controls provides more flexibility if wastewater treatment options are limited, as in LMIC. They also provide an extra layer of prevention if one or more preventive control measures fail.

QMRA is used to estimate the reduction in pathogen concentrations required (ie log pathogen reduction) to achieve the health-based targets for different activities. For example, the WHO (2006) estimate that a 7-log reduction is required for consumption of root vegetables eaten raw, and consumed without washing or peeling, and the AWRG (NRMMC et al 2006) require a 6.0-log reduction of viruses for food eaten raw and grown in contact with soil surface (eg lettuce). AWRG (NRMMC et al 2006) estimate a 6.5-log reduction is required for dual reticulation systems. Different wastewater treatment systems achieve variable levels of pathogen removal: a wastewater treatment plant using filtration, chlorination or ultraviolet (UV) treatment can produce a very high-quality disinfected wastewater with 6.5-log removal of viral pathogens, whereas a wastewater stabilization pond may result in only a 2-log removal of pathogens (NRMMC et al 2006). Depending on the level of treatment in the wastewater treatment plant, other preventive measures are used to achieve the cumulative pathogen log reduction required. Common preventive control measures described by the WHO (2006) and NRMMC et al (2006) include:

- preparation of food (eg washing, cooking and peeling produce)
- time for pathogens to die off (eg before harvesting food or access to recreational areas)
- restricting access to a site when spray irrigation occurs
- restricting irrigation methods (eg drip irrigation reduces the risks associated with spray irrigation)
- restricting the crops that can be irrigated, including fodder or pasture grazed by milk or meat-producing animals.

It should be noted that log reduction data used to assess the effectiveness of the preventive control may be based on the survival of FIB, equating the survival of FIB to that of the pathogen (i.e., the pathogen:FIB ratio is assumed to be the same after wastewater treatment and survival in the environment). Viruses and protozoa survive longer in certain environments than do FIB, so those survival studies based on FIB alone may underestimate viral and protozoa survival, and hence overestimate their reduction.

2.4.2 Monitoring

Quality control and assurance are an important component of risk management (WHO 2006, EU 2020, ISO 20426 (ISO 2018a), ISO 16075-4 (ISO 2021b)). Monitoring programmes need to be developed that deal with health and environmental risks. There are three types of monitoring:

- validation to ensure that the systems work when they are commissioned
- operational monitoring to ensure the systems perform as required
- verification monitoring to ensure regulatory criteria are met.

Validation monitoring is required by the NRMMC et al (2006), WHO (2006), and EU (2020) guidelines while ISO 20246 (ISO 2018a) includes it with operational monitoring. Commissioning tests are undertaken to confirm that the system is operating as designed when installed. Removal of pathogens may simply be given as FIB reduction, however, where high levels of treatment are critical (eg dual reticulation), removal of target pathogens may be required to be demonstrated. Or, more often, viral and protozoan surrogates such as bacteriophage or *Clostridium perfringens* spores are used to confirm viral and protozoa log reduction (NRMMC et al 2006, EU 2020). Nutrient removal may also be required if receiving waterways are sensitive to additional nutrient loads or if agronomic nutrient requirements are exceeded.

Operational monitoring is required by the AWRG (NRMMC et al 2006), ISO 20426 (2018a) and WHO (2006) guidelines to ensure that the system is performing correctly. As well as the FIB concentration, monitoring can include parameters which reflect the performance of the treatment system. Key parameters for wastewater treatment are total suspended solids (TSS) and organic matter (measured as BOD_5[1]), as these may affect the performance of the wastewater treatment system. Disinfection by chlorination can be affected by high concentrations of TSS and BOD_5 as they react with chlorine, leaving insufficient for disinfection. Solids also affect disinfection by UV light by shielding pathogens from UV irradiation and the colour associated with high BOD_5 may reduce the transmissivity of the UV light in the wastewater. Solids may also block irrigation lines and biological growth can occur from the presence of organic matter. A residual chlorine concentration is usually required to stop pathogen regrowth and biological growth within an irrigation system. As chlorination by-products may be toxic to the environment, maximum residual chlorine concentrations may be specified. Turbidity may be used as a surrogate for TSS and has the advantage of being able to be measured continuously. Residual chlorine can also be monitored continuously. Nutrients may be measured where the wastewater plant is required to removal nutrients or to determine if nutrient loading is within agronomic requirements.

Verification monitoring includes ensuring that the wastewater treatment plant effluent meets water quality criteria. Confirmation that viral and protozoan pathogens are removed may also be required periodically. AWRG (NRMMC et al 2006) proposes monthly monitoring of Adenovirus and weekly monitoring of bacteriophage and protozoan spores for reuses with a high risk. The WHO (2006) requires verification that log reductions in pathogens are achieved, but do not specify frequency or methodology.

The receiving environment may be required to be monitored to show that there are no adverse effects on soil, crops or water bodies eg monitoring soil salinity, micro-organisms, nutrients in receiving water or chemicals in food. Verification monitoring can identify trends in treatment plant performance or deterioration in the receiving environment.

Observational monitoring can be included to check there is no ponding, that crop health and yield are good, the right crops are selected, disease vectors are removed, and workers use protective clothing. The WHO (2006) proposes an annual survey to confirm compliance with the requirement that washing, peeling and cooking of food is done. However, AWRG (NRMMC et al 2006) notes that reliance on such preventive measures requires significant education, auditing and surveillance.

2.4.3 Cultural and stakeholder engagement

Unlike in older guidelines (FAO 1992), public perception, a regulatory framework, economic sustainability and addressing cultural sensitivities are additional elements in many guidelines since 2006, to varying degrees. Specific consideration would need to be given to Māori established cultural traditions and associated customary practices for managing human waste and keeping it separate from food (Pauling, Araria 2010). Wastewater reuse for food production is likely to be incompatible with Māori values.

Public perception of wastewater reuse is a key element to success as there can be significant hesitancy to reused wastewater from the community eg for food growing. The WHO (2006), AWRG (NRMMC et al (2006), EU (2020), and ISO 20426 (2018a) guidelines outline the importance of engagement with the community, and the WHO (2006) identifies cultural considerations that may be important, including women and children’s safety. Consultation with the public and formation of stakeholder groups help to engage with

[1] 5 day biological oxygen demand

community and ensure their concerns are addressed. A wastewater reuse system must also be seen as reliable, safe and economically affordable.

Projects need to be supported by a policy and regulation framework. The WHO (2006), EU (2020) and ISO 20426 (ISO 2018a) guidelines provide information on setting up legislative and regulatory structures. The WHO (2006) emphasises that multi-sector engagement is critical as the goals of many agencies may overlap. Systems must also be robust and emergency management plans are part of risk management.

2.5 SUMMARY

The WHO (2006), AWRG (NRMMC et al 2006) and ISO 20426 (ISO 2018a) use a risk framework to manage risks to human health and the environment. This provides flexibility to manage the risks according to local constraints and resources. The health-based target is a DALY of 10^{-6}. WHO (2006) guidelines include LMIC and acknowledges that the health-based target of 10^{-6} may be too onerous where a better cost benefit can be achieved in a related sector (eg provision of drinking water). The advantage of a risk framework is that preventive control measures can be selected to manage risk, rather than the previous prescriptive guideline approach of criteria and detailing wastewater treatment systems. Initial and on-going monitoring and review of data is essential to ensure that the system is working as designed and to identify trends that may indicate problems.

The risk from pathogens is considered the greatest human health risk (WHO 2006, ISO 20426 (2018a)). The studies used in the WHO (2006) and AWRG (NRMMC et al 2006) guidelines to derive FIB criteria are dated and new research may provide better information on the human health risks. While there was little information available on the environmental fate of emerging organic chemicals or antimicrobial resistance in the guidelines, ISO 20760-1 (ISO 2018b) proposes source control to avoid toxic chemicals and the US EPA (2012) has funded some research on anti-microbial resistance. ISO 16075-1 (ISO 2020a) does not include guideline values due to a lack of evidence that emerging contaminants cause health, environmental or crop issues in wastewater reuse.

3. WASTEWATER REUSE FOR AGRICULTURE

3.1 INTRODUCTION

Wastewater provides nutrients and water for agricultural activities. Reuse can support plant growth for food, crops, pasture, silviculture or plant nurseries. Direct or indirect exposure to pathogens and chemicals may occur through ingestion of affected produce, inhalation of aerosols, skin penetration (eg helminths) or dermal absorption through the skin or via wound entry. People potentially at risk include consumers of products, agricultural workers and the local community. In this section, the derivation of guideline criteria by the WHO (2006) and AWRG (NRMMC et al 2006) and the differences in application of preventive control measures are compared.

FIB criteria and monitoring requirements are compared from the WHO (2006) AWRG (NRMMC et al 2006) FAO (1992), EU (2020), Israel (Ministry of Health Israel (nd)a) and ISO 16075-2 (ISO 2020b) guidelines where wastewater is reused to irrigate food which is consumed raw, processed or cooked and crops, pasture or fodder, and non-food crops.

In New Zealand agricultural reuse of wastewater is more likely to support pastoral activities. The use of wastewater for food production is likely to be incompatible with Māori traditions and values. AWRG (NRMMC 2006) reports that levels of community acceptance of wastewater reuse, reduce as personal contact increases.

Although not the most likely use, food consumed raw is discussed first as it highlights application of the use of different combinations of preventive controls to manage health risk.

3.2 QUANTITATIVE MICROIBAL RISK ASSESSMENT

The WHO (2006) and NRMMC et al (2006) characterise the risk of microbial infection from the direct consumption of food contaminated with residual wastewater. WHO (2006) also assesses risks from the contaminated soil present on food eaten raw without peeling or washing, while NRMMC et al (2006) assess the risk from inhalation of aerosols (eg from spray irrigation and hand-to-mouth ingestion). WHO (2006) is focussed on LMIC and uses QMRA to highlight the reduction in risk using mechanised agriculture compared to labour intensive agricultural practices.

Figure 2 presents an example of the risk assessment steps for lettuce eaten raw.

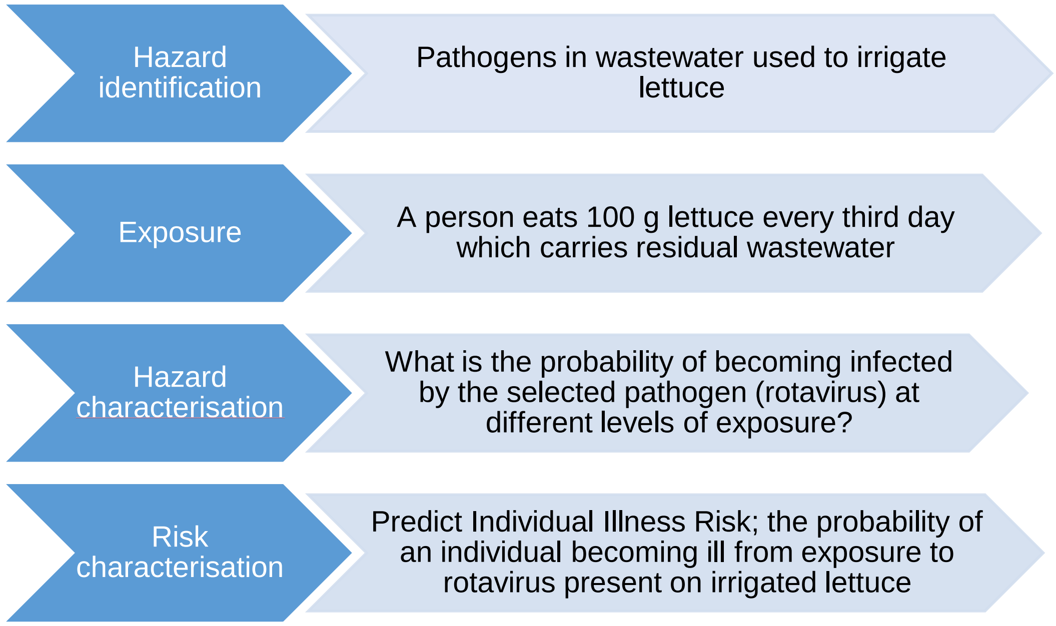

Figure 2 Example of QMRA for irrigation of wastewater on food eaten raw

From the QMRA, the highest risk to human health is from the consumption of food eaten raw (WHO 2006). For vegetables consumed raw and grown in contact with soil, such as lettuce, a 6-log pathogen reduction is required to meet the health target. The WHO (2006) also assessed the risk from consumption of root vegetables (onions) eaten raw and showed a 7-log pathogen reduction was required. For irrigation of non-food crops, lower pathogen reduction targets apply (NRMMC et al 2006). The risk management plan identifies the critical control points in a process, the preventive control measures required to reduce the risk to meet the health target and monitoring requirements.

3.3 IRRIGATION OF FOOD EATEN RAW

3.3.1 Preventive measures

The preventive measures for agriculture for food consumed raw are given in Table 1 with literature values for the pathogen log reduction. While the WHO (2006), ISO 16075-2 (2020b) and AGRW (NRMMC et al 2006) apply the same pathogen log reduction for most preventive measures, the notable exception is pathogen die-off after harvesting, which is assigned lower log pathogen reduction in the AWRG (NRMMC et al 2006). ISO 16075-2 (2020b) focuses on a “barrier” approach to achieve log pathogen reductions and presents examples of the types of barriers required for different foods including orchards and vineyards based on the ISO committee members’ experience, the US EPA (2012) and the WHO (2006) guidelines.

Table 1 Comparison of log pathogen reductions of preventive control measures between WHO, AWRG and ISO 16075-2 guidelines

Preventive measure	WHO (Table 4.3)	AWRG (Table 3.5) commercial crops	ISO 16075-2 (Table 2)
Wastewater treatment	1-6	0->6	Not stated
Drip irrigation of low growing corps	2	2	2
Drip irrigation of high growing crops	4	4	4
Drip irrigation of crops and no soil contact	No value	5	2-6
Spray drift control	1	1	2-4
Spray buffer zone	1	1	1
Pathogen die off	0.5-2.0/day	0.5	0.5-2.0/day

Preventive measure	**WHO (Table 4.3)**	**AWRG (Table 3.5) commercial crops**	**ISO 16075-2 (Table 2)**
Washing produce	1	No value	1
Peeling produce	2	2	2
Cooking produce	6-7	5-6	6-7

Table 1 shows different combinations of preventive controls and highlights how differences in the assigned pathogen log reductions affect the *E. coli* criteria required by the wastewater treatment process. For example, for vegetables consumed raw and grown in contact with soil, the WHO criteria for *E. coli* in effluent from a wastewater treatment system is ≤10,000/100 mL, while AWRG (NRMMC et al 2006) requires <1 *E. coli* /100 mL in the wastewater treatment plant effluent to achieve a 6-log pathogen reduction (Table 2). The WHO guideline allows for a 2-log reduction due to microbial die-off after harvesting and 1-log reduction from washing vegetables. In contrast, the AWRG (NRMMC et al 2006) allows only 0.5-log reduction for microbial die-off after harvesting for commercial crops and no pathogen log reduction for washing vegetables. ISO 16075-2 (2020b) uses the same pathogen log reductions for pathogen die-off and washing as the WHO (2006). The *E. coli* criteria in the AWRG (NRMMC et al 2006) relate to log reductions in viruses while in WHO they relate to log reductions of *E. coli.*

As in Australia, commercial crops in New Zealand are likely to be refrigerated as soon as they are harvested which will mean lower pathogen die-off rates. New Zealand also has a temperate climate with cooler average summer temperatures than parts of the US, Asia and Australia. As survival times are temperature dependent, cooler temperatures would also increase survival time under New Zealand conditions.

Table 2 Comparison of *E. coli* criteria and effectiveness of other preventive control measures for WHO and AWRG irrigation scenarios.

Food	**Overall pathogen log reduction required**	**WHO**		**AWRG Table 3.8**	
		Treatment plant *E. coli* criteria /100 mL = log reduction	**Other preventive control measure(s) = log reduction**	**Treatment plant *E. coli* criteria /100 mL= virus log reduction**	**Other preventive control measure(s) = log reduction**
Root vegetable	7	≤1,000 = 4	Die off = 2 Washing = 1	Not assessed	Not assessed
Leafy vegetable grown in contact with soil	6	≤1 = 6	None	<1= 6	None
	6	≤10,000 = 3	Die off = 2 Washing =1	<1= 6	Die off = 0.5 (protozoa = 0)
Grown with no contact with soil or harvesting of dropped fruit	6	≤100,000 = 2	Drip irrigation of high growing crop = 4	<100= 3-4	Drip irrigation of high growing crop & skins removed = 4.0
				<1,000= 0.5-1	Drip irrigation of high growing crop & skin removed eg citrus or nuts = 6

Note:

- Data from Figure 4.1 and Table 4.5 WHO (2006) and Table 3.8 (NRMMC et al 2006)

The WHO (2006) also compares the risk to workers (including children under 15 years of age) from soil ingestion using labour intensive agriculture or mechanised agricultural practices. While both scenarios allow for the same level of overall risk, a higher level of wastewater treatment, resulting in a 4-log pathogen reduction, is required to protect labourers (*E. coli* ≤ 10,000/100 mL). By comparison, a 3-log reduction is required to protect workers in higher mechanised agriculture (*E. coli* ≤100,000/100mL) (WHO 2006).

Additional examples of preventive control measures and *E. coli* criteria for other irrigation scenarios are also provided in the AWRG (NRMMC et al 2006), WHO (2006) and ISO 16075-2 (2020b) guidelines.

Some guideline criteria reflect the reduction in risk where preventive controls, such as growing high crops (edible portions not in contact with soil) and/or drip irrigation, are used. Other preventive control measures may include:

- buffer zones
- restricting access to protect people from aerosols from spray irrigation
- drift control for spray irrigation sprinklers
- withholding periods to allow wetted surfaces to dry and pathogens to die-off
- setback distances between irrigation activities and drinking water sources (
- type of irrigation eg drip irrigation)
- cooking
- no wet harvest of food.

FIB criteria are taken from the WHO (2006), FAO (1992), ISO 20426 (2018a) ISO 20760-1 (2018b), ISO 16075-2 (2020b), EU (2020), the AWRG (NRMMC et al 2006), Israel (Ministry of Health (nd). The FIB criteria are summarised in Table 3 for crops eaten raw with corresponding FIB criteria, and preventive control measures, where identified. There may be other regulations such as plumbing regulations and signage requirements which are not included in the table. Either *E. coli* or faecal coliforms are used as FIB. Helminth criteria are given in guidelines from FAO (1992), WHO (2006) and EU (2020). Spray irrigation is an exposure route through spray drift or aerosols and ISO 16075-2 (ISO 2020b) and EU (2020) have criteria for *Legionella*. For the high-risk category of food eaten raw, without peeling and grown in contact with the soil, there is a large range in FIB criteria from not detected (<1/100 mL) in the US EPA (2012) and AWRG (NMMRC 2006) guidelines to ≤10,000/100 mL (WHO 2006). Table 3 highlights that the WHO (2006) FIB of 10,000/100mL is much greater than all other guidelines.

Table 3 Comparison of FIB criteria from a wastewater treatment plant for food eaten raw with different preventive control measures

Maximum FIB conc. /100 mL	Grown in contact with soil	Not grown in contract with soil eg high crops &/or drip irrigation and other preventive measures	Unspecified
<1	US EPA-SB, AWRG		
≤10	EU, ISO	Israel# SSI-SB	
≤100		EU, AWRG*-NWHV-WHP-C-RA-DI—P	
≤1,000		EU, AWRG-C-DI-RA-B-NWHV-SPIC	FAO
≤10,000	WHO		
≤100,000		WHO	

Notes:

- FIB may be *E. coli* or faecal coliforms. WHO, ISO, FAO, EU and Israel use less than or equal to FIB criterion. US EPA “not detectable”/100 mL is given as <1 /100 mL.
- Preventive measures B = buffer zone, DI = drip irrigation, NWH = no wet harvesting of food, P= food is peeled before consumption, RA = restricted access, SB = setback distance to wells

used for drinking water supply, SPIC= spray irrigation control or extended buffer zone, SSI subsurface drip irrigation, WHP= withholding period.

- *preventive control measures depend on log pathogen reduction required
- # preventive control measures may allow higher FIB criterion (WRAP 2023)

The addition of preventive control measures, such as drip irrigation or crops grown above the ground without contact with the treated wastewater, increases FIB criteria. However, the specific preventive controls may vary. For example, the EU (2020) and AWRG (NRMMC et al 2006) allow food crops to be drip irrigated where the *E. coli* concentration is <u><</u>1,000/100 mL, but the AWRG does not required disinfection (NRMMC et al 2006). However, the AWRG specify other preventive control measures, such as requiring that the crop must be peeled before consumption (eg citrus), no harvesting while the product is wet, or if it is dropped fruit and a minimum of two days withholding period (WHP) before harvesting if spray irrigated. Again WHO (2006) has the highest criterion of <u><</u>100,00/100 mL which is two orders of magnitude greater than other FIB criteria where drip irrigation and/or only high crops are grown.

FAO does not use the risk-based approach so does not make allowances for additional preventive control measures for pathogen removal and has a single criterion for faecal coliforms of <u><</u>1,000/100 mL.

3.3.2 Monitoring irrigation of food eaten raw

Monitoring is an important part of the risk management plan as it provides assurance that regulatory criteria are met for irrigation and in the receiving environment. Meeting FIB criteria is critical to ensure that the required log pathogen reduction has occurred during the treatment and irrigation process. Many guidelines also require operational monitoring of the key parameters that indicate the performance of treatment process.

Performance of the FIB and wastewater treatment plant parameters are compared in Table 4. Daily monitoring of FIB is required by US EPA (2012). At least weekly monitoring is required by ISO 16075-4 (ISO 2021b) and AWRG (NRMMC et al 2006). Weekly monitoring of the treatment plant performance is required for BOD_5 and/or TSS for EU (2020), ISO 16075-4 (2021b) and US EPA (2012) and is proposed in the AWRG (NRMMC et al 2006). Continuous monitoring of turbidity (a surrogate for TSS) is required by the US EPA (2012), ISO 16075-4 (2021b) and EU (2020). AWRG (NRMMC et al 2006) recommends weekly monitoring of phage as viral surrogates for high exposure schemes.

Table 4 Comparison of FIB and operational monitoring frequency at different FIB for food eaten raw

FIB Monitoring					**Wastewater monitoring for BOD_5 and TSS**		
Maximum conc. /100 mL	**Daily**	**At least weekly**	**Monthly**	**Unspecified**	**At least weekly**	**Unspecified**	**Regular turbidity/ disinfection/ residual Cl monitoring**
<1	US EPA	AWRG			US EPA, AWRG	EU	US EPA, AWRG,
<u><</u>10		EU , ISO 16075-4		Israel	EU, ISO 16075-4		EU, ISO 16075-
<100		AWRG			AWRG		AWRG
<u><</u>1,000		AWRG		FAO			
<u><</u>10,000			WHO				

Notes:

- FIB may be *E. coli* or faecal coliforms.
- WHO, ISO, FAO, EU and Israel use less than or equal to FIB criterion.
- US EPA "not detectable"/100 mL is given as <1 /100 mL
- # BOD_5 monitoring for high exposure schemes, otherwise monthly.

3.4 IRRIGATION OF NON-FOOD CROPS OR PROCESSED FOOD

3.4.1 Preventive control measures

Processed food or non-food seed, fibre, energy or industrial crops present lower risks to health. Lower quality wastewater is suitable for other types of agricultural irrigation compared to food eaten raw. Activities tend to be grouped into:

- cooked or processed food
- plant nurseries, turf farms
- pasture or fodder used for milk or meat producing animals
- pasture, fodder, fibre, industrial crops which may include seed and energy crops
- silviculture or tree lots.

Not all guidelines reviewed provide criteria for all activities listed above. The FAO (1992) and WHO (2006) do not specify a FIB requirement for processed food and have no FIB criteria for non-food crops. The FIB criteria for different activities are shown in Table 5 with preventive control measures where they are specified in the guidelines. In addition to preventive control measures listed above the type of irrigation may be controlled eg subsurface irrigation, SSI, or whether milk producing animals are permitted on pasture irrigated with wastewater (M). Other regulations such as plumbing regulations or signage are not included in the table. The guidelines from the EU (2020) and ISO:16075 (2020, 2021) are land irrigation guidelines and do not address forestry or irrigation of ornamentals and nursery plants.

Table 5 Summary of FIB criteria for cooked or processed crops and non-food agricultural reuse

Maximum FIB conc./100 mL	Cooked or processed crops	Plant nurseries, turf farms	Fodder crops, non-food crops, pasture	Trees, flowers, forests
≤14			US EPA if no WHP	
≤100			EU, AWRG -M-WHP-RA or SSI-B	
≤200	US EPA-SB-WHP for M, ISO 16075-2^		US EPA SB-B	
≤1,000	AWRG -RA-B-DI		EU, ISO 16075-2, AWRG-RA-WHP-B-SPIC	
≤2,400				
<10,000		AWRG -RA-DI-B-SPIC		AWRG -RA-DI-B-SPIC

Notes:

- ^industrial and seeded crops
- Preventive control measures B = buffer zone, DI = drip irrigation, M=milk/meat production, RA = restricted access, SB set back, SPIC= spray irrigation control or extended buffer zone, SSI=subsurface irrigation control, WHP= withholding period.
- FIB may be *E. coli*, faecal coliforms or thermotolerant coliforms. WHO, ISO, FAO, EU and Israel use less than or equal to FIB criterion.

The US EPA (2012) and Israel (Ministry of Health (nd) a) have the same criteria for all activities, 200/100 mL and 10/100 mL, respectively.

FIB criteria can be highly variable across the guidelines for the same activity.

- Cooking provides a 6-log pathogen reduction (Table 1), but ISO 16075-4 (2021b) and US EPA (2012) have FIB criteria for processed/cooked food crops ≤200 /100 mL while AWRG has <1,000/100 mL (NRMMC et al 2006) with additional preventive control measures of restricted access, a buffer zone and drip irrigation.
- The AWRG (NRMMC et al 2006) have FIB criteria for pasture for milk producing animals of <100/100 mL.
- Disinfection is required for all wastewater reuse for pasture irrigation except for ISO 16075 (2021b) which requires 2 barriers for wastewater treatment by stabilisation ponds and wetlands and AWRG which requires withholding periods for grazing stock, restricted access, buffer zones and spray drift control.
- The AWRG (NRMMC et al 2006) have FIB criterion of <10,000/100 mL) for trees, turf farms, woodlots and growing flowers. However, other preventive barriers are used with restrictions on irrigation, access and a buffer zone.
- Some guidelines have no limits on FIB for some activities. ISO 16075-2 (ISO 2020b) has no limits for seeded crops.

3.4.2 Monitoring

Monitoring requirements, summarised in Table 6, show that for non-food crops less frequent monitoring for FIB is required and less monitoring of treatment plant performance. For WHO (2006), EU (2020), ISO (2020b) and national guidelines monitoring requirements range from daily (US EPA 2012) to weekly/fortnightly or unspecified.

Table 6 Summary of monitoring frequency for FIB and wastewater treatment process for cooked or processed crops and non-food agricultural reuse

FIB monitoring				**WWTP BOD5 and/TSS monitoring**		**Regular turbidity/ disinfection/ residual Cl monitoring**
Maximum conc. /100 mL	**Daily**	**At least weekly**	**Unspecified**	**At least weekly unless specified otherwise**	**Unspecified**	
<10			Israel		Israel	
≤30				US EPA^		US EPA
≤100		AWRG#	EU	AWRG#		AWRG
≤200	US EPA	ISO 16075-2		ISO 16075-2		ISO 16075-2
<1,000		AWRG		AWRG		
<10,000		AWRG		AWRG -monthly		

Notes:

- FIB may be *E. coli* or faecal coliforms.
- WHO, ISO, FAO, EU and Israel use less than or equal to FIB criterion
- # BOD_5 monitoring for high exposure schemes, otherwise monthly.

3.5 DISCUSSION ON MICROBIOLOGICAL CRITERIA

Guidelines developed by the WHO (2006) and FAO (1992) for the wastewater reuse in food production focus on LMIC, where there may be many pathways for disease and the benefits of food production are significant. WHO (2006) has the highest FIB criteria for food eaten raw, grown in contact with soil and not peeled or cooked (≤10,000/100 mL) and ≤100,000/100 mL with the preventive controls of drip irrigation and high growing crops. These criteria are not used in any other international guidelines, which set more stringent FIB criteria. WHO (2006) applies pathogen log reductions from preventive control measures such as die-off between harvesting and consumption, washing food and peeling food before eating (Table 2). However, these controls are difficult to audit (NRMMC et al 2006).

WHO (2006) pathogen die-off rates are likely to be too high as die-off rates are temperature sensitive. Raw crops in New Zealand would be chilled as soon as they are harvested to prevent spoilage. A precautionary approach would be the absence of pathogens, FIB criteria <1/100 mL, for growing crops at or below the soil surface as specified by US EPA (2012) and AWRG (NMMR et al 2006) with no reliance on end user preventive controls. The lower FIB criteria used in AWRG (NRMMC et al 2006) also considers that viruses survive better than FIB. With drip irrigation and no wet harvesting or harvesting of food from the ground, a higher FIB criterion of ≤100/100 mL is specified by EU (2020) and <100/100 mL by AWRG (NRMMC et al 2006). A precautionary approach for New Zealand would be to use the AWRG criteria (NRMMC et al 2006).

In addition to national criteria, irrigation of food for export may need to meet international regulations. There may also be differences in criteria to manage food chain quality issues.

For agricultural irrigation of non-food crops, the potential for public interaction with the product or during irrigation may result in low FIB criteria. Addition of preventive control measures, such as withholding periods between irrigation and sale of product, restricting access to the site, or drip irrigation, can increase FIB criteria.

Meat and milk production are part of the human food chain and some guidelines have lower FIB criteria for pasture or fodder crops that are used to feed milk or meat producing animals. Pasteurisation removes bacteria but not human viruses or protozoa. The US EPA (2012) guideline of ≤200/100mL is lowered to ≤14/100 mL if the withholding period is less than 15 days. The AWRG (NRMMC et al 2006) reduces the FIB criteria for pasture from <1,000 to <100/100 mL. In New Zealand Māori traditional customs and associated practices which keep human waste and food separate, or the perceived risk in an export market for foods that form part of the human food chain, which may affect wastewater reuse.

In the EU (2020) and AWRG (NRMMC et al 2006) guidelines pig production is also excluded from pasture or fodder irrigated with treated wastewater due to risks associated with the helminth *Taenia solium* (NRMMC et al 2006). Helminths are not common in New Zealand domestic wastewater and considered unlikely to be a health risk to grazing animals unless raw wastewater is irrigated (MfE, NZWWA 2003). No criteria are set in Department of Health (1992) so helminths would not be important indicators.

The EU (2020), ISO 16075-2 (2020b) FIB criteria are ≤1,000/100 mL for pasture, with <1,000/100 mL in the AWRG guidelines. AWRG (NRMMC et al 2006) has additional restrictions with restricted access, withholding periods and buffer zones. US EPA (2012) specify≤ 200/100 mL and also require buffer zones for spray irrigation and setback distances to drinking water wells.

FIB criteria for trees and woodlots are higher than for pasture, fodder and turf farms, except for US EPA (2012) with ≤200/100 mL. The AWRG (NRMMC et al 2006) has a FIB of <10,000/100 mL for trees and silviculture, where there is limited public access, with additional controls on spray irrigation and spray drift.

The EU (2020) and AWRG (NRMMC et al 2006) guidelines identify that people may be affected by irrigation, with additional preventive controls required. The AWRG (NRMMC et al 2006) specify vegetation screening, buffer zones and spray drift control. The EU (2020) suggests site specific assessment, which is a useful approach in New Zealand as the wind can be a localised feature.

Monitoring requirements align with the risk and the quality of wastewater required. All guidelines have operational monitoring requirements with more frequent monitoring (daily) for low FIB criteria and less monitoring for higher FIB (weekly or monthly). Monitoring may also include other parameters that indicate how well the wastewater treatment plant is performing, or observational monitoring to ensure that access is controlled or that the irrigation equipment is operating properly.

3.6 ASSESSMENT OF HEALTH RISKS FROM CHEMICALS IN WASTEWATER

Where wastewater receives industrial discharges and is subsequently reused there may be potential for risk to human health, the receiving environment and crops from chemicals. International guidelines for the protection of human health from heavy metals are given or referenced in the WHO guidelines (WHO 2006), the AWRG guidelines (NRMMC et al 2006) and FAO guidelines (FAO 1992). AWRG provides information on uptake of heavy metals (NRMMC et al 2006). WHO (2006), FAO (1992), and ISO 16075-1 (ISO 2020a) guidelines provide criteria for heavy metals in food and soil, based on international guidelines.

Crop health is essential to ensure that the activity is sustainable. Some crops are sensitive to different chemicals (eg boron). The AWRG (NRMMC et al 2006), FAO (1992) and WHO (2006) guidelines provide detailed information on the sensitivity of different crops and soils to pH, salinity, sodium, chloride and boron. These do not directly affect human health but can have indirect effects from poor crop yields.

4. URBAN REUSE

4.1 INTRODUCTION

Reuse of wastewater in urban areas has the advantage of being close to the wastewater source. Wastewater provides water and nutrients for irrigation of public and private amenities such as parks, sports grounds and golf courses. In some countries dual potable/non-potable water systems provide treated wastewater for residents to use for gardens and/or toilet flushing. Direct or indirect exposure to pathogens and chemicals could occur through ingestion directly, ingestion/inhalation of aerosols, absorption through the skin (dermal absorption) or wound penetration. People potentially at risk include those who use public or private amenities, industry workers and residents.

In this section the derivation of guidelines for microbial FIB for different preventive control measures are summarised using the risk framework. The WHO (2006), FAO (1992), EU (2020) guidelines deal specifically with agricultural irrigation. The AWRG (NRMMC et al 2006), US EPA (2012), ISO 20760-1 (2017), ISO 20760-2 (2018b), ISO 20761 (2018c) and ISO 20426 (2018a) address urban reuse. ISO 16075-1-4 (2020a, b, 2021a, b) addresses urban irrigation. The AWRG (NRMMC et al 2006) and ISO 16075-2 (2020b) provide criteria. ISO 20761 (2018c) provides examples of criteria for different activities in a range of countries. The EU (2020) irrigation guidelines can be applied to irrigation of urban areas but buffer zones are required to protect people from spray drift.

4.2 QMRA FOR URBAN REUSE

The first step in a risk framework is to identify hazards. The types of hazards will reflect local context. The AWRG QMRA uses rotavirus, *Campylobacter* and *Cryptosporidium* as the target pathogens (NRMMC et al 2006). ISO 2046 (2018a) includes helminths as potential pathogens. ISO 20426 (2018a) references the AWRG for a QMRA. Figure 3 shows the scenario for the potential of infection from irrigation in a public space.

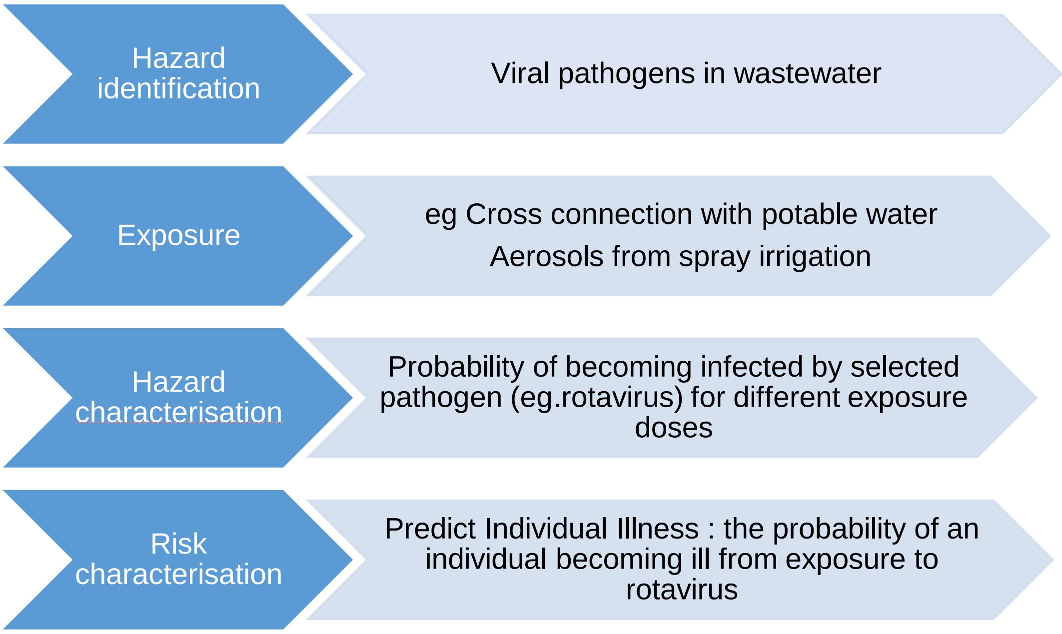

Figure 3 Risk characterisation from urban reuse

4.3 RISK MANAGEMENT

4.3.1 Preventive control measures

When wastewater is reused in an urban setting there are similar hazards to agricultural irrigation with ingestion of pathogens from use in the home vegetable garden or inhalation of aerosols produced by spray irrigation. Preventive control measures and log pathogen reductions are given in Table 7. US EPA (2012) guidelines only provide log reductions for wastewater treatment processes and does not provide log reduction values for preventive measures. The main preventive measures focus on high wastewater treatment quality, irrigation methods, restricting access and controlling the potential effects of spray drift.

Table 7 Preventive control measures and log pathogen reductions for urban reuse

Preventive measure	AWRG Table 3.5
Wastewater treatment	0 - >6
Withholding period	1
Spray drift control -vegetation screening, inward spray drift, anemometer switching	1
Spray buffer zone	1
Pathogen die off	0.5
Drip irrigation of plants and shrubs	4
Subsurface irrigation of plants and shrubs	5-6
No public access during irrigation	2
No public access and limited contact (non-grassed areas)	3

Other preventive control measures not included in the table can include personal protection gear for workers using recycled water for street cleaning or car washing.

Reuse within buildings presents a significant hazard through the potential for cross connections between the reused wastewater and potable water supply. This is a major risk. While avoiding cross connections is critical, a precautionary approach is also required to ensure the wastewater has no pathogens, as the potential for cross connection is estimated in the AWRG risk assessment as 1/1000 NRMMC et al (2006). The AWRG reports four incidents of cross connections in a residential development, one incident affecting 80 households, as well as householders using recycled water to fill swimming pools (NRMMC et al 2006).

Wastewater can be reused in urban areas for a range of activities from urban irrigation, toilet flushing, street maintenance and dust suppression. Table 8 compares the FIB criteria in guidelines from ISO 20761 (ISO 2018c), AWRG (NRMMC et al 2006) and US EPA (2012) Other regulations such as plumbing regulations and signage are not included in the table. For reticulation of water to homes for toilet flushing the FIB criteria of <1 FIB/100 mL (or not detected) is required by US EPA (2012), AWRG (NRMMC et al (2006) and the countries mentioned in ISO 20761 (ISO 2018c) except for China which has a criterion of $\leq$3 total coliforms/100 mL. AWRG (NRMMC et al 2006) specify <1 FIB /100 mL for dual reticulation systems which may be used for irrigation of domestic gardens.

Table 8 Comparison of FIB criteria for urban reuse with preventive control measures.

Maximum conc. FIB /100 mL	Toilet flushing or dual reticulation	Landscape -unrestricted	Landscape - restricted	Fire protection/ Fire fighting	Dust suppression, street cleaning
≤3 TC	China			China	
<1	Israel, Spain, Canada, Japan, US EPA, AWRG	US EPA, AWRG, Israel		Japan, Spain, US EPA, AWRG	AWRG
<100			AWRG -WHP-B		
<200			Portugal, US EPA, China		
<1,000			AWRG -WHP-B-DI		

Notes:

- DI = drip irrigation, WHP = withholding period, B = buffer
- FIB may be *E. coli* or faecal coliforms and TC is total coliforms.
- WHO, ISO, FAO, EU and Israel use less than or equal to FIB criterion but “not detectable”/100 mL is <1 /100 mL
- Data for Portugal, Japan, Spain, Canada, Israel and China is from ISO 20761 (ISO 2018c).

For irrigation of urban areas where there is unrestricted access, there is a high potential for people to be exposed to the irrigated wastewater. As the quality of the wastewater is the primary preventive control, the guidelines have low FIB criteria, (<1/100 mL). FIB criteria for US EPA (2012), Israel (ISO 2018c) and AWRG (NRMMC et al 2006) are the same as toilet flushing (<1 *E. coli* /100 mL).

For municipal irrigation, restricting access allows a lower quality wastewater to be used. AWRG (NRMMC et al 2006) allocate 2-3 log reductions in pathogens for restrictions on access.

There is a broad range of FIB criteria for municipal irrigation with restricted access (Table 8). AWRG (NRMMC et al 2006) specifies <100/100 mL, but with additional preventive control measures such as buffer zones, withholding periods, and control of spray drift, this increases to <1,000/100 mL, which is consistent with the log pathogen reduction given in Table 7.

Buffer zones are used to minimise the potential adverse effects of spray drift and distances are specified in AWRG (NRMMC et al 2006) while the EU (2020) requires that appropriate buffer zones are used to protect public and workers. The AWRG assigns a 1-log pathogen reduction for buffer zones (Table 7). The US EPA (2012) also requires set back distances around wells used for drinking water and buffer zones in areas accessible by the public.

Withholding periods allow surfaces to dry out and pathogens to die off due to desiccation. AWRG (NRMMC et al 2006) gives a 1-log pathogen reduction if withholding periods are used (Table 7). While a withholding period of four hours is proposed by the AWRG (NRMMC et al 2006), more recent data indicates that longer periods are required to inactivate viruses (O'Toole et al 2008). The temperature under which data generated for log removal rates for pathogen die-off need to be relevant for the New Zealand climate. In temperatures of 4-10°C rotavirus inactivation rates were 0.1hr^{-1} compared to 0.2hr^{-1} in summer with temperatures of 36-41C° (Badawy et al 1990). To achieve 2 log removal this would take 16-24 hours in winter and 8-10 hours in summer. However, New Zealand average daily summer temperatures are not that high. At temperatures 17-19°C, which is more likely in New Zealand summer, a one log pathogen removal was achieved in 12.5 hours (Sidhu et al 2008). This has important implications for access restrictions to be effective and indicates that 12.5 hours would better reflect New Zealand conditions – bearing in mind that these average temperatures may only be achieved in certain areas of New Zealand for limited periods. The following periods are when the average daily temperature is 17°C or above (NIWA nd):

- December – March: Auckland, Tauranga, Whangarei, extending to April around Kaitaia
- January-March: Hamilton, Wanganui Gisborne and Napier,
- January-February: Rotorua, Taupo, Masterton, New Plymouth, Palmerston North, Blenheim, Nelson, Christchurch
- February: Wellington.

Withholding periods in New Zealand need to be significantly longer than the four hours specified in the AWRG (NRMMC et al 2006) for water reuse to achieve log removal.

Wastewater is also reused for firefighting or fire protection and dust suppression (Table 8). Aerosols and spray generated can be from firefighting, and the water can discharge to stormwater drains or nearby water courses. Depending on the time of day that dust suppression occurs, people may be exposed to the wastewater. These are activities which may affect the health of the worker, as well as people in the vicinity. Japan (ISO 20761 2018c), US EPA (2012) and AWRG (NRMMC et al 2006) have low FIB criteria for these activities, but Spain (ISO 20761 2018c) has much higher FIB - up to ≤200/100 mL.

4.3.2 Monitoring

The criteria for FIB are very low for unrestricted urban reuse and toilet flushing and monitoring requirements for FIB and treatment plant performance are summarised in Table 9 against FIB criteria. Where FIB monitoring frequency is specified, it is daily to weekly. The US EPA (2012) guidelines requires daily monitoring. AWRG (NRMMC et al 2006) proposes weekly monitoring of *E. coli* except in small, low exposure schemes, where it is monthly. The frequency of monitoring is not given in ISO 20761 (ISO 2018c). AWRG (NRMMC et al 2006) requires monitoring to show virus and protozoan removal either directly with pathogens or with surrogates for high exposure schemes.

Most guidelines require monitoring of wastewater treatment plant performance using surrogates such as turbidity and chlorine residual, with BOD_5 and TSS monitoring also required. China requires removal of colour, which would improve the aesthetic quality of the water and limits nutrients (ISO 2018c). While the frequency of monitoring is not given in ISO 20761 (ISO 2018c), all countries listed have plant performance monitoring requirements and it recommends continuous monitoring for activities with a high risk for exposure

The monitoring requirements for restricted wastewater reuse are summarised in Table 10. Comparison with Table 9 shows that less frequent monitoring is required for FIB and treatment plant performance. ISO 20426 (ISO 2018a) recommends weekly monitoring of FIB for high-risk projects and monthly or quarterly monitoring for activities with a low risk of potential exposure.

Table 9 Summary of monitoring requirements for unrestricted reuse for toilet flushing or irrigation.

FIB monitoring				WWTP BOD5 and/TSS monitoring			Regular turbidity/ disinfection/ residual Cl monitoring
Maximum conc./100 mL	**Daily**	**Weekly**	**Unspecified**	**Daily**	**Weekly**	**Unspecified**	
≤3 TC			China			China	China
<1	US EPA	AWRG#	Japan, Spain, Israel, Canada, China	USEPA	AWRG#, US EPA	Spain, Canada	Japan, USEPA, Spain, Israel, Canada, China, AWRG
≤10		AWRG#	Israel		AWRG #	Israel	AWRG
≤100		AWRG#					AWRG
<1,000		AWRG#			AWRG#		

Table 10 Summary of monitoring requirements for restricted urban reuse

FIB monitoring				WWTP BOD_5 and/TSS monitoring			Regular turbidity/ disinfection/ residual Cl monitoring
Maximum conc./100 mL	**Daily**	**Weekly**	**Unspecified**	**Daily**	**Weekly**	**Unspecified**	
<1		AWRG#			AWRG#		AWRG
<10			Israel			Israel	AWRG
<100		AWRG#			AWRG#		AWRG
≤200	US EPA		Portugal, China	US EPA		China	US EPA
≤1000		AWRG#	Japan		AWRG#	Japan	AWRG

Notes to Tables 9 and 10:

- FIB may be *E. coli* or faecal coliforms and TC is total coliforms
- WHO, ISO, FAO, EU and Israel use less than or equal to FIB criterion but "not detectable"/100 mL is <1 /100 mL
- # Weekly monitoring of FIB and BOD_5 for high exposure schemes, otherwise monthly
- Data for Japan, Portugal, Israel and China is from ISO 20761 (ISO 2018c).

5. INDUSTRIAL REUSE

Treated wastewater may also be used as a water source in industries, excluding food processing. In Singapore significant volumes of highly treated wastewater are reused by the technology industries (PUB nd), but more common uses are for boiler water, cooling towers, cement manufacture and washdown. As in urban reuse, industries may also reuse water for dust suppression or irrigation of grounds, in which case the urban guidelines apply..

Direct or indirect exposure to pathogens and chemicals in treated wastewater can occur through ingestion directly or as aerosols, penetration or absorption through the skin or wounds. People potentially at risk are the industry workers and the public, depending on the proximity to the activity. In this section the guideline criteria are summarised from the US EPA (2012) and the AWRG (NRMMC et al 2006) guidelines.

5.1 RISK CHARACTERISATION FOR INDUSTRIAL REUSE

The first step in a risk framework is to identify potential hazards. ISO 20246 (2018a) and the AWRG (NRMMC et al 2006) present methodologies, but do not provide a risk characterisation for industrial reuse. Figure 4 presents some scenarios for the potential risk for infection by microorganisms in reused industrial wastewater.

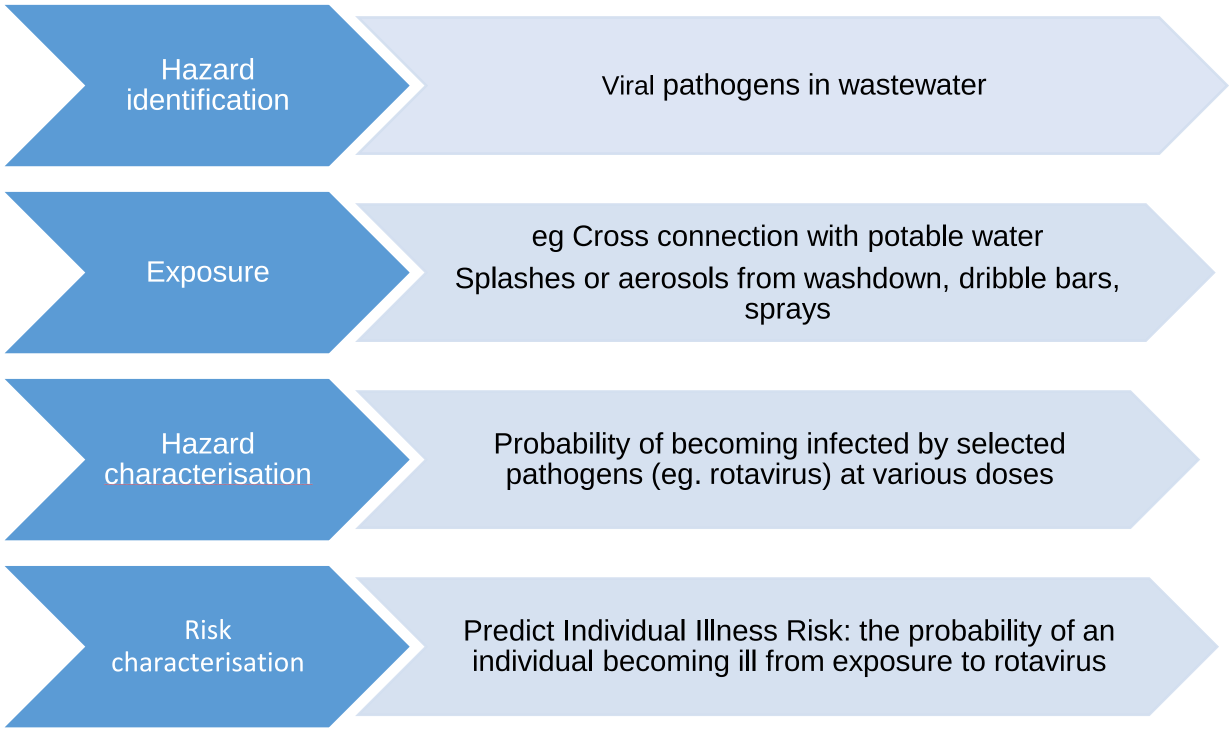

Figure 4 Risk characterisation for industrial reuse

5.2 RISK MANAGEMENT

Exposure for workers is likely to be the greatest risk from wastewater reuse. Potential risks from cooling tower include aerosols, blowdown disposal, scaling, corrosion, fouling and biological growth (US EPA 2012, ISO 20761 2018d). Where there is the potential for ingestion of aerosols, preventive control measures would include personal protective equipment such as masks and waterproof overalls. More personal protection would be required for manual vehicle cleaning than automatic cleaning (ISO 20761 2018d). Good hygiene practices such as not drinking, eating, or smoking reduce the opportunity for hand to mouth ingestion. Risk assessment methodologies can be applied to the site-specific cases, where there are no guidelines.

5.3 FIB CRITERIA AND MONITORING

The US EPA (2012) has criteria for cooling towers of ≤200 MPN/100 mL, requires that spray will not affect workers or the public and that there is continuous disinfection for circulating cooling towers. Other activities are assessed and managed on a site specific basis which is also proposed in ISO 20761 (2018d). AWRG (NRMMC et al 2006) specifies a FIB criterion only for dairy shed washdown (<100 MPN/100 mL). While ISO 20761 (ISO 2018d) does not provide FIB criteria it indicates that *Legionella* is a risk. Australian and US FIB criteria and monitoring requirements are compared in Table 11.

Table 11 comparison of Australian and US guidelines for industrial reuses

FIB monitoring				BOD_5 and/or TSS monitoring		
Maximum conc./100 mL	**Daily**	**Weekly**	**Unspecified**	**Weekly**	**Unspecified**	**Continuous turbidity/ disinfection/ residual Cl monitoring**
<100		AWRG#			AWRG#	AWRG
≤200	US EPA-B			US EPA		US EPA

Notes:

- FIB may be *E. coli*, or faecal coliforms
- B= buffer zone
- # Weekly monitoring of FIB and BOD_5 for high exposure schemes, otherwise monthly

6. SUMMARY

6.1 A RISK BASED FRAMEWORK

A risk-based framework for guidelines provides a more flexible and contextual approach to managing risk, allowing wastewater treatment to be used in conjunction with other preventive control measures to achieve a designated health target.

The key components in a risk based framework for managing wastewater reuse system are:

- setting health based targets
- identifying health risks from potential hazards and exposure routes
- risk management planning which identifies critical control points, along with preventive control measures to reduce the risk to achieve the health based targets
- monitoring to ensure the preventive control measures are effective and highlight data trends.
- regular review of the system, reporting and emergency planning.

A QMRA can be used to identify the health risk and determine the level of pathogen reduction that is required to manage the health risks. Pathogen reduction can be achieved by different levels of wastewater treatment combined with a range of preventive control measures which have differing levels of pathogen reduction. For example the level of pathogen reduction required to meet a health based target can be achieved by wastewater treatment alone, or a lower level of wastewater treatment combined with preventive control measures such crop selection, drip irrigation, buffer zones, withholding periods before food is harvested, restricting public access or controlling spray irrigation. The WHO (2006) and AWRG (NRMMC et al 2006) provide details of the risk assessment. Along with ISO 20426 (ISO 2018 a) and ISO 16075-2 (2020b) these guidelines provide guidance on the levels of pathogen reduction that can be achieved with different preventive control measures, or barriers. Monitoring is required for commissioning, operation and verification of the process to ensure health targets and regulatory requirements are met. A risk management plan is developed which includes the components of the system, operation, monitoring and emergency planning.

This review summarises the risk assessment approach to managing wastewater reuse which is used in the guidelines of most international organisations reviewed (WHO 2006, ISO 2018a-c, ISO 2017, ISO 2020a, b, ISO 2021a, b, EU 2020, AWRG (NRMMC et al 2006) and the US EPA (2012). The types of wastewater reuse activities reviewed are:

- agricultural irrigation
  - irrigation of food crops
  - irrigation of non-food crops
  - irrigation of crops which are part of the human food chain (eg pigs and milk producing animals)
- urban reuse
  - unrestricted urban reuse (eg toilet-flushing, home garden irrigation, school playgrounds, golf courses)
  - restricted urban reuse (eg municipal park with controlled access)
- industrial reuse.

The focus of this review is on the human health risk from microbial pathogens, as this is the greatest risk to human health (WHO 2006) and there is significant inconsistency in guideline criteria from various international organisations and jurisdictions.

6.2 GUIDELINES FOR WASTEWATER REUSE

The risk based approach of AWRG (NRMMC et al 2006) is more precautionary than WHO (2006), and is more consistent with the other international guidelines. However, the effect of spray drift and length of withholding periods would need to be adapted to take into account New Zealand climatic conditions. It is also important to highlight that Māori cultural traditions and associated practices keep food and human waste separate (Pauling, Ataria 2010). Therefore wastewater reuse for food production is not likely to be a compatible form of reuse.

The combinations of wastewater treatment, indicated by FIB criteria, and preventive control measure are summarised below.

6.2.1 Agricultural irrigation

FIB criteria are taken from the WHO (2006), FAO (1992), ISO (2018a, b), ISO 16075-2 (2020b), EU (2020), the AWRG (NRMMC et al 2006). As FIB criteria increase the importance of preventive control measures other than wastewater treatment increases.

For food grown in soil or contact with wastewater and eaten raw without peeling or cooking, the FIB of <1/100 mL in AWRG (NRMMC et al 2006) is more appropriate for New Zealand than the higher WHO (2006) and FAO (1992) FIB criteria. AWRG (NRMMC et al 2006) has a more precautionary assessment of the effectiveness preventive control measures for pathogen reduction and is more in keeping with New Zealand's temperature climate and harvesting practices.

Irrigation of pasture for growing animals which form part of the human food chain may have a lower FIB criterion than for other pasture uses eg AWRG (NRMMC et al 2006). There may also be a perceived risk in an export market around foods that form part of the human food chain, which may affect the FIB criteria. The links between human waste and food may also be too close to be acceptable to Māori cultural traditions and associated practices.

For pasture without any link to the human food chain, the AWRG (NRMMC et al 2006) have FIB criteria of <1,000/100 mL with other preventive control measures to achieve the log pathogen reduction required. This is consistent with the FIB criteria in the EU (2020) and ISO 16075-2 (ISO 2020b) guidelines. While US EPA (2012) and AWRG (NRMMC et al 2006) specify a buffer distance site, specific assessments of spray drift would be a useful approach in New Zealand as the wind can be a localised feature.

For woodlots the AWRG (NRMMC et al 2006) the FIB criterion is 10,000/100 mL. This is higher than FIB criteria of 1,000/100 mL in the EU (2020) and ISO (2020b) guidelines and <200/00 mL in the US EPA guidelines. However, the AWRG (NRMMC et al 2006) guidelines also specify restricted access and other preventive control measures to achieve the log pathogen reduction required.

6.2.2 Urban reuse

The AWRG (NRMMC et al 2006), US EPA (2012) and ISO 20761 (ISO 2018d) include a range of urban activities including dual reticulation for toilet flushing and residential irrigation, irrigation of sports grounds, parks and golf courses, dust suppression and firefighting.

The greatest risk from toilet flushing or a dual reticulation system is cross connection to potable water and the most effective preventive control measure is wastewater treatment with FIB criterion of >1/100 mL. The occurrence of cross connections is noted in AWRG (NRMMC et al 2006).

Irrigation is a common activity in urban reuse. Where access is unrestricted, low FIB criteria are required as there is a higher risk of potential for exposure to pathogens eg aerosols from spray irrigation or contact with wet surfaces. US EPA and AWRG (NRMMC et al 2006) specify FIB <1/100 mL. Higher FIB criteria are appropriate where preventive control measures such as restricted access and withholding periods are implemented to allow surfaces to dry out, and spray drift is controlled by selection of sprinklers, use of vegetative screens and buffer zones. The US EPA uses ≤200/100 mL where access is restricted, but application of additional preventive controls increases the FIB criteria for restricted irrigation from <100/100 mL to <1,000/100 mL in the AWRG (NRMMC et al 2006).

However, while AWRG (NRMMC et al 2006) proposes a four-hour withholding period for pathogen die-off this would need to be increased in New Zealand due to lower average summer temperatures and therefore less pathogen die-off. Lower temperatures may also increase the time for surfaces to dry off which reduces the potential for contact with the wastewater.

FIB criteria for firefighting and dust suppression range from ≤3 total coliforms/100 mL to ≤200 E. coli /100 mL, with most countries requiring no detection of FIB/100 mL (ISO 20761 2018c).

6.2.3 Industrial reuse

While industrial reuse is mentioned in ISO 20761 (2018c), no criteria are given and it is proposed that case by case specific risk assessments be undertaken. The US EPA gives a criterion of ≤200/100 mL for cooling towers. Other industrial reuses are managed on the site specific end use. The only criterion given in the AWRG (NRMMC et al 2006) is <100/100 mL for dairy shed washing.

6.3 AREAS WHERE FURTHER INFORMATION IS REQUIRED

The risk from pathogens is considered the greatest human health risk. The studies used in the WHO (2006) and AWRG (2006) guidelines to derive FIB criteria are dated and new research may provide better information on the human health risks. There was little information available on the environmental fate of emerging organic chemicals or antimicrobial resistance in guidelines and ISO 16075-1 (ISO 2020a) does not include guideline values due to a lack of evidence that emerging contaminants cause health, environmental or crop issues in wastewater reuse. ISO 20760-1 (ISO 2018d) proposes source control to avoid toxic chemicals, while

A literature review could be used to ensure that the most recent data is available to manage public health risks in decision making on wastewater reuse in New Zealand.

APPENDIX A: SUMMARIES OF INTERNATIONAL GUIDELINES ON WASTEWATER REUSE

A.1 World Health Organisation (WHO) WHO guidelines for the safe use of wastewater, excreta and greywater

These guidelines address microbiological risks from agricultural reuse. The current version is dated 2006. There are four volumes:

1. Policy and regulatory aspects
2. Wastewater use in aquaculture
3. Wastewater and excreta use in agriculture
4. Safe use of wastewater, excreta and greywater.

The most relevant volumes for wastewater reuse are volumes 1 and 2.

A.1.1 Volume 1 Policy and Regulatory Aspects

The objective of the guidelines is to maximize the health and environmental benefits associated with wastewater reuse. The guidelines highlight links to the UN Millennium Development Goals (MDG). Volume 1 looks at the policy framework including hierarchy and linkages to other policy goals. Three key objectives are identified:

- health protection
- environmental benefits
- food security.

The guidelines recognise that in many developing countries with arid and semi-arid climates, wastewater and excreta are already used for agriculture and aquaculture. The focus of these guidelines is on safe use to protect workers, local communities and consumers of products. In developing countries with poor sanitation and hygiene, intestinal worms are identified as the greatest health risk and in countries with developed wastewater infrastructure, viruses present the greatest health risk. The guidelines set out a framework for policy development and intersectoral collaboration to ensure good linkages between the health sector and other sectors and between the different levels of governance.

Regulation supports the policy objectives and should be realistic and take into account capability, capacity and jurisdiction. The first steps are hazard identification and evidence of health risk. However, it is noted that a direct relationship between reuse of wastewater and disease may be difficult to estimate due to multiple transmission pathways or exposures. The typical level of tolerable human health risk used in health based targets is 10^{-6} DALY pppy. Data is given on exposure risks for consumption of food irrigated with wastewater for unrestricted irrigation and protection of workers in mechanised and labour intensive scenarios with restricted irrigation. Examples are given using different options for pathogen reduction to meet the DALY with pathogen log reduction values and *E. coli* concentrations for different control options for restricted and unrestricted agricultural uses. Pathogen reduction as log units is given for different processes. Greywater is considered to have less health risks compared to wastewater.

Multiple barriers have an advantage compared to relying on a sole barrier and can be used even in low resource-settings. Monitoring occurs at different levels:

- validation tests the system and component parts to ensure it can meet targets
- operational tests and observations to determine if the health protection measures are operating within design parameters
- verification tests to determine compliance with design parameters and criteria.

A risk management plan is proposed for effective management of the system and the key steps provided. It is recommended that an accurate flow diagram is prepared to ensure all potential hazards in the process are identified and control measures assessed.

Volume 1 includes the Executive Summaries of Volumes 2-4.

A.1.2 Volume 2: Wastewater Use in Agriculture.

This volume describes the drivers for wastewater reuse including achieving Millennium Development Goals. The Stockholm framework is applied to provide a harmonised approach to achieve health based targets by taking into account management objectives in other sectors. This framework is used in other WHO water related guidelines.

The Stockholm framework uses an assessment of health risk based on epidemiological studies and Quantitative Microbial Risk Assessment (QMRA). Target pathogens are selected for the assessment and the effect on vulnerable groups are considered. Health burden is related to location and information on gastrointestinal disease burden in developing and developed countries, common helminth infections in different locations and vector borne diseases are provided.

Tolerable health risk targets are set which are relevant to the region/country and are cost effective. The WHO sets health based targets at 10^{-6} DALY pppy for unrestricted and restricted irrigation. The next step, health risk management, is based on achieving the health-based targets using risk management strategies such as prevention of exposure and multiple barriers. Water quality objectives need to be defined for the wastewater reuse sector as well as for other sectors which overlap. Key points of risk are identified for development of monitoring programmes, including catastrophic events. Monitoring ensures the process works effectively, it operates within design guidelines and the criteria required to achieve the objectives are met and trends can be identified.

The assessment of health risk identifies target pathogens and the faecal indicator organisms also present in wastewater. A QMRA is undertaken with different scenarios based on unpublished studies by Mara and colleagues which gives the risk of infection from rotavirus, *Campylobacter* and *Cryptosporidium* from the ingestion of soil or consumption of lettuce and onions. Rotavirus is the pathogen with the highest median infection risk per person per year (pppy). The QMRA models the reduction in pathogens required to achieve different tolerable risk of infection for consumption of lettuce or onions. Information is given on factors affecting pathogen survival and survival rates in soil at 20-30°C and vegetables for a small number of target pathogens. Log reductions in pathogen concentrations are derived to meet a health based target of 10^{-6} DALY pppy (Table 4.3) which may be combined to achieve the target pathogen reduction. Epidemiological evidence is reviewed for pathogens. Children under 15 years of age are most susceptible to helminth infection. Direct contact with wastewater also increases the risk of diarrhoeal disease and children are more at risk. Wastewater treatment reduces the risk for adults but not children. The studies indicate that water quality should be <10,000 thermotolerant coliforms/100 mL.

Details are given on health protection measures using wastewater treatment and barriers such as drip irrigation systems, withholding periods, treatment of food after harvesting, immunisation status and hygiene practices. Appropriate protective equipment for workers and their families is listed. It notes that residents may face similar risks as workers in unrestricted irrigation areas, especially for vector born disease.

Risk assessment of chemical exposure is difficult to quantify. Acute toxicity is unlikely at the concentrations likely following wastewater reuse. Chronic effects may occur but humans are exposed to most chemicals through multiple exposure routes which again makes direct health impacts from any single exposure route difficult to assess. Maximum tolerable soil concentrations of 41 chemicals (26 organic compounds and 15 elements) are presented. Another difficulty in undertaking chemical risk assessment is that uptake by plants is highly variable and is dependent on the types of chemicals as well as the proprieties of different soil types. Limiting discharge of chemicals to the wastewater stream is a method of reducing their concentrations in wastewater.

Indirect effects may also occur from chemicals such as nitrogen contaminating drinking water. Phosphorous and nitrogen may cause eutrophication in water resulting in the growth of cyanobacteria and algae which produce toxins. Chemical elements can be beneficial in small quantities but may affect plants and soils in larger quantities.

The three types of monitoring are discussed. Monitoring based on *E. coli* concentrations verify that the pathogen reductions are being met for restricted and unrestricted irrigation and for labour intensive and mechanised agricultural systems and minimum verification monitoring frequencies are given.

The guideline recognises that some developing countries may wish to set lower health based targets. If the disease burden is high, efforts in sanitation and clean drinking water may be more useful measures to improve health outcomes. Bacterial infections may be more important as they can reoccur, whereas immunity to rotavirus is generally achieved by the age of five.

Health based targets have been set based on exposure from contamination of soils in the food chain pathway. Maximum concentrations of elements and organic compounds in soils are given. Food regulations may also limit concentrations in plants. Physicochemical requirements for plant growth are given Annex 1 (from FAO).

Health protection measures include those for raw wastewater use, as it does occur in some developing countries. Withholding periods before harvesting product, crop restriction, fencing and good food preparation practices, immunisation and chemotherapy may reduce risk. Drip irrigation is also encouraged. Education is a key health promotion tool.

Good monitoring programmes require a multidisciplinary team of experts to ensure that all critical control points are identified and monitored. A risk management plan needs to be developed with an appropriate monitoring programme that addresses validation, operation and verification. The parameters for different control measures, monitoring methods and frequency are given.

The need for public engagement is addressed in section 7 which includes religious and cultural beliefs and public perception.

Schemes need to have good financial planning to be successful. At a governance level, policy, legislation, institutional framework and regulations are required to achieve objectives of safe wastewater reuse. Protection of human health should be the highest priority and link with other public health programmes such as drinking water, sanitation and health promotion.

A.2 ISO 16075 Guidelines for Treated Wastewater Use for Irrigation Projects

The ISO guidelines specify water quality criteria for different reuse and barriers (preventive control measures) including wastewater treatment plant performance. They provide guidance on irrigation systems, hazards for soil, environmental and human health, irrigation regimes and monitoring requirements. The focus is on a “fit-for-purpose” approach which meets the end-use. Parts 1 -4 are reviewed. Part 5 addresses disinfection and is not reviewed.

A.2.3 ISO 16075-1:2020 Guidelines for Treated Wastewater Use for Irrigation Projects — Part 1: The Basis of a Reuse Project for Irrigation (ISO 2020a)

This guideline has been developed to support consistency in wastewater reuse in agricultural and urban settings across arid and semi-arid climates, with different soil types, growing different types of crops. Part 1 addresses the parameters in wastewater in terms of effects on agronomics, public health and irrigation practices. Emerging contaminants are not addressed in the guideline due to a lack of evidence that they cause environmental, crop or public health issues in wastewater reuse. It identifies the components of raw wastewater that affect plant and soil health including nutrients, salinity, boron, heavy metals and halogens. It notes that heavy metals partition to the sludge during wastewater treatment. Pathogenic micro-organisms will be present in the treated wastewater depending on the level of treatment. Thermotolerant coliforms are chosen as the faecal indictor bacteria.

Local climatic conditions and crops need to be taken into account in managing wastewater reuse. Guidance is provided on managing effects of wastewater components and the method of irrigation on soil and plant health (eg salinity, pH, boron and sodium). The presence of pathogens in wastewater can affect the health of workers, people and animals as consumers of crops and the general public. Transmission pathways from the irrigated area or irrigation infrastructure to surface water and groundwater sources are noted with further information in ISO 16075-3, 6.6. Information of the principles for protection of water sources is also given.

A.2.4 ISO 16075-2:2020 Guidelines for Treated Wastewater Use For Irrigation Projects — Part 2: Development of the Project (ISO 2020b)

This part of the guideline specifies water quality criteria for effluent from a wastewater treatment system for different reuses in five categories A-E. It includes plant performance criteria for BOD_5 and TSS for different quality wastewater with a description of the type of use and treatment systems. Where disinfection is required (Categories A-C) it specifies thermotolerant coliforms criteria. Pathogen reductions (as log removal) are suggested for a range of barriers to minimise pathogen transfer. The barriers include disinfection, type of irrigation system, the treatment of produce eg cooking, with-holding periods before access is permitted to irrigated areas, night-time irrigation and a setback distance of 70m to residential or public access areas. It is noted that while cooking may reduce pathogens there is a chance that cross contamination of other foods may occur.

Appendix 1 provides more details on holding times for poorer quality wastewater before irrigation and barrier levels. A distance of 50 cm between drip irrigation and vegetables/fruit is considered equal to two barriers and a distance of 25-50cm one barrier. For spray irrigation the distance is taken from the height of the spray and only considered one barrier due to the production of aerosols. The number of barriers for different reuses is determined. It is derived from WHO (2006) and US EPA (2012) and includes the practical experience of members. For urban reuse, irrigation of private gardens or landscape with unrestricted access is forbidden for Category C wastewater (thermotolerant coliforms ≤1,000/100 mL) and lower quality categories of wastewater. Irrigation of vegetables consumed raw is permitted with no additional barriers for Category A wastewater (thermotolerant coliforms ≤10/100 mL), one barrier for Category B wastewater (thermotolerant coliforms ≤200/100 mL) and three barriers for Category C wastewater. Reuse of wastewater which is not disinfected is not permitted for private and public landscape irrigation and irrigation of vegetables consumed raw. However, non-disinfected Category E wastewater can be used for irrigation of vegetables consumed after processing and for pastures with two barriers but is not permitted for Category D wastewater.

The potential for helminth infection due to flood and furrow systems and the protection of workers are discussed. Setback distances from the wetted area of spray irrigation are given for different quality treated wastewater and maximum operating pressure, with and without screening (trees, screens, walls, wind break nets) for a wind speed of 4m/s (14 km/hr).

A.2.5 ISO 16075-3:2021 Guidelines for Treated Wastewater Use for Irrigation Projects — Part 3: Components of a Reuse Project for Irrigation (ISO 2021a)

Component parts of an irrigation system are detailed, with measures to reduce problems with storage of the water in reservoirs. Distribution and irrigation systems are discussed in detail. Information on filtration and additional disinfection are provided to prevent clogging and growth of slime in the irrigation system.

To reduce risk to human health drip irrigation is preferred. Drip irrigation also reduces potential harm to plants as it does not land on the leaves. Spray irrigation is described but should NOT be used for low quality treated wastewater. Protection of drinking water sources is managed through the length of time taken for wastewater to travel to a source. A time of 200 days is specified for main supply lines and a 50 day period for irrigated plots, assuming that the soil will provide a filtration effect. Less time may be appropriate in sandy aquifers, due to the filtration effect, with longer times for fractured aquifers. Hydrological calculations for travel times are described for countries where there is no local guidance. Where chlorine is continuously added, travel times may be halved. Guidance is given for irrigation above drinking water pipelines and to minimise the chance of cross connections. The guidelines provide details on equipment requirements for different irrigation systems eg discharge rate, filter size. A table provides details on the clogging potential from different water quality and restoring irrigation after a major failure caused by solids blockages.

A.2.6 ISO 16075-4:2021 Guidelines for Treated Wastewater Use for Irrigation Projects — Part 4: Monitoring (ISO 2021b)

Part 4 details monitoring requirements to be used for the water quality criteria specified in Part 2. Monitoring programmes ensure the following different objectives are achieved.

- Wastewater treatment process performance - to ensure the water quality meets the criteria that will protect the health of people and prevent adverse effects on the receiving environment (soils and water) and plants.
- Treated water in storage reservoirs – to ensure that water quality doesn't deteriorate below the criteria for reuse.
- Irrigation systems – to ensure that they can operate properly eg without clogging.
- Plants and soil - to ensure they are healthy.
- Potential receiving waters - to ensure they do not become contaminated.

Details are provided on the type and frequency of sampling required to meet different objectives, including seasonal sampling, collection, preservation, transport and quality control. Monitoring frequency is given for the different categories of water quality to protect health and meet agronomic requirements and assess the health of the crops. As salinisation is a potential risk, information on soil sampling methods, procedures and frequency is provided. A water monitoring programme is required where there is a risk of contamination of surface or groundwater. Monitoring programmes for water bodies may also be required where water reuse is occurring in a sensitive area or in proximity to drinking water sources.

A.3 ISO 20426:2018 Guidelines for Health Risk Assessment and Management for Non-Potable Water Reuse. (ISO 2018a)

This guideline set out the risk framework for assessing reuse for agriculture, urban (landscape and non-potable use), recreational and environmental uses and industrial uses and development of risk management plans. For health risk assessment the hazards and hazardous events are evaluated. Risk evaluation can be undertaken with a quantitative framework where human contact is likely, or a qualitative risk evaluation framework for other risk assessment. The standard refers to the AWRG (NRMMC et al 2006) for quantitative risk assessment. The DALY can be used for setting a health-based target, but no target is proposed.

A risk management plan uses preventive control measures (Performance Control Points) to minimise risk followed by reassessment of the risk to determine how effective the control measures are. Examples are presented of typical wastewater treatment process to achieve different quality wastewater for reuse. As well as treatment processes, post treatment controls include:

- restricting uses
- setting withholding periods
- controlling access to an area
- cross-connection and backflow control
- signage
- residual chlorine.

Monitoring is critical to ensure safe the quality of water provided for reuse. Compliance monitoring ensures regulatory requirements are met and performance monitoring ensures treatment process effectiveness. Proposed parameters are *E. coli*, turbidity or TSS, BOD and chlorine residual. No criteria are provided but ISO 16075-2 (ISO 2020) has criteria for agricultural reuse and ISO 20760-1 (ISO 2018b) and ISO 20760-2 (ISO 2017) for urban reuse.

The approach in this document can be applied to chemical contaminants if applicable. This document considers compliance and performance monitoring, and monitoring of water quality parameters in treated water quality prior to distribution, or at the point of use. Its approach includes maintenance and calibration of online and field analytical instruments, and the use of more stringent verification requirements for new technologies or projects with high risk of human exposure.

A.4 ISO 20760-1 Water Reuse in Urban Areas – Guidelines for Centralised Water Reuse System - Part 1 Design Principle of a Centralised Water Reuse System (ISO 2018b)

This standard addresses the design of a centralised water reuse system for urban reuse. Key components for planning include estimating water demand, the site for the centralised system and the system components:

- source water
- treatment
- storage
- distribution
- monitoring.

Different models are presented ranging from a single reuse to multiple reuses, including cascading reuses without retreating the water eg after industrial reuse the water is reused for irrigation.

The basic principles of the design need to include safety, reliability, stability and economic viability. Both treated sewage and untreated sewage are discussed as potential source water. The quality and quantity of the source water must be considered. Factors which affect the quantity of water need to be taken into account, such as leaks, breakages and seasonal fluctuations. Wastewater from hospitals and industries discharging toxic chemicals should be excluded from reuse systems. A source control programme, including permits and monitoring, should be used to manage the quality of the wastewater discharged to the reuse system. Other sources of water of suitable quality may be required as back-up for some uses such as toilet flushing if treated wastewater is unavailable.

Storage of treated water needs to be managed to ensure there is enough water to meet demand, fluctuations in source water and to ensure that the water quality does not deteriorate to an unacceptable level during storage. This is a potential problem as treated wastewater is likely to have higher nutrient and organic matter than environmental freshwater sources.

The standard provides information on infrastructure requirements for distribution of the treated water. Installing dual reticulation in newly developed areas is likely to cost less than retrofitting existing distribution systems. Residual chlorine prevents biological growth within the reticulated system, but de-chlorination may be required if water is reused for environmental augmentation of water. Colour coding, signs and labels are required to differentiate treated wastewater infrastructure from potable water infrastructure. The infrastructure needs to be managed avoid cross-connections and backflow.

Monitoring systems should be designed using the safety evaluation process in ISO 20761 (ISO 2018c). Depending on the reuse and the receiving environment additional parameters may need to be monitored. If water quality does not meet the goals appropriate actions needs to be implemented. In addition to monitoring the components of the system, user sites should also be monitored. Checks for compliance, and particularly for cross-connections, need to be undertaken by trained competent operators. Up-to-date emergency response plans are required to manage impacts which may affect water quality such as extreme weather, plant failure, accidental cross-connections or illness outbreaks.

A.5 ISO 20760-2 Water Reuse in Urban Areas – Guidelines for Centralised Water Reuse System - Part 2 Management of a Centralised Water Reuse System (ISO 2017)

This standard covers the management of all the components of centralised reuse systems:

- water supply
- assessment of the system including health risks and environmental sustainability
- preventive management
- operational procedures and controls
- verification of water quality
- social and public needs
- incident and emergency management.

The management framework needs to have principles and objectives to ensure the system is safe, effective, reliable, efficient and economic addresses health and environmental risks. Protection of public health and the environment is paramount and a preventive risk management approach is required. Each system component identified in Part 1 needs to be covered in the framework. Risks can be managed using a Hazard Analysis and Critical Control Point (HACCP) monitoring plan, ISO 20761 (ISO 2018c), ISO 20426 (ISO 2018a), ISO 22000 (ISO 2018d), AWRG Environmental and health risks (Phase 1) (NRMMC et al 2006), Augmentation of drinking water supplies (Phase 2) (NRMMC et al 2008) , Managing aquifer recharge (Phase 2) (NRMMC et al 2009), Brisbane’s Water quality guidelines for recycled water schemes (DNRW 2013) or the US EPA Guidelines for water reuse (US EPA

2012). Corrective actions, continuous improvement and preventive maintenance measures should match the source of wastewater and the reuse activity.

The framework needs to be responsive to social and public aspects including affordability and acceptability, consultation, cultural aspects, public awareness of pollution prevention and notification signs where reclaimed water is in use. An incidents and emergency response plan is required with appropriate documentation. Incidents or emergencies need to be reviewed and learnings fed back into the management framework. The framework should be formally reviewed periodically.

A.6 ISO 20761:2018 Water Reuse in Urban Areas – Guidelines for Water Reuse Safety Evaluation – Assessment Parameters and Methods (ISO 2018c)

This guideline provides guidance on evaluation and public acceptance methods for designers of wastewater reuse projects, while also protecting public and environmental health and infrastructure. Transmission pathways identified include aerosols from spray irrigation and ingestion. Potential environmental hazard events are aquatic toxicity, eutrophication, sediment and soil contamination and contamination of receiving water. There are also potential hazards to infrastructure such as corrosion of pipes from chemical contaminants such as alkalinity, calcium, ammonia and pH.

Colour and odour are important parameters for public acceptance and aesthetic parameters are proposed in the monitoring plan. As well as microbiological monitoring, reused wastewater should be monitored for nuisance algae, nutrients, residual chlorine, ammonia and physical and chemical parameters given in environmental and recreational standards. It identifies additional personal protection equipment. Rather than setting water quality criteria, the standard presents criteria from other countries against different urban reuse options including environmental augmentation of water bodies, recreational use of augmented water bodies, irrigation, toilet flushing, street maintenance and firefighting.

A.7 Australian Guidelines for Water Recycling: Managing Health and Environmental Risks Phase 1 (NRMMC et al 2006)

The Australian Guidelines for Water Recycling (AWRG) are intended to provide principles and a framework for safe implementation of recycled water schemes. The guidelines are not prescriptive and allow for flexibility of application while ensuring safe water reuse. They provide high-level national guidance on risk assessment and management and guidance on how recycling can be safely and sustainably achieved using a risk management framework.

Phase 1 provides a generic framework for management of recycled water quality and reuse that applies to all combinations of recycled water and end uses for a range of users from residents in single dwellings, to municipal, to agriculture. It also provides specific guidance on the use of treated sewage and greywater for purposes other than drinking water and maintaining or enhancing environmental flows.

The framework for water recycling is based on the framework used in the Australian drinking water guidelines to identify and manage risks to human and environmental health.

Aspects included in the water recycling guidelines but not in the drinking water guidelines are:

- the definition of safety, particularly for microbiological quality
- health based performance targets, based on a DALY of 10^{-6} pppy, which is based on the approach of the WHO guidelines for drinking-water quality
- reductions of microbial and chemical hazards
- use of reference pathogens in a QMRA.

Detailed QMRA are given for different reuses using reference bacterial, viral and protozoan pathogens, *Campylobacter*, rotavirus and *Cryptosporidium*. Concentrations of target pathogens in Australian sewage are used to populate the QMRA. Pathways for exposure and volumes ingested are given and rotavirus is assessed as the greatest risk to health. Management of the risk can be undertaken at critical control points at the wastewater treatment plant or on-site preventive control measures. The reduction in pathogen concentrations from wastewater treatment plants using different treatment options is presented with estimates of log reductions in exposure to pathogens from on-site preventive control measures post treatment. Analyses of unpublished data from Australian recycling schemes indicate that chemical elements and organic compounds generally comply with drinking water requirements, but there is very limited data from on-site systems which indicates concentrations may be highly variable. Health risks in smaller systems are considered to be low due to the lower exposure to recycled water. While the risk from emerging organic chemicals is considered to be low for pharmaceuticals, more information is required on endocrine disruptors.

This guideline gives information on protection of beneficial values including those associated with recreational uses, agriculture and irrigation, aquaculture, fisheries and aquatic ecosystems. Information on health risks to livestock from reuse is also provided.

A.8 Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2). Augmentation of Drinking Water Supplies. (NRMMC et al 2008)

These guidelines extend the guidance in phase 1 on the planned use of recycled water (treated sewage and stormwater) to augment drinking water supplies. They focus on the source of the water, initial treatment processes and blending of recycled water with drinking water sources.

There are no established standards for indirect augmentation. Requirements for detention times in rivers, reservoirs or groundwater and dilution rates vary across the states. The guidelines align with other international approaches: indirect use of recycled water to augment drinking water supplies is the favoured approach, far outweighing the direct use of recycled water. The importance of intervention time in assuring safety is emphasised. The essential requirement is that the minimum detention times in receiving waters, taking account of worst-case circumstances, must always exceed the time required to:

- *detect faults* through operational monitoring of control measures and testing of treated recycled waters
- *complete corrective actions* (where required) before addition to drinking water supplies and subsequent supply to consumers.

The minimum detention times should include substantial safety margins, to take into account any and all possible delays in completing monitoring, communicating results and responding to results, where necessary.

Indirect augmentation schemes should be designed so that the time in receiving waters is sufficient to enable operators and regulators to assess recycled water treatment and recycled water quality and, where necessary, to intervene before water is supplied to consumers.

These guidelines include discussion of organic chemicals such as personal care products and compounds, and emerging organic chemicals such as pharmaceuticals and endocrine disrupters, which reflect a heightened concern when recycled water is used to augment drinking water supplies. In drinking water augmentation the level of exposure of end users is much higher than other uses of recycled water eg in Phase 1 the maximum exposure is less than one litre per person per year, but the guidelines for drinking water quality (NHMRC-NRMMC 2011) are based on the consumption of two litres per person per day.

Monitoring requirements are discussed in detail in Chapter 5 of the Phase 1 of the water recycling guidelines (NRMMC et al 2006) and in Sections 4.4, 4.5 and 4.9 of these guidelines. Chapter 5 of the guidelines outlines four different types of monitoring including baseline monitoring, validation, operational and verification monitoring (where baseline monitoring is undertaken before establishing a recycled water system and validation, operational and verification monitoring are undertaken in establishing and running a recycled water system.

A.9 Australian Guidelines for Water Recycling: Managing Health and Environmental Risks. Managed Aquifer Recharge (Phase 2) (NRMMC 2009)

These guidelines build on the National Water Quality Management strategy and the risk assessment framework for management of water quality in Australian Guidelines for Water Recycling: Managing Health and Environmental Risks Phase 1 **(**NRMMC et al 2006*).* Their aim is to support those wanting to assess and manage health and environmental risks associated with managed aquifer recharge, they can also be used to assess risks associated with existing unintentional or unmanaged recharge and for recharge of water not considered to have been recycled. They focus on the protection of aquifers and the quality of the recovered water in managed aquifer recharge projects using all water sources including recycled waters.

A.10 World Health Organization guidelines. Potable Reuse Guidance for Producing Safe Drinking Water (WHO 2017)

These guidelines describe how to apply appropriate management systems to the production of safe drinking-water from municipal wastewater. They consider direct and indirect potable re-use. There is reference to the WHO drinking water guidelines, for example,

- microbiological and chemical monitoring programmes
- chemical contaminants in drinking wate.

No new guideline values are proposed for potable reuse. It is proposed that numerical water quality targets for chemical parameters should be the same as those adopted for other drinking water supplies.

These guidelines have a similar approach to the WHO drinking water guidelines in providing information on water quality, effective management and performance of potable re-use schemes. A multi barrier approach is encouraged.

A.11 Regulation EU 2020/741 of the European Parliament and of the Council of 25 May 2020 on Minimum Requirements for Water Reuse (EU 2020)

The purpose of the regulation is to facilitate the uptake of water re-use whenever it is appropriate and cost-efficient and to create an enabling framework for Member states that wish or need to practice water reuse for agricultural irrigation. This regulation sets minimum requirements for water quality and monitoring and requirements for risk management systems for the safe use of reclaimed water in the context of integrated water management.

It is also to ensure the safety of reclaimed water for agricultural irrigation. and a high level of protection of human and animal health and the environment.

The directive discusses that risk management should incorporate the concept of producing reclaimed water of a specific quality for a particular use. Risk assessment and water reuse management plans should identify any additional water quality requirements necessary to ensure reclaimed water is safely used and managed and that there is sufficient protection of the environment and of human and animal health. WHO (2006) and ISO guidelines ISO 2046 (ISO 2018a) and ISO 16075 (ISO 2020a, b, ISO 2021a, b) are referred to for different reuses. It can be applied to other irrigation eg urban, in which case, risk from exposure to aerosols needs to be considered.

A.12 USEPA Guidelines for Water Reuse 2012 (US EPA 2012)

The prime purpose is to develop water reuse in the US and to provide an authoritative reference on reuse practice. It provides detailed information on planning, management and operation of water reuse schemes. Activities includes surface water augmentation, managed aquifer recharge and alternative water sources, including greywater. Reuse practices are presented using national and international examples.

It provides an overview of the regulations in the different states and the different types of reuse for:

- agricultural
- urban
- impoundment
- environmental reuse
- industry eg cooling towers
- groundwater recharge
- indirect potable reuse (no direct potable reuses occurred in 2012).

It presents an overview of reuse by region. Arizona, California, Florida Hawaii Nevada New Jersey North Carolina, Texas Virginia and Washington have a long experience of water reuse. California first introduced guidelines in 1918. California, Texas, Florida and Arizona account for 90% of reused water in the US and have state guidelines. Other states have implemented guidelines for a range of reuses, most commonly agricultural irrigation. Table 4-4, (US EPA 2012) suggests water quality criteria for different reuses, with frequency of monitoring and preventive controls for the uses listed above. Log removal credits are used where drinking water guidelines apply. The guidelines provide an overview on advances in wastewater treatment technology that protect public and environmental health. The risk management approach is used for assessing and managing the microbial risk to health. Log removal of micro-organisms at different stages of wastewater treatment are presented and a QMRA methodology is referenced. A critical control points analysis is undertaken to inform monitoring.

The US EPA guidelines have been developed with US AID and contain guidance for aid projects. International case studies are used to consider water re-use practices. The guidelines consider resource-endowed countries that tend to have established human health risk guidelines or standards and practices that extend beyond protecting human health to providing environmental protection and restoration. Resource-constrained countries may adopt an approach to protecting human health based on the WHO’s recommendations (WHO 2006) of a fit-for-purpose, gradational process to reduce health risk.

The guidelines recognise that conventional wastewater treatment may not be feasible in resource-constrained settings, and alternative measures to reduce the disease burden of wastewater use are discussed eg on and off farm health protection measures and the associated pathogen reductions are given.

A.13 FAO Wastewater Quality Guidelines for Agricultural Use (FAO, 1992)

FAO guidelines cover agricultural irrigation, aquaculture, application of sewage sludge in arid and semi-arid countries. Target pathogens are *Salmonella*, enterovirus (poliovirus and meningitis), rotavirus (greatest impact on health of children under 5 years of age with immunity at older ages) and intestinal nematodes (penetrates skin eg feet). As an older guideline the approach is based on criteria given in WHO 1989 guidelines with specified treatment systems. There is a chapter providing detailed information on wastewater treatment systems. Waste stabilisation ponds are recommended for LMIC, based on a World Bank report, and maturation ponds with macrophytes. Overland infiltration systems have been used for tertiary treatment of wastewater and are also described for primary treatment and the 1997 US EPA guidelines are referenced.

The guidelines provide information on agriculture which includes the water requirements of different crops, scheduling of irrigation, irrigation methods, leaching and drainage. Salt from wastewater is a potential hazard and the salt tolerance of different crops is given with information on other potentially toxic chemicals which may adversely affect plant health. Guidance is given on salinity, infiltration, specific ion toxicity (depending on whether it is surface or sprinkler irrigation) and miscellaneous effects. Monitoring of heavy metals in soils and plants is recommended. As well as information to assist with crop selection, site selection is also discussed.

Guidance on human health includes tolerance of crops to sodium, chloride and boron. Two categories are considered for protection of human health from microbial hazards:

- Category one consumers, agricultural workers and the general public who may be exposed to pathogens through consumption of food which is not cooked or spray irrigated lawns and parks.
- Category 2 agricultural workers only.

For agriculture the guideline values for crops consumed raw is a geometric mean of $\leq$1000/100 mL faecal coliforms and a series of stabilisation ponds to achieve faecal coliform guidelines values. For public lawns the guideline value is a geometric mean of <200 faecal coliforms /100 mL. No standard is given for irrigation of crops, pasture and trees, but wastewater is to be treated in stabilisation ponds for 8-10 days.

For aquaculture helminths which can be transmitted to humans through plants or fish are discussed. Water quality for wastewater use in aquaculture was estimated to be $\leq$1,000 faecal coliforms/100 mL, but this is a tentative guideline only.

International case studies of wastewater reuse are presented.

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