

Technical guideline

September 2025

|  |
| --- |
| Guidance for emerging contaminants in recycled water |



Authorised and published by the Victorian Government, 1 Treasury Place, Melbourne

epa.vic.gov.au

Environment Protection Authority Victoria

GPO BOX 4395 Melbourne VIC 3001

1300 372 84

## Disclaimer

EPA guidance does not impose compliance obligations. Guidance is designed to provide information to help duty holders understand their obligations under the *Environment Protection Act 2017* and subordinate instruments, including by providing examples of approaches to compliance. In doing so, guidance may refer to, restate or clarify EPA’s approach to statutory obligations in general terms. It does not constitute legal or other professional advice and should not be relied on as a statement of the law. Because it has broad application, it may contain generalisations that are not applicable to you or your particular circumstances. You should obtain professional advice or contact EPA if you have any specific concern. EPA Victoria has made every reasonable effort to provide current and accurate information, but does not make any guarantees regarding the accuracy, currency or completeness of the information.

Except where noted at [epa.vic.gov.au/copyright](https://www.epa.vic.gov.au/copyright), all content in this work\* is licensed under the Creative Commons Attribution 4.0 Licence. To view a copy of this licence, visit [creativecommons.org](https://creativecommons.org/).

EPA acknowledges Victoria’s First Nations peoples as the Traditional Owners of the land and water on which we live and work. We pay our respect to their Elders past and present.

****

Contents

[Disclaimer 2](#_Toc209690923)

[About this guidance 5](#_Toc209690924)

[1. Introduction 6](#_Toc209690925)

[2. Navigating recycled water guidance 6](#_Toc209690926)

[3. Background 8](#_Toc209690927)

[3.1. Overview of recycled water schemes in Victoria 8](#_Toc209690928)

[3.2. Environmental values for recycled water use 10](#_Toc209690929)

[3.3. Background: emerging contaminants in recycled water 11](#_Toc209690930)

[4. Overview of the risk framework 15](#_Toc209690931)

[5. Problem formulation 17](#_Toc209690932)

[5.1. Key considerations to scope risk assessment 17](#_Toc209690933)

[5.2. Identify the potential emerging contaminants present 18](#_Toc209690934)

[5.3. Understanding relevant pathways and receptors 20](#_Toc209690935)

[6. Risk analysis for surface water discharges 22](#_Toc209690936)

[7. Risk analysis for irrigation and stock water 24](#_Toc209690937)

[9. Drought relief 26](#_Toc209690938)

[10. Risk characterisation 27](#_Toc209690939)

[11. Environmental monitoring and quantitative data 27](#_Toc209690940)

[12. Risk management 31](#_Toc209690941)

[12.1. Operational controls and best practice 31](#_Toc209690942)

[12.2. Risk mitigation controls 32](#_Toc209690943)

[12.3. Using environmental monitoring to inform continuous improvement 33](#_Toc209690944)

[Appendix A: Case studies 34](#_Toc209690945)

[Case study 1 34](#_Toc209690946)

[Case study 2 36](#_Toc209690947)

[Case study 3 38](#_Toc209690948)

[Case study 4 40](#_Toc209690949)

[Case study 5. 41](#_Toc209690950)

[Case study 6 43](#_Toc209690951)

[Appendix B: Glossary of key terms and abbreviations 45](#_Toc209690953)

[References 49](#_Toc209690954)

About this guidance

The purpose of this guidance is to assist recycled water scheme proponents and users to characterise, assess and manage risks associated with emerging contaminants as it relates to potential impacts from recycled water use.

It is designed for:

* producers of recycled water (e.g. water corporations, industrial facilities, sewer miners)
* recycled water scheme proponents or managers (e.g. water corporations, facilities, sewer miners)
* users of recycled water (e.g. agriculture, industrial facilities, residential, commercial premises, fire authorities, local governments)
* environmental consultants and environmental auditors.

While our knowledge of emerging contaminants in recycled water is evolving, this guidance will help to:

* characterise and assess risks of emerging contaminants in recycled water, providing key principles that can be applied to a wide range of uses
* apply control measures for managing emerging contaminants, with case studies to step you through the risk framework
* meet your General Environmental Duty (GED) requirements related to emerging contaminants.

This guidance applies the risk management framework used in the Australian Guidelines for Water Recycling to the Victorian context.

This is a technical guideline, and part of a suite of guidance on the safe use of recycled water. To help you understand key terms, refer to the glossary and list of abbreviations at **Appendix B**.

1. Introduction

The Victorian Government encourages safe and sustainable recycled water use for non-potable purposes. Recycled water involves treating sewage or industrial wastewater, which may contain microbial and chemical hazards, to a suitable quality. It can then be used safely for agricultural irrigation and watering parks and gardens, or in other ways that provide economic or social benefit (direct or indirect).

This reduces the volume of water we harvest from stressed and over-allocated water sources including watercourses, groundwater and reticulated drinking water.

1. Navigating recycled water guidance

Specifically, this guidance provides detailed technical information on ecological considerations related to emerging contaminants. It is part of a suite of guidance supporting the safe use of recycled water in Victoria, for suppliers, managers and users of treated wastewater (Figure 1).

Together, these provide important context, background, the latest evidence and regulatory requirements relating to recycled water. For ease of reference, the Table 1 below explains important guidance to read in conjunction with this document.

A diagram of water recycling

AI-generated content may be incorrect.

#### *Figure 1. Relationship between recycled water guidance. The figure outlines how this guideline relates to existing recycled water guidance, in particular guidance on irrigation, recycled water use in surface water and the parent guidance on water recycling (1919.2 and 1911.2).*

#### *Table 1. Complementary material to read in conjunction with this guidance*

| Guideline | Purpose |
| --- | --- |
| [Victorian guideline for water recycling](https://www.epa.vic.gov.au/victorian-guidance-water-recycling) (Publication 1910.2) | To provide clear guidelines for the safe and sustainable use of recycled water in Victoria for suppliers, managers and users of treated wastewater. This guideline outlines regulatory processes and requirements for water recycling. |
| [Technical information for the Victorian guideline for water recycling](https://www.epa.vic.gov.au/19112-technical-information-victorian-guideline-water-recycling) (Publication 1911.2) | To provide best-practice technical approaches and methods that can be used to comply with Victorian Guideline for Water Recycling. For example, it provides information on how to complete health and environment management plans (HEMPs), how to classify risk, suggestions on how to approach community consultation and useful checklists. |
| [Victorian guideline for irrigation with recycled water](https://www.epa.vic.gov.au/victorian-guideline-irrigation-recycled-water-168) (Publication 168.3) | To support the design and management of recycled water irrigation schemes. It aims to help designers and operators understand their responsibilities under Victoria’s Environment Protection Act 2017 and GED. |
| [Recycled water use in surface waters guideline](https://www.epa.vic.gov.au/recycled-water-use-surface-waters-guideline) (Publication 3005) | To outline the permission required and the information needed to provide to EPA when seeking approval to use recycled water in surface waters. The guideline applies to permission applicants who conduct an A03 Sewage Treatment activity. This can include water corporations or other facilities that treat sewage and produce and use recycled water. |
| [Guidance for risk assessment of wastewater discharges to surface waters](https://www.epa.vic.gov.au/guidance-risk-assessment-wastewater-discharges-surface-waters) (Publication 1287) | To provide a step-by-step guide to assess the environmental and human health risks associated with point-source wastewater discharges to surface waters. It has been developed to help those responsible for prescribed permission activities. |
| [Guide to the Environment Reference Standard](https://www.epa.vic.gov.au/1992-guide-environment-reference-standard) (ERS) (Publication 1992) | To provide information about how the Environment Reference Standard (ERS) should be applied to support decision making, and how the environmental values, indicators and objectives for each element of the environment should be interpreted. |
| [Emerging contaminants in recycled water](https://www.epa.vic.gov.au/emerging-contaminants-recycled-water) (Publication 2054) | To identify the prevalence and frequency of emerging and legacy contaminants in recycled water in Victoria. The publication provides:   * a list of emerging contaminants for monitoring * information about how to establish baseline data for emerging contaminants present in wastewater * more detail on monitoring programs for recycled water schemes. |
| [Reasonably practicable](https://www.epa.vic.gov.au/1856-reasonably-practicable) (Publication 1856) | To understand how you can comply with the GED by eliminating risks when ‘reasonably practicable’. The GED requires all Victorians (including producers, suppliers and users of recycled water) to:   * understand how their activities put our environment or community at risk * take reasonable steps to reduce those risks. |
| Assessing and controlling risk: A guide for business (Publication 1695.1) | To understand risk management framework suitable for your business. Its principles can be applied to businesses of any size, and of varying levels of risk, but larger businesses or those that pose a high level of risk to the environment and public health may need to adopt more complex methods. |

1. Background
   1. Overview of recycled water schemes in Victoria

A diagram of a water treatment system

Description automatically generatedRecycled water is the result of treatment of wastewater from sewage or industrial processes, which may contain microbial and chemical hazards, to a quality suitable for its intended use (Figure 2).

*Figure 2. Overview of recycled water system outlining wastewater sources, treatment systems, storages and distribution systems, intended use scenarios for residential, municipal, agricultural, fire and industrial water uses, unintended releases and potential for human and environmental exposures*

Chemicals found in wastewater, because of their everyday use in consumer products, include cleaning products, cosmetics, personal care and medicines. Industrial, commercial and retail facilities can discharge a wide range of chemicals, such as byproducts of manufacturing processes, food preparation, hospital and veterinary wastes.

Source control of chemicals may be a practical option in certain circumstances. For example, through trade waste agreements, industry can facilitate a reduction of hazardous chemicals discharged to the wastewater system. However, for household chemicals, source control requires a combination of regulation at the national level (e.g. removing certain chemicals from the list of chemicals permitted for use in Australia) and citizens taking action to reduce the use of certain products in their homes. As a result of these activities, many contaminants are present in sewage/wastewater before it reaches a wastewater treatment plant (WWTP).

Before treated wastewater can be classed as recycled water, it must be of appropriate quality as specified in EPA guidelines (EPA Publications 1910.2, 1911.2, 168.3, 3005). These publications address the microbiological quality of the water, as well as water quality parameters such as pH, suspended solids and biological oxygen demand.

The level of treatment at a WWTP will determine its **classification** and potential end uses. For example:

* **Class A:** irrigation, agricultural food production, domestic garden watering, toilets
* **Class B:** pasture irrigation, industrial uses (e.g. washdown water)
* **Class C:** urban non-potable with controlled public access, pasture irrigation, industrial processes with no worker exposure.

Overall, recycled water suppliers should consider appropriate end-users for the treated wastewater. Environmental and human health risks posed by recycled water schemes will vary and will depend upon the end-use.

Further information about the recycled water supply system can be found in EPA Publication 1911.2, including key documentation, roles and responsibilities. For example, key documentation includes information on the contents of a **Health and Environment Management Plan** (HEMP), which must be prepared in accordance with EPA guidelines before recycled water use can be approved by EPA. The HEMP provides the overall risk assessment and the related communication, management, auditing and reporting required for the recycled water scheme.

Components of the HEMP include:

• Human health:

* Health Management Plan (HMP) and
* Recycled Water Quality Management Plan (RWQMP) for class A recycled water use

• Environment and agricultural:

* Environmental Management Plan (EMP) and
* Land Capability Assessment (LCA).

The HEMP must be approved by EPA, with the appropriate endorsement from the Chief Veterinary Officer where relevant. To assist in managing risks to the environment, agreements are developed between the supplier and recycled water users. For irrigation end uses, this may include a user site management plan.

* 1. Environmental values for recycled water use

Recycled water use schemes must consider the environment protection indicators and objectives set out in the ERS, with the relevant environmental values varying depending on the specific use and receiving environment. The ERS is used to assess risk but is not intended to represent design criteria (see EPA Publication 1992 for further information).

The relevant environmental values may include:

* water dependent ecosystems and species
* human consumption after appropriate treatment
* agriculture and irrigation
* human consumption of aquatic foods
* aquaculture
* industrial and commercial use
* water-based recreation (primary, secondary contact and aesthetic enjoyment)
* Traditional Owner cultural values
* navigation and shipping.

Table 2 provides a summary of the key uses of recycled water to assist water managers and identifies environmental components and environmental receptors relevant to each recycled water scheme.

*Table 2. A summary of key uses of recycled water to assist water managers in identifying relevant environmental components and receptors as per recycled water class scheme*.

| Use | Class A | Class B | Class C | Environmental Components | Human health and ecological receptors |
| --- | --- | --- | --- | --- | --- |
| Irrigation – horticulture (landscape, gardens, turf) | Y | Y | Y | Land  Surface water  Groundwater | Human health (irrigation spray)  Plant/crop health  Terrestrial ecosystems  Surface water biota  Groundwater ecosystems |
| Irrigation – raw food | Y | N | N | Land  Surface water  Groundwater | Human health (food consumption, irrigation spray)  Plant/crop health  Terrestrial ecosystems  Surface water biota  Groundwater ecosystems |
| Irrigation –pasture for cattle | Y | Y | Y | Land  Surface water  Groundwater | Human health (food consumption)  Plant/crop health  Terrestrial ecosystems  Surface water biota  Groundwater ecosystems  Livestock (animal health) |
| Stock water (drinking water for livestock) | Y | Y | N | Surface water  Groundwater | Livestock (animal health)  Human health (food consumption) |
| Residential and commercial non-potable open systems – car washing, clothes washing | Y | N | N | Land  Surface water  Groundwater | Human health (direct contact)  Surface water biota  Groundwater ecosystems  Terrestrial ecosystems  Plant/crop health |
| Industrial wash-down water | Y | Y | N | Land  Surface water  Groundwater | Human health (direct contact)  Surface water biota  Groundwater ecosystems  Terrestrial ecosystems |
| Environmental flow/discharge to waterways | Y | Y | Y | Surface water  Sediment | Human health (recreational use, fishing for consumption)  Surface water biota  Terrestrial ecosystems  Groundwater ecosystems |

* 1. Background: emerging contaminants in recycled water

Emerging contaminants are chemicals that have:

* been newly introduced to the environment
* been newly detected in the environment due to improved analytical methods
* become important due to new science demonstrating their effects on human health and the environment.

Chemicals are found in wastewater, because of their everyday use in consumer products. This includes chemicals in cleaning products, cosmetics, personal care and medicines. Industrial, commercial and retail facilities can also discharge a wide range of chemicals, such as byproducts of manufacturing processes, food preparation, hospital and veterinary wastes.

Some of these chemicals persist after wastewater treatment and are found in recycled water. Examples of emerging contaminants detected in recycled water include pharmaceuticals and personal care products (PPCPs), endocrine disrupting chemicals (EDCs), plastic additives like phthalates, pesticides including herbicides and fungicides, per- and polyfluoroalkyl substances (PFAS), other surfactants including phenols disinfection byproducts and artificial sweeteners (Shi et al. 2022; Verlicchi et al. 2023, EPA publication 2054, Saaristo et al. 2024).

Worldwide, studies have shown differences in the concentration and frequency of emerging contaminants detected in wastewater influent. Factors that influence these differences include land use types, demographics (population and substance use patterns) as well as treatment processes.

Key characteristics to consider when assessing emerging contaminants include:

* **Persistence** – resistance to degradation, allowing them to remain in the environment for extended periods
* **Bioaccumulation** – the tendency to build up in organisms over time, potentially affecting food chains
* **Toxicity** – harmful effects on ecosystems and/or human health
* **Mobility** - ability to travel long distances via surface water, erosion, groundwater or air.

The presence of emerging contaminants in recycled water, or in the environment more generally, does not mean that there are risks to environment and human health. For example, a chemical being present in the environment (e.g. in water) does not necessarily mean it is biologically active or present at concentrations high enough to pose a threat to human health or the environment.

However, it is important to improve understanding of the potential for risk. Several studies suggest that for specific classes of contaminants such as PPCPs, low concentrations can exhibit subtle or sublethal effects on non-target organisms (Bertram et al. 2024). In addition, there is an increasing awareness among water industry professionals of the issue of antimicrobial resistance (AMR) genes. There is currently little data on the removal of AMR genes through the wastewater treatment system or on their fate in the receiving environment.

Analytical methods are actively being developed and improved; therefore, the list of emerging contaminants will continue to grow. The science on ecotoxicity to emerging contaminants is rapidly evolving. As research progresses, our understanding of their toxicity, environmental pathways and behaviour will continue to grow.

The issue of emerging contaminants has been recognised by EPA Victoria for some time (Sardina et al. 2019; EPA Publication 1911; EPA Publication 2054). However, addressing and managing risks for emerging contaminants is complex.

EPA Victoria and the Department of Energy, Environment and Climate Action (DEECA), in collaboration with the water industry, have adopted a tiered approach to understanding and managing emerging contaminants in recycled water in Victoria.

* Tier 1: In early 2020, the VicWater desktop risk assessment of over 100 WWTPs was completed and prioritised parameters for monitoring. It relied on modelling the fate of chemicals through the treatment processes trains, using Australian and international data.
* Tier 2: In March 2021, the Department of Environment, Land, Water and Planning (DELWP) funded EPA to sample emerging contaminants in influent/effluent waters of 31 WWTPs across Victoria (EPA Victoria 2023b). This data set, reported in EPA Publication 2054, was used to update and improve the 2020 risk assessment.
* Tier 3: In June 2022, DEECA funded EPA to develop guidance on emerging contaminants in recycled water. This technical guideline is part of this package of work.

As part of Tier 3, EPA Victoria undertook an investigation into uptake of emerging contaminants into edible crops irrigated with recycled water. The study (Recycled water use in irrigated crops 2023-2025) found:

* recycled water consistently contained a greater number and concentration of emerging contaminants compared to reference water
* there was limited evidence of emerging contaminants transferring into edible plant tissues
* there was no observable impact of recycled water use on crop health. Differences in plant pigments and biomass appeared to be linked to crop maturity, not to irrigation sources
* at reference farms that did not use recycled water for irrigation, there were some pesticides in the edible parts of the plants, suggesting there were on-farm sources (e.g. direct pesticide application)
* Irrigation water at the reference broccoli farm contained PPCPs, indicating that external sources like river water may be contributing emerging contaminants to the site
* concentrations of PFAS found in edible crops do not present an adverse risk to human health
* that recycled water is suitable for crop irrigation, provided its quality is regularly monitored and its use managed appropriately.

*What we know about the efficacy of existing treatment technologies*

The efficacy of removal of emerging contaminants during wastewater treatment is influenced by internal and external factors.

Internal factors are contaminant-based, such as the specific physicochemical properties of the chemicals (e.g., hydrophobicity, biodegradability or volatility). For emerging contaminants, the complex molecular structure, low biodegradability and low concentrations are the main limiting factors for removal by conventional approaches (Yap et al. 2019).

External factors are based on treatment conditions, such as hydraulic retention time and loading rate, and on environmental conditions, such as sunlight, temperature and pH (Yap et al. 2019). Variations in pH can influence microbial enzyme activities and the solubility of compounds, whereas temperature can affect biodegradation and partitioning of chemicals, thus affecting removal of these contaminants (Luo et al. 2014).

In WWTPs, emerging contaminant removal efficiency varies from low to high during the primary, secondary, and tertiary treatment steps, respectively (Rout et al. 2021). Common processes used in treatment trains in Victorian WWTPs are summarised in Table 3.

Table 3. Summary of some treatment train processes commonly used in Victoria

|  |  |
| --- | --- |
| Treatment process | Processes that result in removal of contamination |
| Activated sludge process (ASP) – Normal aeration | * Biodegradation in primary, aerated and settling tanks or ponds * Volatilization * Partitioning to solids |
| ASP – Extended aeration | * As above for ASP, but with extended hydraulic retention time (HRT) in the aeration tank, which permits more time for removal of certain contaminants with lower biodegradation rates |
| ASP – Intermittently Decanted Extended aeration (IDEA) | * As above for ASP with 3 phases, aeration, settling and decanting in a single tank and operating in cycles for enhanced removal of contaminants like nitrogen and phosphorus, due to the controlled phases. |
| Lagoon | * Biodegradation * Oxidation via photolysis (by UV light absorption) |
| Aerated lagoon | * As above for Lagoon, but with higher contaminant removal rate via biodegradation |
| Oxidation: chlorination | * Oxidation via chlorination (note that other oxidation removal processes such as UV treatment, photocatalysis or ozonation are also used) |
| Membrane filtration | * Filtration via membrane separation of particles; classified as microfiltration, ultrafiltration, nanofiltration or reverse osmosis (RO) |

The first step in any treatment train includes conventional primary treatment processes such as coagulation, flocculation and sedimentation. These are typically applied for removal of suspended solids but are generally not effective (<10%) in the removal of emerging contaminants from water (Rout et al. 2021; Shahid et al. 2021). The main treatment process involved in primary treatment for removal of emerging contaminants is adsorption onto the suspended solids, of which removal efficiencies are also comparatively low and of high variability. For example, removal efficiencies of several common PPCPs during primary treatment were found to range from 10-50% (reviewed in Luo et al. 2014; Tiwari et al. 2017).

The secondary treatment stage aims to remove organics or nutrients, primarily through biological degradation, and of which the activated sludge process (ASP) is the conventional treatment technology. During the secondary treatment stage, the predominant removal mechanisms of emerging contaminants are via biotransformation or biodegradation, and sorption (Rout et al. 2021). The activated sludge process has been previously shown to remove some emerging contaminants during the secondary treatment stage. For example, removal efficiencies of between 30-70% have been reported (Tiwari et al. 2017; reviewed in Ahmed et al. 2017).

Tertiary treatment technologies are considered the most suitable alternatives for emerging contaminant treatment, although complete removal is yet to be achieved. Conventional tertiary treatment technologies typically involve oxidation processes, such as chlorination or ozonation, or adsorption via a wide range of available absorbents (Ahmed et al, 2017; Rout et al. 2021; Radwan et al. 2023). Tertiary treatment has shown high removal efficiencies for emerging contaminants, at above 90% for some groups (reviewed in Ahmed et al. 2017; Rout et al. 2021). Recent advancements in physical treatment processes using membrane-based filtration have also shown to be highly effective in removal of emerging contaminants (Ahmed et al. 2022; Radwan et al. 2023).

*Percent reduction (contaminant concentration)*

Percent reduction is a key concept to the treatment train risk score that is introduced in Table 5.

Percent reduction is an estimation of the change in concentration for individual emerging contaminants during the treatment process. It is calculated to understand how different emerging contaminants behave in each treatment train.

The percent reduction calculation follows the method described in Luo et al. (2014). Specifically, the mean effluent concentration (2-3 grab samples or a 24-hour composite sample) and a single 24-hour composite influent sample is used to estimate percent reduction (%R) for each compound passing through the treatment train process.

The formula is, as follows:

**Percent reduction (%R) = 100 × (C𝑖𝑛𝑓−C𝑒𝑓𝑓/C𝑖𝑛𝑓)**

where a positive reduction (%R) indicates a decrease, and a negative percent reduction (%R) indicates a potential increase.

Cinf = 24 hr autosampler influent concentration (composite sample)

Ceff = mean effluent concentration based on 2-3 grab effluent samples or a 24-hour composite effluent sample

See EPA Publication 2054 Appendix A for further details about data handling for the percent reduction calculations.

The potential reduction pathways from the treatment plants include physical and chemical degradation, transformation, biodegradation (through anaerobic and aerobic bacteria), photolysis, and adsorption to solids and settlement. As such, mixing pond detention time, the volume of influent, and the scale of each treatment process play a role in reduction of contaminants.

It is acknowledged that the estimation of percent reduction does not incorporate a mass balance approach, which would consider:

* both influent load versus effluent load with sorption and settling of sludge (e.g. Jelic et al. 2011; Gallen et al. 2018)
* metabolites or transformation of precursors (e.g. Eriksson et al. 2017; Lu et al 2020; Lenka et al. 2021)
* changes in volume through evaporative loss, transpiration
* diversion to recycled water over different seasons (e.g. Matamoros and Salvadó, 2012).

Overall, the percent reduction should be taken as an estimate, rather than an absolute measurement.

1. Overview of the risk framework

Given the limited knowledge and evolving science around the environmental and human health impacts of emerging contaminants, this guidance does not rely on detailed quantitative risk assessments for specific substances. Instead, it focuses on evaluating risks associated with treatment trains based on input variables, removal efficiency (%R) and output variables.

To ensure all potential factors can be clearly identified and appropriately characterised, there are four phases to this environmental risk framework:

1. Problem formulation
2. Risk analysis
3. Risk characterisation
4. Risk management



Figure 3. Risk assessment framework outlining key stages of problem formulation, risk analysis, risk characterisation and risk management, supported at every stage by communication, consultation and ongoing monitoring and review

While these phases are shown in a linear fashion above (Figure 3), environmental risk frameworks are often interactive and iterative processes. For example, as more is learnt about the potential risks, you may need to re-evaluate your previous assumptions and problem formulation, collect new data or conduct more analysis.

The key for an effective risk framework is risk management, including implementation of effective site controls, designing a monitoring program to provide early warning of changes in wastewater quality and to measure the effectiveness of site controls in minimising impacts to the surrounding environment.

1. Problem formulation

The problem formulation stage determines the focus and scope of the environmental risk framework, to enable prioritisation and development of appropriate risk management programs.

* 1. Key considerations to scope risk assessment

To define the scope of your assessment, it is important to develop a relevant conceptual source-pathway-receptor model for your intended uses of the recycled water (Figure 4). This will enable you to develop a risk profile that informs risk management controls.

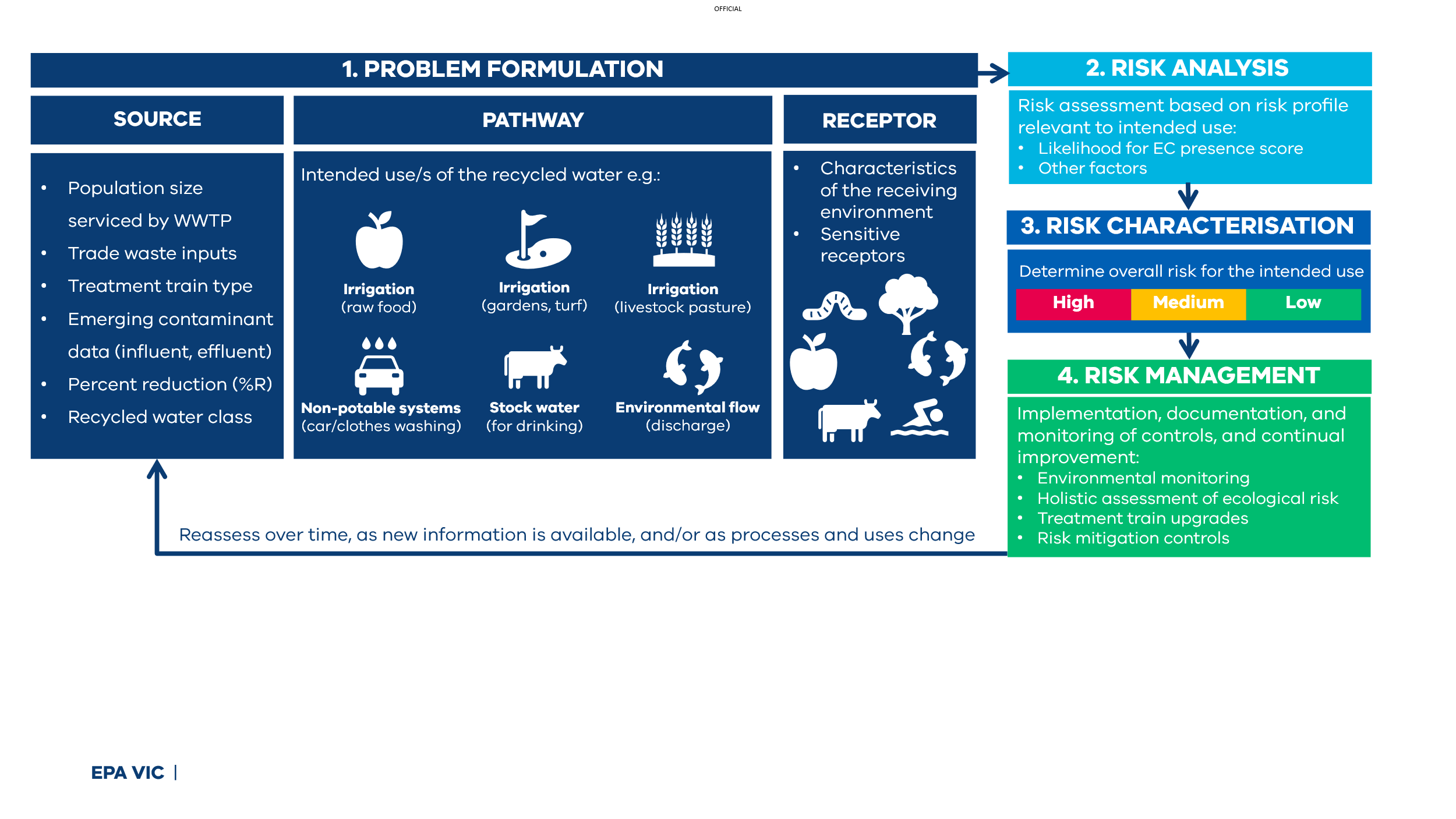


Figure 4. Conceptual site model (CSM) of the risk framework for emerging contaminants in recycled water

* Source assessment enables identification of contaminants of interest that may be released to the environment and include:
  + characterisation of source water including:
    - existing baseline data (if any) or literature data on emerging contaminants associated with wastewater (influent/effluent) (see EPA Publication 2054)
    - population size the WWTP is servicing
    - trade waste and industrial wastewater inputs
    - treatment train in place at the WWTP
    - capability of the various treatment units to reduce/remove emerging contaminants
    - limitations of conventional treatment processes
* Pathways assessment enables consideration of potential routes of exposure from intended uses:
  + class of treated water determines relevant pathways such as:
    - residential uses
    - municipal (irrigation, dust suppression)
    - agricultural (irrigation, stock water)
    - fire control and industrial
  + the intended use will also determine the need for helminth treatment
* Receptor assessment enables identification of key relevant receptors and local factors that might influence risk level with the associated use:
  + receptor type:
    - human exposure (direct contact e.g. recreational water, and indirect e.g. consumption of food, non-consumption domestic uses e.g. washing)
    - environmental exposures (biota, plants, soils, surface water, groundwater)
  + characteristics of the receiving environment:
    - environments with high conservation or ecological value
    - natural indigenous or historic places of particular significance to Traditional Owners
    - catchments with heavy recreational water use, special water supply catchments, areas with significant use for stock water
    - groundwater-dependent ecosystems (e.g. wetlands, riparian vegetation, baseflow-dependent streams)
* Risk management and mitigation controls in place:
  + Operational controls and monitoring to ensure effectiveness
  + Risk mitigation measures to reduce impact to the environment

These assessment steps, including recycled water characterisation (based on source influent and treatment train in place), exposure pathways, and receptor sensitivity will help refine the scope of the recycled water risk assessment to reflect the needs of the intended use and the sensitivity of the local receiving environment.

This enables clear articulation of appropriate risk management goals, treatment performance, operational controls, and roles and responsibilities, which should be captured in the HEMP, RWQMP and any applicable site-specific management plans, supporting effective prioritisation and management of emerging contaminants.

* 1. Identify the potential emerging contaminants present

There are several factors that may influence presence of emerging contaminants in influent and effluent waters, and ultimately in recycled water, including:

* proportion of trade waste:
  + high contribution (>10%)
  + low contribution (<10%)
* population size (sewage treatment):
  + large (>25,000 people)
  + medium (5,000 – 25,000 people)
  + small (<5,000 people)
* treatment train in place at the WWTP

While more emerging contaminants are being identified or developed every year, see Table 4 for some examples of groups of chemicals present in wastewater and recycled water.

Table 4. Examples of chemical groups likely to be present in wastewater and recycled water

| Grouping | Use | Pathway to wastewater | Example chemicals |
| --- | --- | --- | --- |
| Pesticides, including fungicides, herbicides and insecticides | Used to control pests, insects, weeds, moulds and fungi. | Use in industry and commercial premises and around the home and garden to control pests may wash off into the wastewater system. Also, may be used around WWTPs. | Simazine  MCPA  Diuron  Simazine  Atrazine |
| Pharmaceuticals | Chemicals used in medicines to treat symptoms or disease (or from the use of illicit drugs). | People excrete some of what they ingest when they take medication or dispose of excess medicine directly into the wastewater system. | Ibuprofen  Paracetamol  Carbamazepine  Sulfamethoxazole  Venlafaxine |
| Personal care products | Chemicals included in soaps, shampoos, conditioners, moisturisers, sunscreens, cosmetics. | People use these products every day and the chemicals in them can wash off during bathing, showering or washing hands. | Tonalid  Galaxolide  Triclosan  DEET |
| Food additives or ingredients | Chemicals added to foods to enhance flavour, or as a supplement. | Excretion via consumption of food and drink products or via waste from food processing. | Acesulfame K  Caffeine |
| Industrial chemicals | Chemicals that may be present in cleaning products used in homes businesses, or chemicals that are used in manufacturing and formulation of products such as furniture, paints, glues, or surface coatings. | Excretion, wash off or direct discharge into the wastewater system depending on the use pattern for the chemical. | Chlorophenols  PFAS  Triphenyl phosphate  Phenols |
| Endocrine disrupting chemicals | Chemicals that may be present in personal care products, cleaning products, pesticides, fire retardants and medicines or chemicals that are used in manufacturing and formulation of products. Some naturally occurring chemicals also have this characteristic. | Excretion or wash off or direct discharge into the wastewater system depending on the use pattern for the chemical. | Nonylphenol  Bisphenol A  PFAS  Estrone  Androsterone |

*Source: Emerging contaminants in recycled water (Publication 2054, EPA Victoria 2023b).*

### Consideration of treatment train and percent reduction of emerging contaminants in effluent

**Step 1:** If you have data on removal efficiency (%R) of emerging contaminants for your WWTP, you can use it to assign a likelihood of emerging contaminants being present in effluent based on percent reduction, as follows:

* high (percent reduction 0-45%)
* medium (46-70%) or
* low (71-100%).

If you do not have data, you can use default treatment train (TT) percent reduction, outlined below in Table 5. The percent reduction ranges for emerging contaminants per category (high, medium, low likelihood) are based on data from EPA Publication 2054.

Table 5. Likelihood of emerging contaminants (ECs) presence in wastewater based on treatment trains and percent reduction, with further information on recycled water class to inform consideration of potential use scenarios.

| Treatment train category | Class | Percent reduction of emerging contaminants1 | Likelihood of ECs presence score |
| --- | --- | --- | --- |
| TT1: Lagoon | B, C | 0-45% | High |
| TT2: Aerated lagoon, Lagoon | B, C | 0-45% | High |
| TT3: Aerated lagoon, Lagoon, Chlorination | C | 0-45% | High |
| TT4: Activated sludge process (ASP) with extended aeration | B, C | 46-70% | Medium |
| TT5: ASP with extended aeration, Membrane filtration (reverse osmosis) | A | 71-100% | Low |
| TT6: ASP with extended aeration, Lagoon | NA | 46-70% | Medium |
| TT7: ASP | B, C | 46-70% | Medium |
| TT8: ASP, Chlorination | A, B, C | 46-70% | Medium |
| TT9: ASP, Lagoon | B, C | 46-70% | Medium |
| TT10: ASP, Lagoon, Membrane filtration | A | 71-100% | Low |
| TT11: ASP, Lagoon, Chlorination | A | 71-100% | Low |
| TT12: ASP with extended aeration, Membrane filtration (ultrafiltration and reverse osmosis), Chlorination | A | 71-100% | Low |
| TT13: ASP, Lagoon, Membrane filtration (reverse osmosis), Chlorination | A | 71-100% | Low |
| TT14: ASP with extended aeration, Chlorination | A | 71-100% | Low |

*1 Emerging contaminants in recycled water (Publication 2054, EPA Victoria 2023b).*

* 1. Understanding relevant pathways and receptors

Information about the class of recycled water and level of treatment assist in developing a refined source pathway receptor model. For example:

* restricted pathways e.g. drinking, cooking, bathing and showering, domestic swimming pools and children’s water toys are not allowed
* limited use scenarios e.g. only Class A recycled water can be used for livestock drinking water
* pathways with inherent controls to manage exposure to other contaminants, such as pathogens, for example non-potable domestic supply, livestock drinking water or irrigation of pasture.

Once the treatment level (class) identifies general use categories, further consideration may include site specific factors before identifying receiving sites.

Additional factors that influence the presence of emerging contaminants or the exposure in the receiving environment, include:

* dilution in surface waters (see EPA publication 1287):
  + higher risk: low or no dilution (< 1:3 parts)
  + medium risk: medium (<1:5 to >1:3 parts dilution)
  + lower risk: high dilution (>1:5 parts river flow)
  + lowest risk: extreme dilution in marine outfall settings (>1:1000 parts)
* discharge volume (indicator of mass of emerging contaminants):
  + higher risk: low or no dilution (< 1:3 parts)
  + medium risk: medium (<1:5 to >1:3 parts dilution)
  + lower risk: high dilution (>1:5 parts river flow)
  + lowest risk: very high dilution due to marine outfall.

Domestic water uses

For urban domestic and industrial water supply the primary pathways are for non-closed loop systems where recycled water may be discharged to the environment as run-off. See EPA Publication 1911 for further information.

Surface water discharges

See EPA Publication 1287 for further information and technical guidance for assessing risks associated with point-source wastewater discharges to surface waters.

Irrigation scenarios

In deciding to use recycled water for irrigation, there are several factors to consider that influence design of a recycled water scheme, including:

* quality of the recycled water and its acceptable uses
* recycled water volume
* site selection (land capability and suitability of the site)
* land use and crop selection
* risk to the environment
* management experience of the site operator

See EPA Publications 1910, 1911, and 168.3 (Tables 3-1, 3-2 and 3-2) for further detail on considerations for recycled water use for irrigation. This includes suitable uses, indicative risk levels and suitability for recycled water for irrigation purposes for each class of recycled water.

Understanding the land system is crucial for schemes where recycled water is applied directly to the land. A Land Capability Assessment (LCA) characterises environmental pressures and forms the basis for environmental risk assessment, considering all elements of the physical environment, including climate, geology, topography, soils, hydrology, and vegetation. In the context of emerging contaminants, the LCA process is useful for two reasons:

* understanding land characteristics that increase risk of exposure to emerging contaminants
* considering level of management likely to be applied for a particular site under standard operating conditions to enable assessment of whether additional controls may be required for managing emerging contaminants

1. Risk analysis for surface water discharges

Once the risk profile relevant to intended use has been identified, risk assessment can be undertaken using qualitative methods and where feasible, quantitative risk assessment.

Table 6 presents lines of evidence approach for determining a risk score for other factors that may influence the overall risk of emerging contaminants. It is suitable for domestic and industrial water use scenarios, and surface water discharge. Table 9 presents lines of evidence approach for irrigation use scenario.

The weighting outlined below has been developed to enable relative risk consideration, however it is qualitative and suppliers may need to consider additional information of current operations to develop a suitable approach. While the qualitative approach enables an overview of the broader level of risk, understanding the key drivers is essential to determining operational controls and risk management approaches.

Table 6. Risks of emerging contaminants in wastewater based on other factors for surface water discharge

|  |  |  |  |
| --- | --- | --- | --- |
| Factor (line of evidence) | High risk | Medium risk | Low risk |
| **Source factors (likelihood of EC presence in effluent)** | | | |
| **Trade waste** | **15** |  | **5** |
|  | >10% |  | <10% |
| **Population size** (de Haas et al. 2018) | **10** | **5** | **1** |
|  | Large (>25,000) | Medium (5000-25,000) | Small (<5000) |
| **Mean discharged volume** | **15** | **10** | **5** |
| Accounts for loads and effective population size | Large: >5 ML/day | Medium: 1 ML/day to 5 ML/day | Small: <1ML /day |
| **Pathway/exposure factors** | | | |
| **Median dilution rate** | **30** | **20** | **10** |
| Accounts for concentration *(note marine outfall dilution is considered significant)* | Low or no dilution: <=1:3 (less than 1 part effluent to 3 parts river flow) | Medium: <1:5->1:3 | High: >=1:5 (1 part effluent to 10 parts river flow) |
| **Receptors** | | | |
| **Freshwater and marine\* environments (ecological)** | **30** | **20** | **10** |
| Sensitive receptors include:   * sites with ecological value (e.g. threatened species) * aquatic reserves segment in the ERS | Largely unmodified ecosystems - ANZG 99% species protection applies# | Slightly to moderately modified ecosystems - ANZG 95% species applies | Highly modified ecosystems - ANZG 90% species protection applies |
| Special water catchments | **30** | | |
| Catchments that service drinking water | Site specific risk assessment may be necessary | | |
| **Total risk score range for the other factors** | **High risk = 50-100** | **Medium risk =36-49** | **Low risk = 0-35** |

#For bioaccumulative contaminants, use 99% species protection level in slightly to moderately disturbed ecosystems.

\*For indicators and objectives for open coasts, see tables 5.12-5.17 in Environmental reference standard, 2022 (<https://www.epa.vic.gov.au/environment-reference-standard>)

Use Table 7 to calculate your overall risk score by combining your risk scores from Steps 1 (percent reduction) and 2 (other factors).

Table 7. Overall risk score (Step 3) for emerging contaminants in wastewater

|  |  |  |  |
| --- | --- | --- | --- |
| Step 1: Percent reduction | Step 2: Other factors | | |
| High | Medium | Low |
| High | High | High | Medium |
| Medium | High | Medium | Low |
| Low | Medium | Low | Low |

As shown in Table 7, the other factors risk score affects the Step 1 (percent reduction), as follows:

• Low risk score – downgrades percent reduction score to one level

• High – upgrades percent reduction score to one level

• Medium – no change to percent reduction score

The same logic applies to adjusted overall risk scores. Further examples are presented as case studies in **Appendix A**.

Table 8 illustrates how site-specific baseline data on the removal efficiency (%R) of emerging contaminants can be used to adjust the overall risk score. In this example, rather than relying solely on the default percent reduction score from the treatment train in Table 5, information based on the collected baseline data is added, which enables calculating the site-specific percent reduction of emerging contaminants in effluent.

In the example provided, the initial default treatment train score (Step 1) indicated a high risk. However, when additional contextual factors were considered (Step 2), the overall risk was downgraded to medium. Following baseline monitoring at the site, which confirmed a removal efficiency greater than 70%, the risk score was further adjusted to low – reflecting the improved performance of the treatment process.

If there is no site-specific baseline monitoring data available, the overall risk assessment finishes at Step 3. It cannot be completed using data from other sources or sites.

Table 8. Example of adjusted overall risk score based on site-specific baseline data

|  |  |  |
| --- | --- | --- |
| Step | Description | Risk |
| 1 | Risk score based on percent reduction (Table 5: TT1, Lagoon) | High |
| 2 | Risk score based on other factors | Low |
| 3 | Overall risk score | Medium |
| 4 | Adjusted overall risk (baseline data shows %R > 70%) | **Low** |

Understanding site-specific mitigating factors informs the influence of controls and ongoing monitoring needs, whether it is treatment performance, operational control monitoring or environmental monitoring to support validation of the risk score. For example, should the trade waste volume increase significantly, this may require operational changes to surface water such as dilution rate or volume.

1. Risk analysis for irrigation and stock water

Table 9 sets out an approach to consider risks from emerging contaminants in irrigation. The general weighting outlined below has been developed to enable relative risk consideration, however it is qualitative and suppliers may need to consider additional information of current operations to develop a suitable approach. For each key risk driver for emerging contaminants source, the relevant factor is added.

Potential exposure pathways and receptors are dependent on the water quality produced, and as such the class and level of helminths treatment are essential pieces of information. For example, a scheme producing Class C water with no helminths treatment will only be suitable for the following uses:

* cooked and processed food crops or raw crops without direct exposure
* non-food crops – woodlots, turf, flowers
* public open spaces

Numerical values are not used in the Table 9 risk ranking due to the wide range of factors that can influence the risk profile. Further information on these factors is outlined in EPA publication 168.

Table 9. Risks of emerging contaminants in treated wastewater based on other factors for irrigation water use

| Factor (line of evidence) | High risk | Medium risk | Low risk |
| --- | --- | --- | --- |
| **Source factors (likelihood of EC presence in recycled water)** | | | |
| Trade waste | >10% |  | <10% |
| Population size (de Haas et al. 2018) | Large (>25,000) | Medium (5000-25,000) | Small (<5000) |
| Treatment train (percent reduction as per Table 3) | 0-46% | 47 - 70% | 71-100% |
| **Pathway/exposure factors** | | | |
| Irrigation volume (see 1911, 168) | High | Medium | Low |
| Slope | Steep/undulating >10% |  | Flat to moderate and uniform grades |
| Depth to groundwater | < 5m | < 10m | > 10m |
| Salinity (TDS) | <1000 | 1000-7100 | >7100 |
| Soil salinity/sodic soils | High soil salinity  (>4 dS/mECe) |  | Low soil salinity  (<2 dS/m Ece) |
| Soil type | Shallow soils  Highly permeable sands  Heavy poorly structured clays  Duplex soils with shallow topsoils and heavy clay subsoil |  | Deep sandy loam |
| Run off to surface water | Waterways or wetlands on-site or within 100m |  | None present within 500m |
| **Receptors** | | | |
| Terrestrial ecosystems | Sites with high ecological value and/or threatened species | Slightly to moderately modified ecosystems | Highly modified ecosystems (commercial/industrial land) |
| Irrigation schemes | Edible crops (raw and processed)  Pasture | Horticulture and tree fruits | Public places (ornamental gardens, turf, ski resorts) |
| Groundwater bores in use - proximity | 500 m | 1000m | >1000m |
| Surface water abstraction | Abstraction licences within 100m  Potable water supply catchment area |  | Abstraction licences >500m |
| Living cultural heritage values | As per Table 3-2 EPA publication 168 |  | As per Table 3-2 EPA publication 168 |

Table 10. Overall risk profile (Step 3) for emerging contaminants in wastewater for proposed irrigation uses

|  |  |  |  |
| --- | --- | --- | --- |
| Step 1: Percent reduction | Step 2: Other factors | | |
| High | Medium | Low |
| High | High | High | Medium |
| Medium | High | Medium | Low |
| Low | Medium | Low | Low |

As with surface water discharge, it is important to understand the risk profile to ensure risk management and monitoring approaches will be fit for purpose.

Approaches to risk assessment for stock water

Stock water is important for two reasons: the potential to impact stock health and the potential for accumulation in food consumed by humans.

Stock water use applies only to Class A and helminths treated water, with further guidance on requirements within EPA Publication 1911. Where there are Australian Drinking Water Guidelines for emerging contaminants, they are typically considered also protective of stock health.

For emerging contaminants that bioaccumulate or have relevant food investigation criteria or maximum limits, a more detailed risk assessment may be necessary to ensure that risks to human health from consumption are also considered. This may need engagement with relevant government agencies whose jurisdiction addresses food safety and market access, in addition to EPA Victoria.

1. Drought relief

Further guidance on use of recycled water for drought relief scenarios is outlined in EPA publication 1911.2. Drought relief involves the access of water from standpipes for temporary uses, such as:

* livestock
* crop irrigation
* dust suppression
* municipal gardens and landscapes (amenity horticulture).

Although Victoria’s regulatory framework for recycled water is well established, drought relief schemes require some variations to the ‘default’ recycled water controls. These variations reflect that drought relief end-uses are expected to involve the temporary application of small volumes of water and are likely to be managed by people with limited recycled water experience. Such uses may qualify for fast-tracked HEMP approval.

Consideration of emerging contaminants in drought relief scenarios can include relevant considerations for volumes, duration and frequency of use, proportionate to the risks posed more generally by the treatment level e.g. class and helminths treatment. Table 27 in EPA Publication 1911.2 outlines drought relief recycled water uses and treatment levels.

1. Risk characterisation

Several use scenarios may be under consideration by any one recycled water scheme. When deciding potential recycled water use options, outlining the risk profile is helpful to then inform risk management controls. This is particularly important as controls may be implemented by different stakeholders across the scheme management chain, with roles and responsibilities clearly understood.

Therefore, risk characterisation may need to document:

* identification of risks to each of the environmental values relevant to proposed use scenarios (e.g. one or several of surface water discharge, irrigation, stock water and domestic water scenarios)
* each risk with an evaluation of the level of change or impact to the environmental value and likelihood of the risk occurring, including the conditions under which the risk is likely to occur
* identification of the risk drivers across source, treatment performance, proposed recycled water use and its associated exposure pathways and receptors
* comparison and prioritisation of the risks identified and relevant stakeholders
* reporting of the assumptions, uncertainties, and strengths and limitations of the risk analyses
* a discussion of all information obtained and when the predicted risk is low, advice about the potential for risk to occur under changed conditions
* identification of key operational controls influencing understanding and management of risk
* suggested monitoring and assessment program to assess risk assessment predictions and potential effectiveness of management actions.

1. Environmental monitoring and quantitative data

Environmental monitoring programs

Monitoring recycled water for emerging contaminants provides an understanding of potential risks associated with treated wastewater. Where baseline monitoring data is available, the risk score can be adjusted.

Establishing the objective or purpose of monitoring is key to developing a robust program. Objectives may include:

* understanding of removal efficiency (%R) of the treatment train process (influent vs effluent)
* characterising emerging contaminants in recycled water based on:
  + persistence, bioaccumulation and toxicity (to humans and the environment) and mobility in the environment
  + concentrations relative to established screening levels where available
* monitoring for changes to influent based on new sources e.g. increase in trade waste, population changes over time
* understanding implications of operational control changes
* validating environmental controls in the environment

Monitoring programs can also be scaled to meet the intended purpose of the intended use.

Routine monitoring for new and existing schemes

When designing a monitoring program for emerging contaminants, document the reasoning around your choices for:

**Sampling methods.** You can use different sampling methods, including novel techniques, such as:

* targeted analysis – use autosamplers for the influent and effluent sampling and collect 48-hour composite samples. Screen samples for emerging contaminants based on EPA Publication 2054.
* passive sampling – these devices can be deployed in a waterway or discharge structure over an extended period and give an estimation of average concentration over a period (e.g. 28 days). See further information about how to use passive samplers in EPA Publication 2054.
* non-target analysis – this is a qualitative method which helps determine presence or absence of contaminants. These methods can provide a useful initial screening step to help refine a monitoring program.
* in vitro bioassays – these can detect the mixture effects of all active chemicals in a sample, including transformation products and unknown chemicals. They offer a cost-effective, high-throughput tool for assessing aquatic toxicity of complex mixtures in water samples. They are recommended to be used in combination with targeted analytical screening (Escher et al. 2021).

**Frequency.** This should be based on the level of risk. For example, if the treated wastewater is low risk, monitoring frequency can be once or twice a year (EPA Publication 2054). However, if the treated wastewater is high risk, an intensive (7-day sampling) followed by monthly sampling using a combination of targeted analysis and bioassays are encouraged to capture the true risk of the treated wastewater.

Wastewater is known to vary between days and samples collected at different times of day, as well as collected on a Friday or Monday will differ from samples collected on Wednesday (Szabo et al. 2023). Therefore, it is recommended to conduct a more intensive sampling campaign (sampling over 7-day period) once a year to improve assessment of risks in the wastewater.

**Analysis method.** Use a laboratory with a current National Association of Testing Authorities (NATA) accreditation for the target analytes, or in cases where this is not feasible, a laboratory with an accreditation to ISO 17025. For some analytes, it is recognised that accreditation may not be possible (e.g. non-target analysis).

Care should also be taken in:

* storage, handling and collection of samples prior to analysis
* using the correct sample bottles to avoid contamination and ensure accurate results
* choosing the lowest possible limit of detection available (e.g. ultra-trace level) for the analysis.

The ongoing collation of monitoring data enables detecting trends and changes in the chemical loads, as well as detecting new emerging contaminants. Over time, the routine monitoring should be adjusted based on the site-specific risks.

Guidelines and quantitative risk assessments

There are many approaches to screening risk from emerging contaminants. The key options identified here include:

* consideration of persistence, bioaccumulation, toxicity and mobility (PBTM) characteristics of identified contaminants.
* screening of quantitative data against guideline values where available
* holistic or mixture approaches to ecological risk
* monitoring of crop health.

Screening based on PBTM

Chemical prioritisation approaches often focus on environmental persistence (P), and may also consider bioaccumulation (B), toxicity (T) and mobility (M). These PBTM approaches are widely used by chemical regulators to assess substances listed in national chemical inventories. These approaches are used to determine which chemicals in their inventories could need further assessment and/or further regulation.

Indicators of emerging contaminants that might be important in recycled water assessments can include things like the degradation half-life and the partitioning coefficients. Other parameters like water solubility, vapour pressure and Henrys Law constant help in understanding if and how an emerging contaminant might travel from the point of use to a location where people or ecosystems may be exposed.

The list of emerging contaminants that need to be assessed for recycled water from a particular wastewater treatment plant can be ranked based on persistence, bioaccumulation potential and mobility using degradation half-lives, Kow (octanol-water partition coefficient) and/or Koc (organic carbon-water partition coefficient), where relevant values can be sourced from reputable organisations. For persistence, classifications such as ready biodegradability may also be useful if data like degradation half-life values are not available.

Values for parameters relevant for a particular emerging contaminant can be sourced from reputable organisations and databases including:

* Risk Assessment Information System (RAIS)[[1]](#footnote-2) – refer to chemical tools/chemical parameters (RAIS).
* AICIS (Australian Industrial Chemicals Introduction Scheme) assessments – most easily accessed via the OECD eChemPortal[[2]](#footnote-3).
* USEPA CompTox Dashboard – database maintained by USEPA using computational toxicology data as well as PubChem data and the USEPA ECOTOX database[[3]](#footnote-4)
* USEPA Regional Screening Levels – refer to the chemical specific parameter spreadsheet[[4]](#footnote-5)
* USEPA RED (reregistration eligibility decisions for pesticides)[[5]](#footnote-6)
* PubChem[[6]](#footnote-7) – database maintained by the National Library of Medicine in the US.
* ECHA Chemical dossiers[[7]](#footnote-8) – see “REACH registered substance factsheets”.
* EFSA Scientific Opinions for pesticides[[8]](#footnote-9) – search the pesticide name and look for a document titled “conclusion on the peer review of the pesticide human health risk assessment of the active substance …”. These assessments include a listing of relevant parameters in the list of endpoints appendix.
* ECHIDNA (Emerging Chemicals Database for National Awareness)[[9]](#footnote-10) – refer to chemical tools/chemical parameters.

Water quality guidelines

A limited number of emerging contaminants have water quality guidelines that can be used in quantitative risk assessment. This is because the science on their toxicity and risks to the environment is still evolving. Therefore, the list of guidelines provided below is not exhaustive and will change over time.

* Australian and New Zealand guidelines for fresh and marine water quality (ANZG 2018)
* Australian Drinking Water Guidelines (ADWG, 2011)
* PFAS NEMP 3.0. (2025)
* European Chemicals Agency (ECHA), [Environmental quality standards](https://echa.europa.eu/environmental-quality-standards)
* ECHA, [Predicted no effect concentrations (PNECs) in individual chemical dossiers](https://echa.europa.eu/)
* United States Environmental Protection Agency (USEPA), [National recommended aquatic life criteria](https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table)
* Canadian Council of Ministers of the Environment (CCME), [Canadian environmental quality guidelines](https://ccme.ca/en/summary-table)

In addition, state/territory derived guideline values exist. For example, Queensland government has derived [guidelines for 22 herbicides determined for the Great Barrier Reef](https://www.publications.qld.gov.au/dataset/method-development-pesticide-risk-metric-baseline-condition-of-waterways-to-gbr/resource/c65858f9-d7ba-4aef-aa4f-e148f950220f).

Consider information from other sources specific to emerging contaminants in recycled water like:

* other state, territory and federal governments
* international regulatory bodies including United States Environmental Protection Agency (US EPA), ECHA, European Food Safety Authority, European Environment Agency, Canadian Council of Ministers of the Environment (CCME), Environment and Climate Change, Canada
* scientific literature as published by universities and research centres
* industry organisations (Australian and international) including:
  + [Australian Water Association](https://www.awa.asn.au/)
  + [Water Services Association of Australia](https://www.wsaa.asn.au/)
  + [Water Reuse Association](https://watereuse.org/)
  + [American Water Works Association](https://www.awwa.org/)
  + [Water Research Foundation](https://www.waterrf.org/)
  + [EurEau](https://www.eureau.org/)
  + [European Water Association](https://www.ewa-online.eu/home.html)

Holistic or mixtures approach to assessing ecological risks

Due to the complexity of emerging contaminants and limited number of guideline values for specific contaminants, it is recommended to use a more holistic approach for assessment of risk. This could include toxicity tests to gain a better understanding of the potential mixture effects and overall toxicity of treated wastewater to the surrounding environment.

In aquatic settings, the following toxicity tests could be explored:

* whole-effluent test (WET) – analysis of aggregate toxic effect to aquatic organisms from all pollutants contained in effluent.
* bioassays (see Lewis et al. 2024 for further details)
* non-traditional ecotoxicological endpoints (e.g. transcriptomics, behavioural assays) (see Bertram et al. 2024 for further details).

In terrestrial settings, the following standard toxicity tests could be explored:

* plant toxicity test OECD 208 (Terrestrial Plant Test: Seedling Emergence and Seedling Growth Test)
* earthworm reproduction test OECD 222 (Earthworm Reproduction Test (*Eisenia fetida/Eisenia andrei*)
* bacterial toxicity tests (OECD, biodegradation tests 7)
* soil invertebrate avoidance test (ISO 2008, ISO 2011).

Monitoring of crops and plants:

* specific ongoing management controls will vary according to the land use selected and should be determined during scheme establishment. Visual monitoring of plant health is a good starting point, as is benchmarking your crop production with regional data.
* for some settings, existing standard monitoring options may still be appropriate. See existing guidance for crop yield and quality observations (e.g. EPA publication 168.2. Victorian guideline for irrigation with recycled water).
* outcomes of routine monitoring or investigative studies.

1. Risk management

Risk management involves the implementation of controls, documentation, checking or monitoring of controls and continual improvement. EPA guidance on developing risk management plans for recycled water are available in EPA Publications 1910, 1911 and 168.

* 1. Operational controls and best practice

Best practice for managing emerging contaminants in recycled water is centered around a risk-based, multiple-barrier approach, consistent with the Australian Guidelines for Water Recycling and EPA Victoria’s framework (Publications 1910.2 and 1911.2) and the GED. This includes:

* source control as the first line of defence, targeting pollutants at the source which includes strictly adhering to trade waste agreements and regulators’ requirements
* fit-for-purpose treatment by matching the level of treatment to the risk associated with the intended end use (e.g. Class A for high-contact uses). Treatment trains that incorporate extended aeration, membrane filtration, and disinfection are widely considered more effective for reducing a broader spectrum of emerging contaminants
* monitoring of operational controls
* monitoring and performance validation by establishing baseline data for emerging contaminants in influent and effluent, calculating percent removal (%R), and periodically reviewing performance
* ecotoxicity testing to assess aggregate environmental risks beyond chemical-by-chemical analysis, especially when effluent is discharged to sensitive environments
* transparent documentation and continual improvement: Embedding controls and responsibilities in the HEMP and RWQMP, and reviewing them regularly in response to new information, monitoring results, or changes in inputs.

Below is a list of the key operational controls that are already being implemented in the water sector in response to emerging contaminants:

* routine influent and effluent monitoring for emerging contaminants
* percent reduction (%R) of emerging contaminants removed across the treatment process to inform internal risk ratings and refine control priorities
* upgrading treatment systems (where needed), particularly in high-risk schemes or where recycled water is supplied as Class A or discharged to surface waters
* embedding emerging contaminants risk into the HEMP and RWQMP where scheme managers are increasingly recognising the need to formally document how they manage residual and emerging risks
* use restrictions or conditional approvals where some authorities are limiting certain recycled water uses where treatment or receiving environment sensitivity presents elevated risks
* participating in research to understand the fate and behaviour of emerging contaminants.

Iterative review of controls can ensure their continued effectiveness and relevance. This review may include, but is not limited to, consideration of the following:

* changes in influent characteristics (e.g. new or variable trade waste inputs)
* treatment performance and operational control monitoring
* updated knowledge on the presence, behaviour, or risks of emerging contaminants
* evolving regulatory expectations or compliance obligations.
  1. Risk mitigation controls

Risk mitigation controls aim to reduce the likelihood and/or consequences of harm from emerging contaminants where preventative controls are insufficient or where residual risk remains. Mitigation controls should be proportionate to the risk level (low, medium, high) and may include a combination of engineering, administrative, and monitoring-based responses. They should complement the preventative controls and be documented within the HEMP, and/or the RWQMP. Examples of mitigation controls could include:

* Restricting or modifying end uses. For instance:
* avoiding application near sensitive environmental receptors or restricting irrigation to non-edible crops
* drip irrigation can be effective in avoiding plant uptake of pharmaceuticals because it reduces the contact of water with edible parts of the crop (Manas et al. 2009)
* use of clay soils, which enhance the retention of pharmaceuticals, can lead to a lower uptake into plants (Sunyer-Caldu et al. 2023)
* temporal or conditional reuse restrictions, such as withholding recycled water use during low-flow conditions in receiving waters
* buffer zones or setbacks to protect nearby surface water, or culturally significant areas
* incorporation of real-time monitoring or early warning systems to detect treatment underperformance or variability in influent quality
* sampling and testing to assess and validate the effectiveness of the treatment system beyond theoretical analysis alone
* improved risk communication and recordkeeping, ensuring scheme users understand residual risks and their role in maintaining compliance. For example:
  + ensuring stormwater runoff from the area where recycled water is used is collected and managed on the site, and is not permitted to discharge to off-site areas
  + conducting irrigation (where recycled water is sprayed) under low wind conditions to minimise spray drift off-site
* review and consideration of upgrading treatment processes to improve contaminant removal (e.g. installation of advanced oxidation, activated carbon, or membrane filtration systems).
  1. Using environmental monitoring to inform continuous improvement

When developing a risk management plan, consider the following approaches to guide your risk mitigation strategy. For example, negotiating more stringent trade waste agreements or improving treatment technologies at the WWTP will influence the quality of the wastewater and reduce risks of emerging contaminants in recycled water.

### Low risk sites:

* establish seasonal baseline for emerging contaminants by sampling wastewater (influent and effluent) in summer and in winter over a year
* use autosamplers for the influent and effluent sampling and collect 48-hour composite samples
* calculate percent reduction of emerging contaminants in the treated wastewater to refine risk score for Step 1
* if percent reduction is above 70%, then monitor wastewater (influent, effluent), as per your routine monitoring
* if percent reduction is below 70%, assess toxicity of the wastewater using bioassays or WET assays to confirm no adverse effects to the environment

### Medium risk sites:

* set up your seasonal baseline for emerging contaminants by sampling wastewater (influent and effluent) in summer and winter over a year
* use autosamplers for the influent and effluent sampling and collect 48-hour composite samples
* calculate percent reduction of emerging contaminants in the treated wastewater to refine risk score for Step 1
* if percent reduction varies, assess toxicity of the wastewater using bioassays or WET assays, and revise the risk rating accordingly
* if bioassays or WET assays indicate adverse effects, consider appropriate use scenarios and risk mitigation options to reduce risks
  + in certain use scenarios, upgrading the WWTP might be the best option to improve risk rating.
* if bioassays or WET assays do not indicate adverse effects, then continue your routine monitoring
* the use of bioassays or WET assays are encouraged as part of the routine monitoring to confirm that the treated wastewater is not harmful for the surrounding environment.

### High risk sites:

* set up your seasonal baseline for emerging contaminants by sampling wastewater (influent and effluent) in summer, spring, winter and autumn (4 sampling campaigns) over a year. This increased monitoring frequency is warranted due to higher level of risk
* use autosamplers for the influent and effluent sampling and collect 48-hour composite samples
* calculate percent reduction of emerging contaminants in the treated wastewater to refine risk score for Step 1
* if percent reduction varies, assess toxicity of the wastewater using bioassays or WET assays, and revise the risk rating accordingly
* if bioassays or WET assays indicate adverse effects, consider appropriate use scenarios for recycled water
* if bioassays or WET assays do not indicate adverse effects, continue seasonal baseline sampling
* the use of bioassays or WET assays are encouraged as part of the routine monitoring to confirm that the treated wastewater is not harmful for the surrounding environment
* should the recycled water be intended for more sensitive use, longer-term plan should be to enable recycled water to move from ‘high’ to ‘medium’ to ‘low’ risk. This may include upgrading the WWTP.

# Appendix A: Case studies

These case studies provide examples for specific recycled water re-use scenarios.

## Case study 1

**Site identification:** WWTP in regional Victoria.

**Treatment train process:** Lagoon (TT1).

### Assessment of risk for emerging contaminants

#### Step 1. Treatment train risk score: High

TT1 removes 0-45% of a range of emerging contaminants, which gives the site an emerging contaminant likelihood score of ‘High’.

#### Step 2. Other factors risk assessment: Low

* Source factors:
  + trade waste: <10% trade waste
  + population size: 14,000
  + mean discharged volume: <1ML/day
* Pathway/exposure factors:
  + median dilution rate: >1:1000
* Receptors:
  + freshwater and marine environments: highly modified ecosystem (no sensitive receptors)
  + special water catchment: not relevant to this
  + catchments that service drinking water: not relevant to this site

|  |  |  |
| --- | --- | --- |
| Factor | Risk rating | Risk score |
| Trade waste | Low | 5 |
| Population size | Medium | 5 |
| Mean discharged volume | Low | 5 |
| Median dilution rate | Low | 10 |
| Freshwater and marine environment (sensitive receptors) | Low | 10 |
| **Total score** | **Low** | **35** |

#### Step 3. Overall risk score: Medium

|  |  |
| --- | --- |
| Score | Risk |
| Step 1 | High |
| Step 2 | Low |
| Step 3 (Overall score) | Medium |

#### Step 4. Adjusted overall risk based on available data (see summary table below): Low

**Monitoring data:** The WWTP site has set up a seasonal baseline sampling for emerging contaminants by sampling wastewater (influent and effluent) over a period (1-2 years).

* The site uses autosamplers for the influent and effluent sampling and collects 48hr composite samples
* The analytical suite for emerging contaminants follows EPA publication 2054
* Percent reduction (%R) of emerging contaminants is calculated to assess treatment train risk rating. Percent reduction for emerging contaminants is 76%, which indicates a low risk.

**Conclusion:** Based on baseline monitoring, the WWTP treatment process removes over 76% of the emerging contaminants. This indicates that the risk in step 1 of the desktop risk assessment is reduced to Low and therefore the overall risk for the WWTP is downgraded to Low.

A summary of the risk assessment is shown in the table below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Step | | Description | Risk | |
| 1 | Treatment train and percent reduction (no baseline data) | | | High |
| 2 | Other factors | | | Low |
| 3 | Overall risk (step 1 x step 2) | | | Medium |
| 4 | Adjusted overall risk (baseline data) | | | **Low** |

**Risk management and monitoring measures:**

* As per concept of continual improvement, despite the low-risk rating, the water utility is upgrading the WWTP. The upgrade will involve constructing ultra-filtration and reverse osmosis infrastructure to produce fit-for-purpose recycled water
* The upgrade will assist the WWTP to maintain high %R of emerging contaminants, even if the number of the people the site is serving increases
* The water utility will continue monitoring emerging contaminants in influent and effluent waters, as per routine preventative control measure
* Wastewater quality might change over time due to changes in the catchment area (e.g. development, agricultural, industrial activities) and therefore ongoing monitoring is encouraged
* Incorporation of emerging contaminant risk assessment into HEMP documentation.

## Case study 2

**Site identification:** WWTP in regional Victoria with discharge to surface water (Class C).

**Treatment train process:** Activated sludge process (TT7).

**Treatment train risk score assessment:** Medium. TT7 removes 46-70% of a range of emerging contaminants, which gives the WWTP an emerging contaminant likelihood score ‘medium’.

### Assessment of risk for emerging contaminants

#### Step 1. Treatment train risk score: Medium

Based on baseline monitoring, the WWTP removes 59% of the emerging contaminants.

#### Step 2. Other factors risk assessment: High

* Source factors:
  + trade waste: >10% trade waste
  + population size: 19,000
  + mean discharged volume: >5ML/day
* Pathway/exposure factors:
  + median dilution rate: >1:5
* Receptors:
  + freshwater and marine environments: highly modified ecosystem (no sensitive receptors)
  + special water catchment: not relevant to this
  + catchments that service drinking water: not relevant to this site

|  |  |  |
| --- | --- | --- |
| Factor | Risk rating | Risk score |
| Trade waste | High | 15 |
| Population size | Medium | 5 |
| Mean discharged volume | High | 15 |
| Mean dilution rate | Low | 10 |
| Freshwater and marine environments (sensitive receptors) | Low | 10 |
| **Total score** | **High** | **55** |

#### Step 3. Overall risk: High

|  |  |
| --- | --- |
| Score | Risk |
| Step 1 | Medium |
| Step 2 | High |
| Step 3 (Overall score) | High |

#### Step 4. Adjusted overall risk based on available data (see summary table below): High (no change)

**Monitoring data:**

* In 2024, EPA collected composite influent and effluent samples, and environmental samples up-and downstream from the discharge point
* 643 emerging contaminants were analysed in each sample. It followed the analytical suite of EPA Publication 2054 but included additional pesticides, phthalates, and artificial sweeteners
* As a measure of overall contaminant toxicity, a battery of bioassays was applied to influent, effluent and surface samples. Specially, six bioassays were applied:
  + BLT-Screen for bacterial toxicity due to a range of general contaminants
  + IPAM assay for photosynthesis inhibition and toxicity to algae due to herbicides and pesticides
  + ER-GeneBLAzer for estrogenic and anti-estrogenic endocrine disrupting chemicals (EDCs)
  + HiTMiN assay for genotoxic and cytotoxic chemicals
  + ARE-GeneBLAzer for oxidative stress due to general contamination
  + AhR-CAFLUX for dioxin-like compounds and pesticides.
* The study showed a percent reduction (%R) of 59% for emerging contaminants, which indicates medium risk
* Bioassays indicated exceedances for all bioassays in influent samples, for the 24-hour IPAM assay, ER-GeneBLAzer assay, ARE-GeneBLAzer assay and AhR-CAFLUX assay in effluent samples, and for the ER-GeneBLAzer and ARE-GeneBLAzer assays for surface water samples.

**Conclusion:** Based on baseline monitoring, WWTP site removes 59% of the emerging contaminants. This confirms the medium risk in Step 1 of the desktop risk assessment. Bioassays indicated adverse effects, confirming the overall risk for the plant is High.

A summary of the risk assessment is shown in the table below.

|  |  |  |
| --- | --- | --- |
| Step | Description | Risk |
| 1 | Treatment train and percent reduction (no baseline data) | Medium |
| 2 | Other factors | High |
| 3 | Overall risk (Step 1 x Step 2) | High |
| 4 | Adjusted overall risk (baseline data) | **High** |

**Monitoring and risk management measures:**

* Bioassays applied to the wastewater indicate adverse effects to the environment. This result encourages WWTP to upgrade their WWTP to reduce the risks
* The WWTP is being upgraded by replacing ageing infrastructure and upgrading the aeration systems to improve the effectiveness of the treatment process
* Given trade waste is a high risk at the site, an additional preventative control is to investigate source control. The site is undertaking additional testing of trade waste to get a better understanding of the quality of the trade waste
* The WWTP is encouraged to continue monitoring emerging contaminants in influent and effluent waters, and calculating %R, as per routine preventative control measure.
* Wastewater quality might change over time due to changes in the catchment area (e.g. increasing population size, agricultural, industrial activities) and therefore ongoing monitoring including both influent/effluent and bioassays are encouraged
* Incorporation of emerging contaminant risk assessment into HEMP documentation

## Case study 3

**Site identification:** WWTP in regional Victoria with discharge to surface water.

**Treatment train process:** Activated sludge process (TT7).

### Assessment of risk for emerging contaminants

#### Step 1. Treatment train risk score: Medium.

Based on Publication 2054, TT7 removes 46-70% of a range of emerging contaminants, which gives the WWTP risk score of ‘medium’.

#### Step 2. Other factors risk assessment: Low.

* Source factors:
  + trade waste: <10% trade waste
  + population size: 2,300
  + mean discharged volume: <1ML/day
* Pathway/exposure factors:
  + median dilution rate: >1:5
* Receptors:
  + freshwater and marine environments: highly modified ecosystem (no sensitive receptors)
  + special water catchment: not relevant to this
  + catchments that service drinking water: not relevant to this site

|  |  |  |
| --- | --- | --- |
| Factor | Risk rating | Risk score |
| Trade waste | Low | 10 |
| Population size | Low | 10 |
| Mean discharged volume | Low | 5 |
| Median dilution rate | Low | 5 |
| Freshwater and marine environments (sensitive receptors) | Low | 1 |
| **Total score** | **Low** | **31** |

#### Step 3. Overall risk: Low

|  |  |
| --- | --- |
| Score | Risk |
| Step 1 | Medium |
| Step 2 | Low |
| Step 3 (Overall score) | Low |

#### Step 4: Adjusted overall risk based on available data (see summary table below): Low (no change)

**Monitoring data:**

* In 2024, EPA collected composite influent and effluent samples, and environmental samples up-and downstream from the discharge point
* 643 emerging contaminants were analysed in each sample. It followed the analytical suite of EPA Publication 2054 but included additional analytes
* As a measure of overall contaminant toxicity, a battery of bioassays was applied to influent, effluent and surface samples. Specially, six bioassays were applied:
* BLT-Screen for bacterial toxicity due to a range of general contaminants
* IPAM assay for photosynthesis inhibition and toxicity to algae due to herbicides and pesticides
* ER-GeneBLAzer for estrogenic and anti-estrogenic EDCs
* HiTMiN assay for genotoxic and cytotoxic chemicals
* ARE-GeneBLAzer for oxidative stress due to general contamination
* AhR-CAFLUX for dioxin-like compounds and pesticides
* The study showed a %R for emerging contaminants of 57%. PPCP removal was high (80.41%), as was removal for pesticides (74%).
* Bioassays indicated low risk and no exceedances of the ecoEBT were observed for the site.

**Conclusion:** Based on baseline monitoring, the WWTP site had a %R of 57% for emerging contaminants. This confirms the medium risk in step 1 of the desktop risk assessment. Bioassays indicated no adverse effects, confirming the overall risk for the plant is Low.

A summary of the risk assessment is shown in the table below.

|  |  |  |
| --- | --- | --- |
| Step | Description | Risk |
| 1 | Treatment train and percent reduction (no baseline data) | Medium |
| 2 | Other factors | Low |
| 3 | Overall risk (step 1 x step 2) | Low |
| 4 | Adjusted overall risk (baseline data) | **Low** |

**Monitoring and risk management measures:**

* Bioassays applied to the wastewater indicated no adverse effects to the environment. Ongoing routine monitoring using both influent/effluent sampling and bioassays is encouraged, as a preventative measure
* Wastewater quality might change over time due to changes in the catchment area (e.g. increased population size, agricultural and industrial activities)
* As per concept of continual improvement, consider upgrading your site to control risks. The mean percent reduction, even with the baseline date, indicates a ‘medium’ risk for this site.

## Case study 4

**Site identification:** WWTP in regional Victoria with discharge to surface water.

**Treatment train process:** Lagoon (TT1).

### Assessment of risk for emerging contaminants

#### Step 1. Treatment train emerging contaminant likelihood score: High.

Based on the EPA publication 2054, TT1 removes 0-45% of a range of emerging contaminants, which gives the site a risk score of ‘High’.

#### Step 2. Other factors risk assessment: Low.

* Source factors:
  + trade waste: <10% trade waste
  + population size: 3,500
  + mean discharged volume: <1ML/day
* Pathway/exposure factors:
  + median dilution rate: >1:5
* Receptors:
  + freshwater and marine environments: slightly to moderately modified ecosystem (95% species protection applies)
  + special water catchment: not relevant to this
  + catchments that service drinking water: not relevant to this site

|  |  |  |
| --- | --- | --- |
| Factor | Risk rating | Risk score |
| Trade waste | Low | 5 |
| Population size | Low | 1 |
| Mean discharged volume | Low | 5 |
| Median dilution rate | Low | 10 |
| Freshwater and marine environments (sensitive receptors) | Medium | 20 |
| **Total score** | **Medium** | **41** |

Step 3. Overall risk: Medium

|  |  |
| --- | --- |
| Score | Risk |
| Step 1 | High |
| Step 2 | Medium |
| Step 3 (Overall score) | **High** |

#### Step 4: Not available: High (no change)

**Conclusion:** No baseline data is available and therefore the overall risk score cannot be adjusted.

**Monitoring and risk management measures:** The site will follow the monitoring measures for the ‘High’ risk site, as follows:

* Set up seasonal baseline for emerging contaminants by sampling wastewater (influent and effluent) in summer, spring, winter and autumn (4 sampling campaigns) over a year. This increased monitoring frequency is warranted due to higher level of risk
* Use autosamplers for the influent and effluent sampling and collect 48-hour composite samples
* Calculate percent reduction of emerging contaminants in the treated wastewater to refine risk score for Step 1
* If percent reduction varies, assess toxicity of the wastewater using bioassays or WET assays, and revise the risk rating accordingly
* If bioassays or WET assays indicate adverse effects, consider appropriate use scenarios for recycled water
* If bioassays or WET assays do not indicate adverse effects, continue seasonal baseline sampling
* The use of bioassays or WET assays are encouraged as part of the routine monitoring to confirm that the treated wastewater is not harmful for the surrounding environment
* Should the recycled water be intended for more sensitive use, longer-term plan should be to enable recycled water to move from ‘high’ to ‘medium’ to ‘low’ risk. This may include upgrading the WWTP.

## Case study 5.

### Assessment of risks associated with the recycled water used in snowmaking process to the environment

This case study covers the use of recycled water (Class A) for generating artificial snow. It describes the process that is likely to be undertaken by producers or suppliers of recycled water. Generation of artificial snow at the snowfields is generally undertaken during the night (when conditions are appropriate) using automated equipment which limits how workers or the public could be directly exposed to the recycled water.

#### 1. Problem formulation of the re-use scenario

The scope is to assess the risks of the use of recycled water for snowmaking to the surrounding environment.

* Source
  + TT5 (ASP with extended aeration, membrane filtration, reverse osmosis) removes 71-100% of a range of emerging contaminants, which gives the site a risk score of ‘low’
  + Trade waste: <10% trade waste
  + Population size: 2,300
* Site characteristics (pathway):
  + slope: steep/undulating > 10% (high risk)
  + depth to groundwater > 10m (low risk)
  + salinity > 7100 (low risk)
  + groundwater bores in use (proximity) > 1000m (low risk)
  + soil salinity/sodic soils: low soil salinity (< 2 dS/m Ece) (low risk)
  + soil type: heavy poorly structured clays (high risk)
  + surface waters: none present within 500m (low risk)
* Receptors:
  + irrigation scheme: public places (low risk)
  + moderately modified terrestrial ecosystems (snowfield)
  + no places of significance to Traditional Owners
  + no groundwater-dependent ecosystems
* Operational controls, roles and responsibilities:
  + as per EPA publications 1910.2, 1911.2 and 168.3
  + roles and responsibilities for recycled water supply and use, as it relates to considering emerging contaminants

2. Risk analysis

Class A recycled water produced at this WWTP has a lower likelihood of emerging contaminants presence, due to:

* Low source concentrations (<10% trade waste, low population size)
* High removal efficiency of emerging contaminants due to TT5 treatment train

The volume of water used to support snow making is high, however given the likelihood of emerging contaminants being present is low, the overall mass load introduced to the environment is likely low.

The proposed receptor – human health from direct contact with snow in public open space, has low sensitivity, with moderately modified terrestrial ecosystems posing medium sensitivity.

Overall, the risk is low based on likelihood of low source concentrations and lack of sensitive receptors.

Step 2. Table summarising risk profile

|  |  |
| --- | --- |
| Factor | Risk rating |
| **Source** | |
| Treatment train | Low |
| Trade waste | Low |
| Population size | Low |
| **Exposure pathway** | |
| Mean discharged volume (mass load available for uptake) | High |
| Depth to groundwater | Low |
| Risks from run-off to surface water (sodicity, topography, soil type) | Low |
| **Receptors** | |
| Receptor – moderately modified terrestrial ecosystems | Medium |
| Receptor – human health: public spaces | Low |
| Receptor – human health: groundwater or surface water abstraction | Low |

#### **3. Risk management and monitoring**

The water utility will continue monitoring emerging contaminants in influent and effluent waters, as per routine preventative control measure.

Wastewater quality might change over time due to changes in the catchment area (e.g. development, agricultural, industrial activities) and therefore ongoing monitoring is encouraged.

## Case study 6

## Assessment of risks associated with recycled water used in irrigation

This case study presents a scenario for using Class C recycled water for irrigation. The end use is irrigation at an orchard growing fruit for human consumption.

Step 1A. Problem formulation

* Scope risk assessment
  + Source assessment
    - Characterisation of source water:
      * no baseline data
      * population size 4,000
      * trade waste: < 10%
    - Treatment train process and implications for reduction in contaminants (percent reduction of emerging contaminants):
      * treatment train: lagoon (TT1). Based on EPA publication, TT1 is ‘high risk’.
      * class of treated water: class C
  + Pathways assessment for routes of exposure from intended use
    - Low irrigation volume
    - Flat to moderate grade
    - Groundwater is less than 10m
    - Salinity is 4000
    - Low soil salinity
    - Deep sandy loam
    - No waterways within 500m
  + Receptor assessment
    - human exposure: orchard
    - environmental exposure (biota, plants, soils, surface water, groundwater): yes
  + Characteristics of the receiving environment:
    - no environments with high conservation or ecological value
    - no places of significance to Traditional Owners
    - no groundwater-dependent ecosystems
* Operational controls, roles and responsibilities:
  + as per EPA publications 1910.2, 1911.2 and 168.3
  + roles and responsibilities for recycled water supply and use as it relates to considering emerging contaminants

Step 2. Table summarising risk profile

|  |  |
| --- | --- |
| Factor | Risk rating |
| **Source** | |
| Treatment train | High |
| Trade waste | Low |
| Population size | Low |
| **Exposure pathway** | |
| Mean discharged volume (mass load available for uptake) | Low |
| Depth to groundwater | Low |
| Risks from run-off to surface water (sodicity, topography, soil type) | Low |
| **Receptors** | |
| Receptor – moderately modified ecosystems | Medium |
| Receptor – orchard, tree fruit | Medium |
| Receptor – groundwater or surface water abstraction | Low |

From step 2, the priority source-pathway-receptor linkage relates to onsite irrigation of crops for food consumption. Other pathways e.g. run-off to surface water and abstraction of groundwater were low to medium. The treatment train indicates small percent reduction for emerging contaminants (i.e. high risk), though there is limited trade waste input and the population size is small.

**Monitoring data:** Based on the baseline monitoring conducted by the water utility, the relevant WWTP had a mean percent reduction of 60% for emerging contaminants (**medium** likelihood of emerging contaminants present).

**Source-pathway-receptor assessment:**

* Source: Low risk (<10% trade waste, small population)
* Exposure pathway: Low risk (mass load available for uptake in crops)
* Receptors: Medium risk

Overall source-pathway-receptor risk = low risk.

Percent reduction = medium risk (adjusted based on monitoring data)

Overall risk profile is low.

3. Risk monitoring and management

The water utility will continue monitoring emerging contaminants in influent and effluent waters and consider end uses. Wastewater quality might change over time due to changes in the catchment area (e.g. development, agricultural, industrial activities) and therefore ongoing monitoring is encouraged.

Continue existing monitoring and maintenance of operational controls, as per HEMP to ensure treatment train is effective. In site management plan for end user, include visual monitoring of crop quality, as per EPA publication 168.

# Appendix B: Glossary of key terms and abbreviations

|  |  |
| --- | --- |
| **Term or abbreviation** | **Description** |
| AICIS | Australian Industrial Chemicals Introduction Scheme |
| ANZG | Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018) |
| CCME | Canadian Council of Ministers of the Environment |
| Class of recycled water | Recycled water classes (A, B and C) that include health-related microbiological and process performance requirements but not environmental quality parameters such as salinity or nutrient limits. Information about what defines these classes is provided in Table 1 within EPA Victoria Publication 1910.2 |
| Detection limit | The lowest concentration of a chemical that can reliably be distinguished from a zero concentration. |
| Drinking water | Water suitable for human consumption and other household uses as defined in the Australian Drinking Water Guidelines. Also known as potable water. |
| ECHA | European Chemicals Agency |
| EDC | Endocrine disrupting chemical |
| Emerging contaminants | Chemicals that are newly introduced into the environment (e.g. pharmaceutical, industrial or agricultural compounds that have only recently been developed) or that, although possibly around for longer times, have only recently been detected in the environment due to advances in detection technologies. |
| Ecological value(s) | Plants, animals, fungi or ecological processes associated with a defined area that are of significant societal, ecological or economic significance. |
| Exposure | Contact with a substance by swallowing, breathing, or touching the skin or eyes. Exposure may be short-term (**acute exposure**) of intermediate duration, or long-term (**chronic exposure**). |
| Exposure pathway | The route a substance takes from its source (where it began) to its end point (where it ends), and how people can come into contact with (or get exposed to) it. An exposure pathway has 5 parts: a source of contamination (such as chemical leakage into the subsurface); an [environmental media and transport mechanism](http://www.atsdr.cdc.gov/#Environmental Media and Transport Mechanism) (such as movement through groundwater); a [point of exposure](http://www.atsdr.cdc.gov/#Point of Exposure) (such as a private well); a [route of exposure](http://www.atsdr.cdc.gov/#Route of Exposure) (eating, drinking, breathing, or touching), and a [receptor population](http://www.atsdr.cdc.gov/#Receptor Population) (people potentially or actually exposed). For example, exposure pathways represented in this document stemming from recycled water used for irrigation:   * Irrigation → soil * Irrigation → soil → plants * Irrigation → plants * Irrigation → soil → plants → humans * Irrigation → soil → plants → livestock * Irrigation → soil → plants → livestock → humans * Irrigation → soil → water |
| General Environmental Duty (GED) | Requires all Victorians (including producers, suppliers and users of recycled water) to:   * understand how their activities put our environment or community at risk * take reasonable steps to reduce those risks. |
| Groundwater | Any water contained in or occurring in a geological structure or formation or an artificial landfill below the surface of land. |
| Guideline value | Guideline value is a concentration in soil, sediment, water, biota or air (established by relevant regulatory authorities), that is used to identify conditions below which no adverse effects, nuisance or indirect health effects are expected. The derivation of a guideline value uses relevant studies on animals or humans and relevant factors to account for inter- and intra-species variations and uncertainty factors. Separate guidelines may be identified for protection of human health and the environment. Dependent on the source, guidelines will have different names, such as investigation level, trigger value, ambient guideline etc. |
| Harm | * An adverse effect to human health or the environment (of whatever degree or duration. Harm may arise because of the cumulative effect of harm arising from an activity combined with harm arising from other activities or factors. The concept of cumulative effect of harm is important when surface waters have a history of previous impacts or the potential for present or future impacts from multiple activities or industries in the catchment. |
| Hazard | A biological, chemical, physical or radiological agent that has the potential to cause harm. |
| Industrial wastewater | Industrial wastewater produced from processes at industrial or commercial premises, including all waterborne waste from these facilities except sewage and prescribed industrial waste. |
| Ingestion | The act of swallowing something through eating, drinking, or mouthing objects. A hazardous substance can enter the body this way. |
| Irrigation | The artificial application of water to supply the water requirements of plants and crops for agricultural production, recreational land use or public amenity. |
| Manager (scheme manager) | The body (or bodies) identified as being responsible for the management of recycled water and for engagement with recycled water users. The responsibilities are defined within the NEMP. This is the same as the supplier in most cases. |
| NATA | National Association of Testing Authorities |
| NEPC | National Environment Protection Council |
| Percent reduction | An estimation of the change in concentration for individual emerging contaminants during the treatment process. It helps you to understand how different emerging contaminants behave in each treatment train.  The percent reduction is the percentage from the initial influent to final effluent concentration, based on the 48-hour autosampler influent concentration (Cinf) minus the 48-hour autosampler effluent concentration (Ceff), divided by the influent concentration (Cinf), expressed as a percentage (Luo et al. 2014):  **Percent reduction (%R) = 100 × % (C𝑖𝑛𝑓−C𝑒𝑓𝑓/C𝑖𝑛𝑓)**  where a positive reduction indicates a decrease, and a negative percent reduction indicates a potential increase.  Note that the autosampler is set to 15min sampling intervals and captures a 24-hr period. |
| PFAS | Per- and polyfluoroalkyl substances |
| Proponent (scheme proponent) | The body (or bodies) facilitating the development of a recycled water scheme, but which may not have responsibility for managing the scheme once recycled water is supplied. This may be a developer for instance. |
| PPCP | Pharmaceutical and personal care products |
| Recycled water | Water that has been derived from sewerage systems or industry processes and treated to a standard that is appropriate for its intended use. For the purpose of this guideline, the term does not include water derived from stormwater. |
| Recycled water system | The infrastructure that supplies and conveys recycled water from its source to its point of use and which may include a water recycling plant and other infrastructure. |
| Risk | The likelihood of identified hazards causing harm in exposed populations (over a specified time frame) and the severity of consequences due to exposure to the hazard. |
| Risk assessment | The overall process of using available information to predict how often hazards or specified events may occur (likelihood) and the magnitude of their consequences. |
| Runoff | Surface overland flow of water resulting from rainfall or irrigation exceeding the infiltration capacity of the soil. |
| Scheme | A recycled water scheme can be discrete or can be interconnected and can consist of treatment plants, distribution systems, reticulation networks and users. |
| Sewage | Water that has been used by households, commercial premises or industry and discharged to the sewerage system for treatment at a sewage treatment plant. Also described as wastewater. |
| State of knowledge | What you know, should reasonably know, or what can you find out about the risks your activities pose, which means all the information you should reasonably know about managing your business’s risks. This includes information from EPA and other sources. |
| Supplier (of recycled water) | The body responsible for supplying recycled water. This body may be responsible for producing a Recycled Water Quality Management Plan (RWQMP) if it is not produced by the scheme proponent or scheme manager. Often the scheme manager is the supplier. The supplier treats wastewater and provides recycled water for someone else to use (user) or use themselves. This is often a water corporation that might supply to a third party (market gardeners, residential premises) or use recycled water themselves. The supplier is the proponent when seeking approval. |
| Surface water | Waters other than groundwater. Examples include river, stream, billabong, lake, tidal water, estuary, marine and coastal water. |
| Toxicity | The degree of danger posed by a substance to human, animal or plant life. |
| Trade waste | Any waterborne waste (other than sewage) which is suitable, according to the criteria of a Water Authority, for discharge into the Authority's sewerage system. |
| Treatment train (TT) | A treatment train is a sequence of water treatment stages where each stage uses a specific treatment technology. The output of one treatment stage becomes the input for the next treatment stage. |
| Trigger points | A trigger point is the concentration in water or soil that will not pose an unacceptable risk of harm to people or the environment in relation to relevant emerging contaminants that has been calculated for a specific emerging contaminant in line with the guidance in this document. They are calculated when there is no government approved guideline value for the specific emerging contaminant. Trigger points are essentially a draft of the guideline value for water or soil that is designed to protect people or the environment. |
| US EPA | United States Environmental Protection Agency |
| User (of recycled water) | The body responsible for using recycled water. This body may be responsible for producing a user site management plan if it is not produced by the proponent, manager or supplier. The user receives recycled water from the supplier and uses it. This may include residential premises, market gardeners and councils (parks and gardens). |
| Wastewater | Waste principally consisting of water and including any of the following:   * sewage or another human-derived wastewater * wash down water or cooling water * irrigation runoff or contaminated stormwater * contaminated groundwater * water containing any commercial, industrial and trade waste. |
| Whole-effluent toxicity (WET) tests | Tests which refer to the aggregate toxic effect to aquatic organisms from all pollutants contained in effluent. WET tests measure wastewater's effects on specific test organisms' ability to survive, grow and reproduce. WET test methods consist of exposing living aquatic organisms (plants, vertebrates and invertebrates) to various concentrations of a sample of wastewater, usually from effluent stream. |
| Wastewater treatment plant (WWTP) | A treatment plant that treats wastewater. |
| Water recycling plant | A treatment plant that treats sewage from domestic and industrial sewer catchments and treats it for recycling; or treats industrial wastewater and treats it for recycling. |
| WHO | World Health Organization |

# References

Ahmed, M.B., Zhou, J.L., Ngo, H.H., Guo, W., Thomaidis, N.S., Xu, J., 2017. Progress in the biological and chemical treatment technologies for emerging contaminant removal from wastewater: A critical review. Journal of Hazardous Materials, Special Issue on Emerging Contaminants in engineered and natural environment, 323:274–298. https://doi.org/10.1016/j.jhazmat.2016.04.045

Ahmed, M., Mavukkandy, M.O., Giwa, A., Elektorowicz, M., Katsou, E., Khelifi, O., Naddeo, V., Hasan, S.W., 2022. Recent developments in hazardous pollutants removal from wastewater and water reuse within a circular economy. npj Clean Water 5, 1–25. https://doi.org/10.1038/s41545-022-00154-5

ANZG 2018, Australian and New Zealand Guidelines for Fresh and Marine Water Quality, A joint initiative of the Australian and New Zealand Governments in partnership with the Australian state and territory governments, viewed August 2018, <http://www.waterquality.gov.au/anz-guidelines>.

Australian Government, Department of Health, Australian Industrial Chemicals Introduction Scheme (AICIS), 2021. Galaxolide and a related polycyclic musk. Evaluation statement, pp 22.

Burgman M.A. 2005. Environmental Risk and Decision Analysis: For Conservation and Natural Resource Management. Cambridge University Press, London.

De Haas, D., Appleby, G, Charakos, G., Dinesh, N. 2018. Benchmarking energy use for wastewater treatment plants. Water e-journal, 3, 023. doi.org/10.21139/wej.2018.023

enHealth 2012a, Environmental Health Risk Assessment: Guidelines for assessing human health risks from environmental hazards, Commonwealth of Australia, viewed 18 October 2024, <https://www1.health.gov.au/internet/main/publishing.nsf/Content/A12B57E41EC9F326CA257BF0001F9E7D/$File/Environmental-health-Risk-Assessment.pdf>.

Environmental reference standard, 2022. A consolidated version of the Environment Reference Standard prepared by EPA in March 2022 in accordance with s.16F of the Subordinate Legislation Act 1994. https://www.epa.vic.gov.au/environment-reference-standard.

EPA Victoria 2018. Assessing and controlling risk: a guide for business. Publication 1695.1, EPA Victoria, Melbourne, viewed 13 July 2024, <https://www.epa.vic.gov.au/about-epa/publications/1695-1>.

EPA Victoria 2020. Reasonably Practicable. Publication 1856, EPA Victoria, Melbourne, viewed 13 July 2024, <https://www.epa.vic.gov.au/about-epa/publications/1856>.

EPA Victoria 2021a. Victorian guideline for water recycling. Publication 1910.2, EPA Victoria, Melbourne, viewed 6 June 2024, <https://www.epa.vic.gov.au/about-epa/publications/1910-2>.

EPA Victoria 2021b. Technical information for the Victorian guideline for water recycling. Publication 1911.2, EPA Victoria, Melbourne, viewed 2 July 2024, <https://www.epa.vic.gov.au/about-epa/publications/1911-2>.

EPA Victoria 2021c. Guide to the Environment Reference Standard. Publication 1992. EPA Victoria, Melbourne, viewed 18 October 2024, https://www.epa.vic.gov.au/about-epa/publications/1992.

EPA Victoria 2022. Victorian guideline for irrigation with recycled water. Publication 168.3, EPA Victoria, Melbourne, viewed 2 July 2024, https://www.epa.vic.gov.au/about-epa/publications/168-irrigation-with-recycled-water.

EPA Victoria 2023a. Guidance for environmental and human health risk assessment of wastewater discharges to surface waters. Publication 1287, EPA Victoria, Melbourne, viewed 18 October 2024, <https://www.epa.vic.gov.au/about-epa/publications/1287-guidance-for-risk-assessment-of-wastewater-discharges-to-surface-waters>.

EPA Victoria 2023b, Emerging contaminants in recycled water. Publication 2054, EPA Victoria, Melbourne, viewed 9 November 2024, <https://www.epa.vic.gov.au/about-epa/publications/2054-emerging-contaminants-in-recycled-water>.

EPA Victoria 2024, Recycled water use in surface waters guideline. Publication 3005, viewed 18 October 2024, <https://www.epa.vic.gov.au/about-epa/publications/3005-recycled-water-use-in-surface-waters>.

Fox, D.R. and Burgman, M. 2008. Ecological Risk Assessment. In: Encyclopedia of Quantitative Risk Analysis and Assessment, John Wiley and Sons.

Hart B, Burgman M, Webb A, Allison G, Chapman M, Duivenvoorden L, Feehan P, Grace M, Lund M, Pollino C, Carey J and McCrea A 2005. Ecological Risk Management Framework for the Irrigation Industry. Report to the National Program for Sustainable Irrigation (NPSI) by Water Studies Centre, Monash University, Clayton, Australia.

Knight, E.R., Verhagen, R., Mueller, J.F., Tscharke, B.J., 2023. Spatial and temporal trends of 64 pesticides and their removal from Australian wastewater. *Science of The Total Environment* 905, 166816. https://doi.org/10.1016/j.scitotenv.2023.166816.

Lee, T.H.Y., Ziegler, A.D., Marques dos Santos, M., Srinuansom, K., Tan, S.Y., Snyder, S.A., 2024. Spatial and temporal patterns of emerging and persistent contaminants in a mixed-use catchment: a case study of the Upper Ping in Northern Thailand. ACS EST Water 4, 4:4, 1531–1545. https://doi.org/10.1021/acsestwater.3c00634

Lewis, P., Neale, P.A., Tan, H., Leeder, J., O’Molley, E., Taylor, M.P., Leusch, F.D.L, Saaristo, M., 2025. A bioanalytical and chemical approach for wastewater discharge: Beyond detected chemicals for water quality assessment. Environmental Pollution, 383, 126807.

Luo, Y., Guo, W., Ngo, H.H., Ngheim, L.D., Hai, F.I., Zhang, J., Liang, S., Wang, X.C. 2014. A review on the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment. Science of the Total Environment, 473-474:619-641.

Manas, P., Castro, E. and de Las Heras, J., 2009. Irrigation with treated wastewater: effects on soil, lettuce (Lactuca sativa L.) crop and dynamics of microorganisms. Journal of Environmental Science and Health Part A, 44(12), pp.1261-1273.

Meng, Y., Zhang, J., Fiedler, H., Liu, W., Pan, T., Cao, Z., Zhang, T., 2022. Influence of land use type and urbanization level on the distribution of pharmaceuticals and personal care products and risk assessment in Beiyun River, China. Chemosphere 287:132075. https://doi.org/10.1016/j.chemosphere.2021.132075

Nguyen, H.T., McLachlan, M.S., Tscharke, B., Thai, P., Braeunig, J., Kaserzon, S., O'Brien, J.W., Mueller, J.F., 2022. Background release and potential point sources of per- and polyfluoroalkyl substances to municipal wastewater treatment plants across Australia, Chemosphere 293, 133657. https://doi.org/10.1016/j.chemosphere.2022.133657.

Radwan, E.K., Abdel Ghafar, H.H., Ibrahim, M.B.M., Moursy, A.S., 2023. Recent trends in treatment technologies of emerging contaminants. Environmental Quality Management, 32:7–25. https://doi.org/10.1002/tqem.21877

Rapp-Wright, H., Regan, F., White, B., Barron, L.P., 2023. A year-long study of the occurrence and risk of over 140 contaminants of emerging concern in wastewater influent, effluent and receiving waters in the Republic of Ireland. Science of The Total Environment 860:160379. https://doi.org/10.1016/j.scitotenv.2022.160379

Rout, P., Zhang, T.C., Bhunia, P., Surampalli. R.Y. 2021. Treatment technologies for emerging contaminants in wastewater treatment plants: a review. Science of the Total Environment 753:141990.

Saaristo, M. Sharp, S., McKenzie, R., Hinwood, A. 2024. Pharmaceuticals in biota: the impact of wastewater treatment plant effluents on fish in Australia. Environmental Pollution, 359:124695. https://doi.org/10.1016/j.envpol.2024.124695

Shahid, M.K., Kashif, A., Fuwad, A., Choi, Y., 2021. Current advances in treatment technologies for removal of emerging contaminants from water – A critical review. Coordination Chemistry Reviews 442:213993. https://doi.org/10.1016/j.ccr.2021.213993

Shi, Q., Xiong, Y., Kaur, P., Darlucio Sy, N, Gan, j., 2022. Contaminants of emerging concerns in recycled water: fate and risks in agroecosystems. Science of the Total Environment, 814:152527. https://doi.org/10.1016/j.scitotenv.2021.152527

Sunyer-Caldú, A., Quintana, G., & Diaz-Cruz, M. S., 2023. Factors driving PPCPs uptake by crops after wastewater irrigation and human health implications. Environmental research, 237, 116923.

Suter GW 2006. Ecological Risk Assessment. Second edition, CRC Press, Boca Raton.

Szabo, D., Marchiandi, J., Samandra, S., Johnston, J., Mulder, R.A., Green, M.P., Clarke, B.O., 2023. High-resolution temporal wastewater treatment plant investigation to understand influent mass flux of per- and polyfluoroalkyl substances (PFAS). Journal of Hazardous Materials, 447:130854. https://doi.org/10.1016/j.jhazmat.2023.130854

Tan, H., Fry, K., Richmond, E., Lewis, P., Saaristo, M., 2025. Recycled water use in irrigated crops 2023-2025. EPA publication, 50 pages.

Tiwari, B., Sellamuthu, B., Ouarda, Y., Drogui, P., Tyagi, R.D., Buelna, G., 2017. Review on fate and mechanism of removal of pharmaceutical pollutants from wastewater using biological approach. Bioresource Technology 224:1–12. https://doi.org/10.1016/j.biortech.2016.11.042

Verlicchi, P., Grillini, V., Lacasa, E., Archer, E., Krzeminski, P., Gomes, A.I., Vilar, V.J.P., Rodrigo, M.A., Gäbler, J., Schäfer, L. 2023. Selection of indicator contaminants of emerging concern when reusing reclaimed water for irrigation — A proposed methodology. Science of the Total Environment, 873:162359. https://doi.org/10.1016/j.scitotenv.2023.162359

Yap, H.C., Pang, Y.L., Lim, S., Abdullah, A.Z., Ong, H.C., Wu, C.-H., 2019. A comprehensive review on state-of-the-art photo-, sono-, and sonophotocatalytic treatments to degrade emerging contaminants. International Journal of Environmental Science and Technology 16: 601–628. https://doi.org/10.1007/s13762-018-1961-y.

Accessibility

Contact us if you need this information in an accessible format such as large print or audio.   
Please telephone 1300 372 842 or email [contact@epa.vic.gov.au](mailto:contact@epa.vic.gov.au)

Interpreter assistance



If you need interpreter assistance or want this document translated, please call 131 450 and advise your preferred language. If you are deaf, or have a hearing or speech impairment, contact us through the National Relay Service.



[epa.vic.gov.au](https://www.epa.vic.gov.au/)

Environment Protection Authority Victoria

GPO BOX 4395 Melbourne VIC 3001

1300 372 842

[A black and white x in a circle

Description automatically generated](https://twitter.com/EPA_Victoria) [A black letter f in a white circle

Description automatically generated](https://www.facebook.com/EPAVictoria) [A black and white circle with letters in it

Description automatically generated](https://www.linkedin.com/company/epa---victoria/) [A black and white logo

Description automatically generated](http://www.youtube.com/channel/UCTH9sYvphkFxGlAsIyTecJQ)



Authorised and published by the Victorian Government, 1 Treasury Place, Melbourne

1. https://rais.ornl.gov/ [↑](#footnote-ref-2)
2. <https://www.echemportal.org/echemportal/> [↑](#footnote-ref-3)
3. https://comptox.epa.gov/dashboard/ [↑](#footnote-ref-4)
4. https://www.epa.gov/risk/regional-screening-levels-rsls [↑](#footnote-ref-5)
5. <https://ordspub.epa.gov/ords/pesticides/f?p=chemicalsearch:1> [↑](#footnote-ref-6)
6. <https://pubchem.ncbi.nlm.nih.gov/> [↑](#footnote-ref-7)
7. <https://echa.europa.eu/> [↑](#footnote-ref-8)
8. <https://www.efsa.europa.eu/en> [↑](#footnote-ref-9)
9. <http://echidnacec.com/> (this database is a compilation of information from other databases (mostly USEPA ones); checking the original sources may be more helpful) [↑](#footnote-ref-10)