Final Report

Exposure of cattle to *Taenia saginata*

Mitigation of *T. saginata* exposure to cattle and incidence of C. bovis via official wastewater treatment in Australia

Project Code
2022-1082

Prepared by
Dr Daryl Stevens and Dr Andrew Pointon

Date Submitted
7/2/2022

Published by
Australian Meat Processor Corporation

Date Published
7/2/2022

Contents

Abbreviations

ABS	Australian Bureau of Statistics
ACT	Australian Capital Territory
AGWR	Australian Guideline for Water Recycling
AMPC	Australian Meat Processing Corporation
AMRG	Australian Meat Regulators Group
ANOVA	Analysis of Variance
ASP	Activated Sludge Plants
CCP	Critical control point
CVO	Chief Veterinary Officer
DAWE	Department of Agriculture, Water and Environment
ECP	Environmental control points
EPA	Environmental Protection Authority
HACCP	Hazard Analysis and Critical Control Point
HE	Helminth egg
HRT	Hydraulic retention time
LGA	Local Government Authority
LRV	Log Reduction Value
MEDC	Meat Export Data Collection
NCC	Neurocysticercosis
NLIS	National Livestock Identification System
NOW	NSW Office of Water
NSW	New South Wales
NT	Northern Territory
PMI	Post-mortem inspection
PW	Pathway
QMRA	Quantitative Microbial Risk Assessment
RMR	Risk management rating
RWMP	Recycled water management plan
SA	South Australia
STH	Soil-Transmitted Helminth
WA	Western Australia
WHO	World Health Organisation
WWTP	Wastewater Treatment Plant

Definitions

Recycled water	Water recycled from wastewater containing human faecal material such as raw sewage, septic tank, on-site treatment systems and greywater systems.
C. bovis	Cysticercus bovis causes small cysts in the muscles of cattle. Cattle (definitive host) develop the cysts from the eggs of the helminth *Taenia saginata* found in the faeces of infected humans (intermediate host).

1 Executive Summary

1.1 Objective

The objective of this report was to prepare a situation report of relevant wastewater treatment plants (WWTPs) in Australia regarding the current controls documented for preventing exposure of cattle to *T. saginata* eggs when recycled water is used in the associated farming operation. The treatment systems that produce recycled water are predominantly centralised treatment of sewage (by volume treated), and also potentially include on-site treatment (e.g. greywater, septic tank, on-site treatment systems). Recycled water can be exposed to cattle by irrigation of feed sources, supply of cattle drinking water, and incidental exposure pathways (e.g. sewage effluent released to surface waters that could be exposed to cattle, or poor operation of on-site systems).

The overall aims were to:

- document public health and environmental regulatory and guideline arrangements (through the supply chain) to prevent *T. saginata* exposure of cattle from treated wastewater (Recycled water),
- identify gaps in these regulatory arrangements, and
- assist in the interpretation of results from Cysticercus bovis (C. bovis) detection data over the past 20 years.

1.2 Methodology

A desk-top situation report was undertaken to review the regulation and guidance in states and territories of Australia to produce recycled water fit for the purpose of producing cattle feed (pasture and fodder) and cattle drinking water. Fit-for-purpose in the context of this reports refers to minimising the risk of detecting C. bovis in cattle by ensuring appropriate control measures are in place to manage *T. saginata* egg exposure to cattle via recycled water.

To complete this a system was developed to rate the relevant guidelines used for the protection of cattle from C. bovis and the ated auditing requirements for each state and territory of Australia. Ratings used were: High - satisfactory; Moderate - some improvement required; and Low - unsatisfactory.

1.3 Findings and discussion

The Australia Guideline for Water Recycling (AGWR)(NRMMC et al., 2006) provides the risk management framework based on international standards, including a Hazard Analysis and Critical Control Point (HACCP) component, to assess and manage the risk of C bovis. These principles are used to manage helminth eggs in recycled water with limited control measured identified in the AGWR. The performance criteria for helminth controls specify in the AGWR that a log removal value (LRV) of 4 is required. This is equivalent to a 99.99% removal performance by the treatment plant, or equivalent. Achievement of a LRV of 4 ensures the recycled water is fit for the purpose of cattle production.

Post publication of the AGWR, these basic principles have also been utilised, with knowledge from a number of recent scientific publications (2017 to 2021), to highlight additional treatments and on-site control options to provide additional options for minimising the risk of C. bovis in cattle.

The relevant guideline in states and territories of Australia now reflect the guidance for helminth management documented in the AGWR in 2006, and the AGWR have been implemented across Australia through various state and territory guidelines for water. However, comparison of the documented risk management controls and audit requirements for helminth between states and territories indicated that the helminth risk may not be managed appropriately in the NT and SA, and the auditing could be improved in SA and Tas (Figure 1-1).

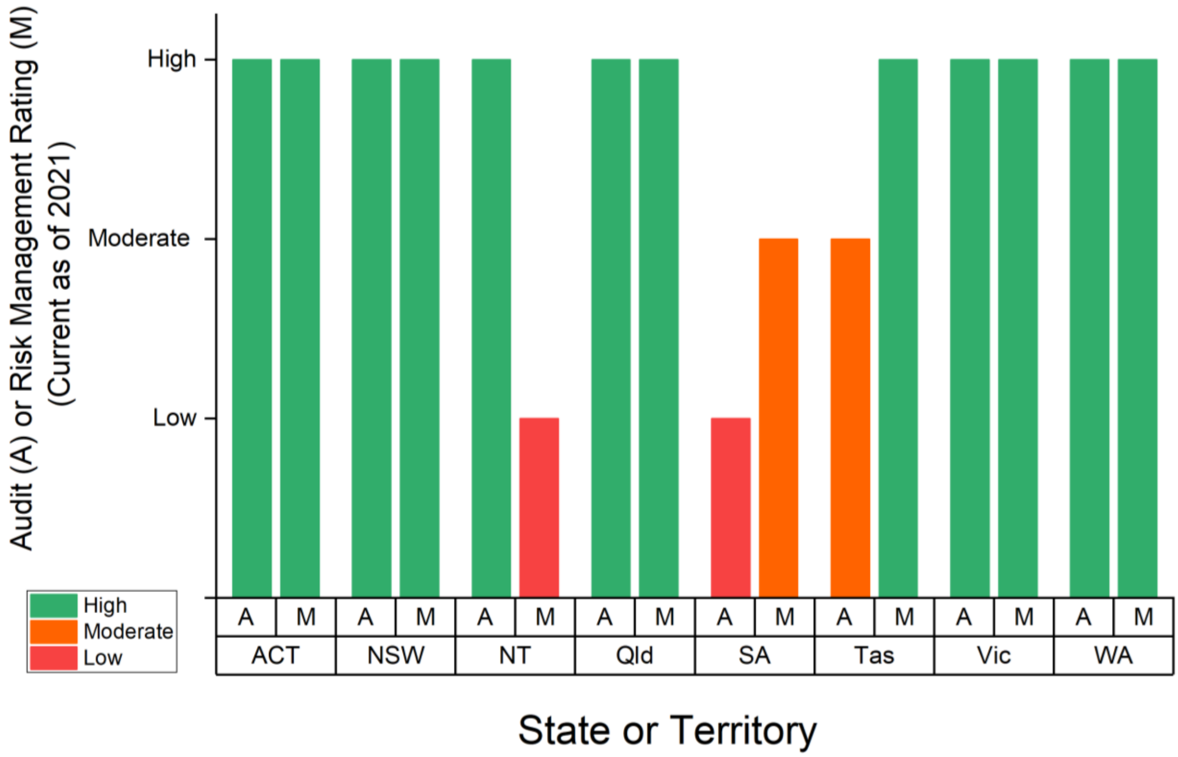

Figure 1-1 Comparison of most current documented audit or risk management rating for states and territories of Australia (Table 5-2 and Table 5-3). High = Acceptable, Moderate = should be improved, Low = not appropriate.

The volume of recycled water produced from centralised WWTP was the highest for agricultural sector Pasture and animal husbandry. The use of recycled water in these sectors has not changed significantly from 2000 to 2019. The volume of recycled water used in this sector was estimated to expose 0.7% of the national cattle population to recycled water annually (an exposure rate of 7,000 $\times 10^{-6}$). This is a significantly higher frequency than C. bovis detection via PMI (an incidence rate of 0 to 4.28 $\times 10^{-6}$). This incident rate for C. bovis detection was from a recent survey of C. bovis in cattle via post-mortem inspection (PMI), indicating that C. bovis (PMI) is rarely detected. Such a low incidence rate, supported by the low number of *T. saginata* eggs found in sewage, indicated that the presence of *T. saginata* in the human population in Australia is very low.

There have been no documented outbreaks of C. bovis related to well managed recycled water schemes. However, the ongoing management of *T. saginata* egg in recycled water (baseload and outbreaks) provides an important control measure that breaks the life cycle of *T. saginata* and minimises the risk C. bovis in cattle.

The impact of the AGWR for the improvement of *T. saginata* egg removal and managed during the production of recycled water is supported by the C. bovis incidence rate. A significant decrease was found in the incidences of carcass condemnation from C. bovis pre- to post-publication of the AGWR. Given the calculated low incident rates, this link is not definitive and could be due to other factors. However, through in-the-field experience, we are aware of some recycled water scheme operations that have improved helminth management and awareness based on the AGWR.

1.4 Conclusions and recommendations

1.4.1 Conclusions

The regulatory arrangements (through the supply chain) to prevent *T. saginata* egg exposure of cattle from recycled water (from sources of human sewage) have been documented for centralised and on-site wastewater treatment systems. Overall guidance for both WWTPs systems typically provides a robust system for managing helminth egg exposure to cattle in Australia. However, gaps in this guidance were identified for some states and territories.

The AGWR was released in 2006 and bases helminth egg management on the treatment system achieving a log reduction value of 4.0 (99.99% removal efficiency or equivalent). Most states and territories achieved a high rating for implementing the guidelines in their related guidance. However, there were some exceptions.

The C. bovis condemnation data assessed suggested that publication of the AGWR have helped lower the incidence rate of C. bovis detected via PMI. The next steps are to align the AGWR with C. bovis data from Department of Agriculture, Water and Environment (DAWE) in AMPC Project 2021 – 1186: Phase 1, to assess this interaction and investigate the integration of the helminth controls used for cattle production with recycled water with the overall supply chain.

Promotion of the benefits for maintaining helminth egg control via centralised and on-site wastewater treatment systems is essential to ensure those who regulate recycled water use are aware of the importance of this control measure and appropriate guidance is continued in future revisions of guidelines for recycled water use.

1.4.2 Recommendations

Recommendations from this report are:

1. There is a trend for health departments (i.e. human health) to rate recycled water schemes that irrigation pasture and fodder as low risk (to humans). As a low-risk scheme, management is then simplified by not requiring management plans. These plans are typically used for the auditing process that determines if appropriate helminth egg management is in place and maintained. Such a trend could lead to *T. saginata* egg management oversites in the future. Such potential oversites need to be brought to the attention of relevant government departments to ensure the controls for helminth egg management is maintained in the future. For example, if recycled water that is fit-for-purpose was an integral part of the production quality assurance guideline for cattle production, this could trigger requirements for recycled water guidelines.

2. Amendments should be made to all on-site treatment guidelines for states and territories across Australia that do not specifically mention exclusion cattle from irrigation areas, as done in NSW. Or, excluding all livestock from the irrigation area to maintain the soil structure and manage helminth risks.

3. How well the documented guidance in states and territories of Australia are implemented practically for all relevant exposure pathways for cattle needs verification. This verification should assess how well recycled water schemes are maintained and audited in the context of preventing *T. saginata* egg exposure to cattle with the responsible government authority (e.g. Department of Health, EPA).

4. Verification of the controls measures for *T. saginata* egg management in the AGWR and any modification and improvements should become integrated with PMI for C. bovis cysts. Current research suggests that helminth controls may be over-protective, leading to increased water treatment costs prohibiting access to recycled water for some sectors of the cattle industry. The most cost effective approach to meet supply chain requirements needs to be investigated.

5. Consideration of grazing history is not relevant for recycled water as it should be fit for the intended purposes of cattle production concerning helminth management if the AGWR guidance is followed, verified, and audited. However, if this quality assurance system for recycled is not used, then C. bovis detection in cattle could be considered to improve management. In this case, the grazing history related to recycled water exposure may be of use. The integration of the recycled water quality assurance system into the whole supply chain should be explored as an alternative C. bovis management system.

2 Introduction

This project (FRP200984), Mitigation of *T. saginata* egg exposure to cattle via regulation of wastewater treatment in Australia, is part of Phase 1 of Project 2021-1186 Risk Management Equivalence Case for Cysticercus bovis (C. bovis) post-mortem inspection (PMI) changes (Figure 2-1).

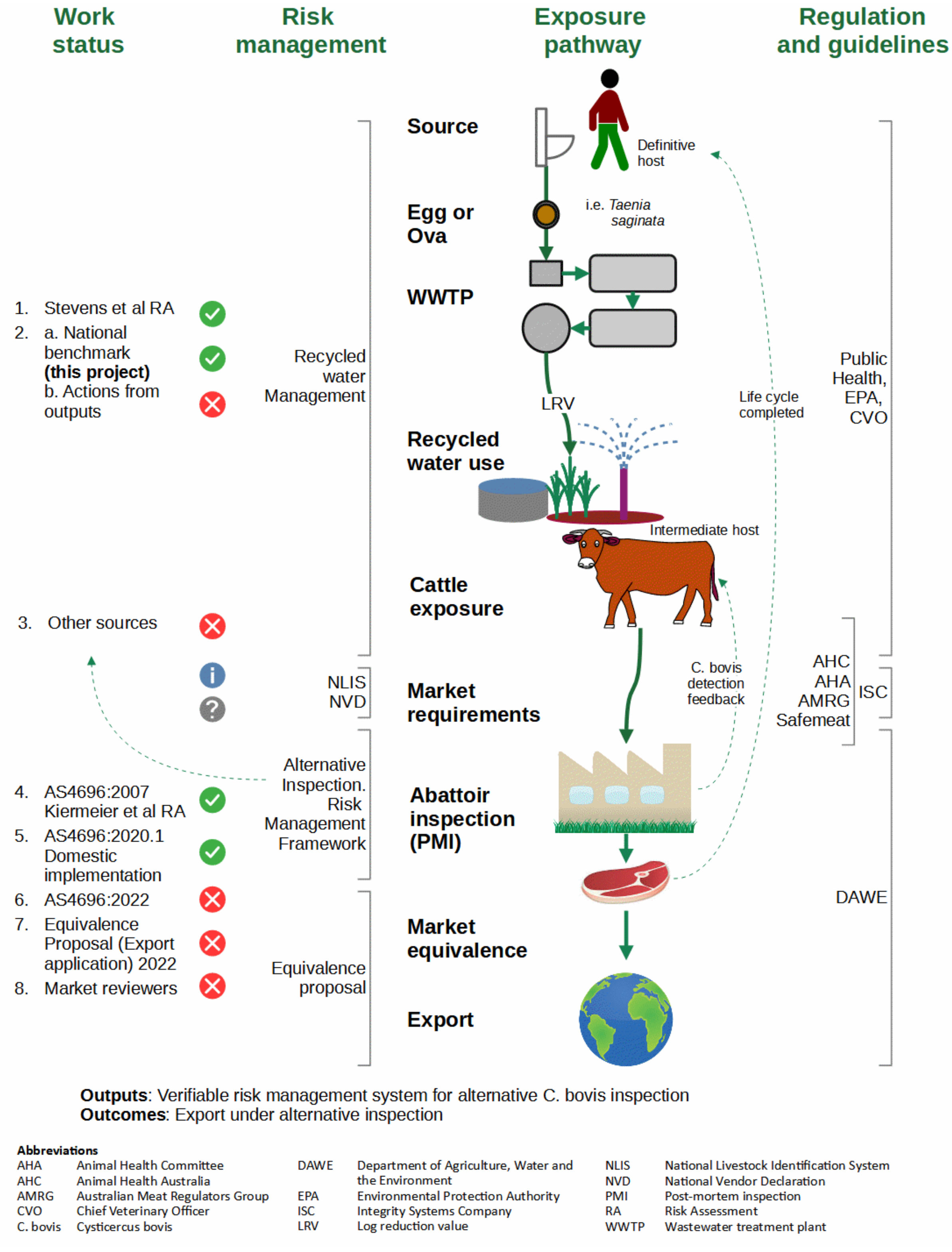

Figure 2-1 C. bovis Risk Management Project: Overview

The overall aim was to capitalise on the associated national survey work and the quantitative risk assessment that has led to changes in C. bovis inspection in Schedule 3 of AMRG Guideline (AS4696:2020) to be read in conjunction with (AS4696, 2007; Pearse et al., 2010; Kiermeier et al., 2019; AMRG, 2020). A revision to the 2007 version is currently being commissioned by Standards Australia (Lucas, 2021). While alternative inspection for C. bovis has been implemented in the domestic sector since the 1st of March 2020, implementation in export establishments depends on the acceptance of the equivalence by Australian importing markets, particularly the United States. This project focuses on validating the amended risk management framework that considers grazing history for C. bovis (PMI) in cattle as a central pillar of the equivalence case to overseas beef export markets.

3 Project Objectives

The report's objectives were to prepare a situation report of relevant wastewater treatment systems in Australia. These treatments systems are primarily (by volume treated) centralised treatment of sewage, but also include treatment of human sewage on-site (e.g. greywater, septic tank, on-site treatment systems). The objective was to assess control of *T. saginata* eggs exposure to cattle via irrigation of cattle feed sources, supply of cattle drinking water and incidental exposure pathways (e.g. sewage release to surface waters that could be exposed to cattle).

This project (FRP200984) describes the public health system that authorises the safe use of treated wastewater for irrigation of stockfeed. In doing so, it will:

- document regulatory arrangements (through the chain) to prevent *T. saginata* exposure of cattle from treated wastewater (Recycled water),
- identify gaps in these arrangements,
- assist additional interpretation results of C. bovis detection data over the past 20 years,
- facilitate consultation with AHC, CCA, ISC, MLA and SAFEMEAT to define further work,
- update industry and jurisdictional stakeholders on the related control measures for mitigation of associated risks, and
- define work required in Phase 2 of AMPC Project No: 2021 – 1186 with the animal health jurisdictions.

4 Methodology

4.1 Desk-top situation report

A desk-top situation report was undertaken to provide the first step towards an exposure assessment of cattle to *T. saginata* eggs via irrigation of feed sources that can cause C. bovis in cattle. The situation report assesses controls and guidance in Australia for managing the risk of *T. saginata* eggs in recycled water used for irrigation of pasture and fodder, and livestock drinking water. Five main areas were assessed:

1. The rationale of Australian Guideline for Water Recycling (AGWR) (NRMMC et al., 2006);
2. Performance criteria of relevant guidelines to manage *T. saginata* eggs;
3. Implementation of the guidelines and their use across Australia;
4. Recycled water used in primary production sectors, focusing on use with cattle; and
5. Mitigation of *T. saginata* exposure to cattle 2001 to 2020.

4.2 Rating of guidelines and auditing documentation

The guidance documentation in a published guideline for the management of *T. saginata* eggs in recycled water was rated as:

- Low - needs to be improved or investigated further.
- Moderate - could be acceptable management. However, it needs confirmation from EPA, or equivalent, to how the guidelines are actioned.
- High - documented controls and management are ideal. If implemented correctly, there should be a low risk of *T. saginata* exposure to cattle.

The auditing documented in the guidelines were rated as:

- Low - not mentioned in the guideline.
- Moderate - confusing and limited information.
- High - easy to understand and provide an ongoing management strategy.

As a rule of thumb, the ratings for both the guidance and auditing documentation for protection of cattle from C. bovis were: High - satisfactory; Moderate - some improvement was required; and Low - unsatisfactory.

4.3 Statistics

A simple model was developed to estimate the head of cattle exposed to recycled water annually. The model used a Monte Carlo simulation to capture the inherent variability of this estimate. Values from the simulation were reported as the median (5th, 95th percentile) to indicate the most likely and possible ranges in values while excluding the extremes that can sometimes be an artefact of this type of modelling.

Data sets from the literature were reported as mean (minimum, maximum).

5 Project Outcomes

5.1 Australian Guidelines for Water Recycling

Since 1990, Australia has moved from small scale irrigation of pastures adjacent to sewage treatment plants to major irrigation schemes using recycled water. This expansion of recycled water use has been accompanied by the development of appropriate guidelines for managing the associated health and environmental risks, together with extensive guidance materials to assist farming businesses in establishing successful practices (Stevens and Anderson, 2013).

The Australian Guidelines for Water Recycling (AGWR) (NRMMC et al., 2006) currently provide the underpinning principles and minimum standards for the treatment of sewage influent to produce recycled water that is fit for the purpose of cattle husbandry in Australia (i.e. fit-for-purpose). This includes the use of recycled water for pasture, fodder and crop irrigation, livestock drinking water, and shed or stockyard wash down (NRMMC et al., 2006). One aim of the AGWR was to ensure that all states and territories of Australia had the best available guidance for the use of recycled water, ensuring its adoption and use across Australia as a valuable water resource.

The AGWR framework provides a structured risk-based approach to recycled water management. It incorporates the concept of identifying and producing recycled water of a quality that is 'fit-for-purpose' and suitable for intended use prior to supplying it to the user. The framework comprises 12 Elements organised within four areas (Figure 5-1):

1. **Commitment** to responsible use and management of recycled water. This involves a commitment to developing and applying preventive risk management to support the sustainable and safe use of recycled water.

2. **System analysis and management**. This involves understanding the entire recycled water system, the hazards and events that can compromise recycled water quality, and the preventive measures and operational controls necessary for risk minimisation, assuring safe and reliable supply and use of recycled water.

3. **Supporting requirements.** These requirements include basic elements of good practice such as employee training, community involvement, research and development, validation of process efficacy, and systems for documentation and reporting.

4. **Review**. This includes evaluation and audit processes to ensure that the management system is effective, and provides the basis for review and continual improvement. Effective risk management systems are not static and must be capable of accommodating change, such as emerging issues, advances in technology and new institutional arrangements. Development should be an ongoing process whereby performance is continually evaluated and reviewed.

The AGWR framework has a Hazard Analysis and Critical Control Point (HACCP) component which is used to undertake this assessment. It also uses the basic risk assessment principles to assess and manage any associated risks (IEC/ISO, 2009; ISO, 2018). The AGWR deals with recycling stormwater, greywater, and treated sewage (NRMMC et al., 2006, 2009a). It states that water for recycling can come from centralised schemes or smaller on-site systems involving, for example, treated sewage or greywater. Noting that on-site systems are generally privately owned, and many are installed on domestic blocks.

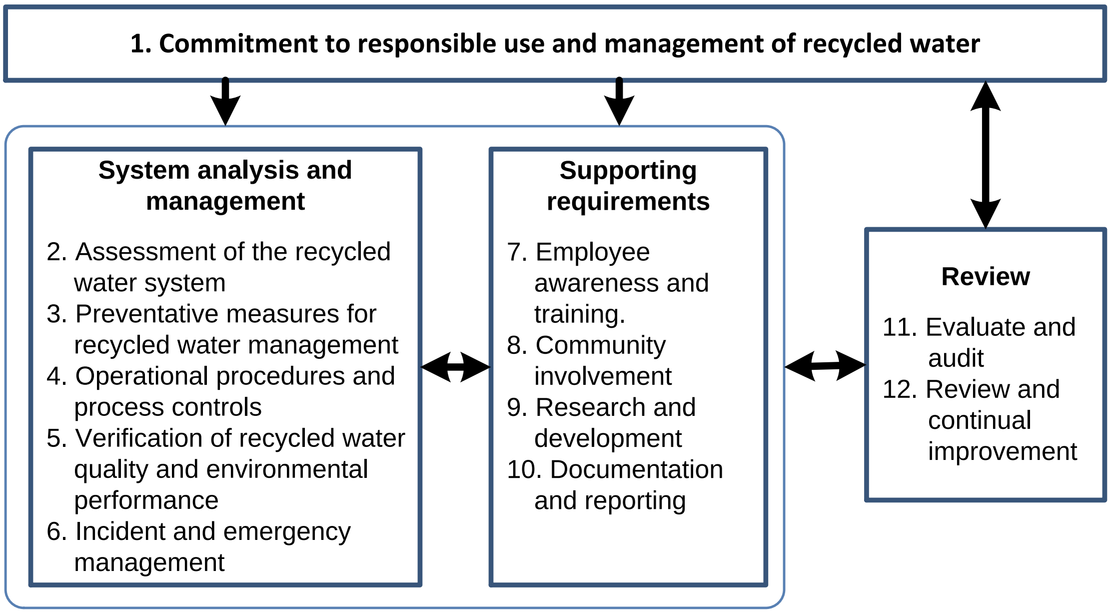

Figure 5-1. The 12 Elements within the four areas of the framework for managing recycled water quality and use (reproduced from the AGWR (NRMMC et al., 2006)).

5.1.1 Aims of the standard pathogen management focusing on *T. saginata* risk management in AGWR

The AGWR (NRMMC et al., 2006) state for *T. saginata* egg management that…

> "Cattle exposed to ova (eggs) of *Taenia saginata*, the human tapeworm, may develop the parasitic cysts of 'beef measles', or Cysticercus bovis (C. bovis). Cysticercus bovis not only causes cysts in cattle, but also has potential to affect human health — eating poorly cooked, contaminated meat can result in infection with the tapeworm. In addition to human health risks, the detection of *T. saginata* in export beef can have economic implications by affecting trade.
>
> The control of *T. saginata* in treated sewage that is to be used in contact with cattle has previously been prescribed through either 25 days of detention in waste stabilisation ponds or equivalent treatment (ARMCANZ et al., 2000). This has seen effective management of the risk posed by *T. saginata*. However, there is no guidance on what constitutes 'equivalent treatment'.
>
> Using the empirical model described by Ayres et al. (1992), a mean hydraulic retention time of 25 days equates to approximately 4 log removal value (LRV detailed in Section 5.2.1) of helminth ova. Therefore, this is the target that alternative treatment processes to waste stabilisation ponds should meet if *T. saginata* requires specific management."

Since the publication of the AGWR in 2006, more recent research in southern Australia has indicated that the exposure risk of *T. saginata* eggs to cattle can also be managed with various other treatment options and consideration of other attributes of the recycled water scheme. Treatment of risk and the associated end-uses can be assessed using an improved empirical model to quantify the associated risk (Stevens et al., 2017, 2021a). These assessments are based on the low baseload concentrations of helminth eggs (HE) in raw sewage influent entering WWTPs. In the last decade, a comprehensive analysis of helminth eggs in southern Australia detection no *Taenia spp.* eggs. Therefore, as the baseload of HE in sewage is inherently low, a requirement for 4 LRV of *T. saginata* eggs is very protective given the last decade of baseline load concentrations in sewage. However, recent risk assessments have highlighted how 3.0 to 4.0 LRV (LRV defined in Section 5.2.1) continues to protect against any outbreak of taeniasis in the community (Stevens et al., 2021a). As no *T. saginata* eggs were detected in sewage or recycled water in southern Australia in the last decade (Stevens et al., 2017, 2021a, 2021b), the disease is rare in this part of Australia. Others have also identified this (Kiermeier et al., 2019). It is most likely due to the quality of recycled water produced in Australia and the associated control measures for centralised WWTPs and on-site treatment systems. It could also be attributed to PMI for cysts and freezing or cooking of meat breaking the life cycle of *T. saginata* (Figure 5-2).

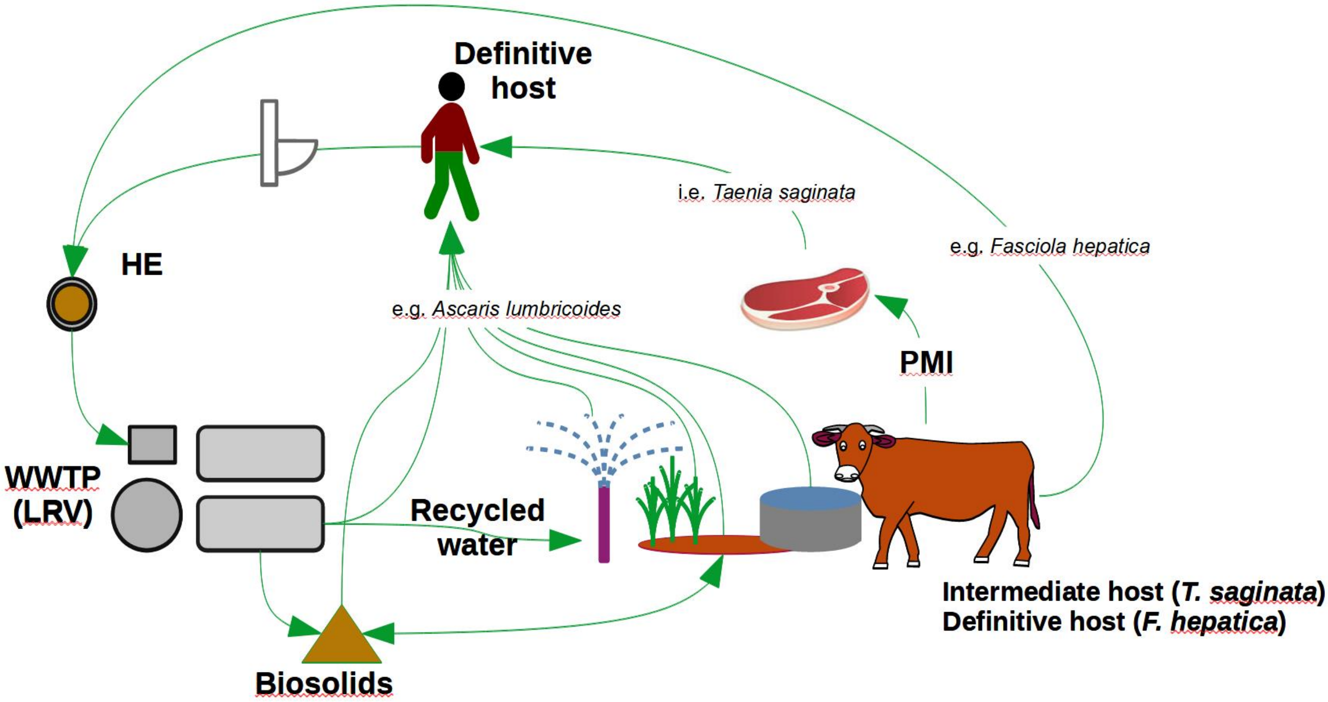

Figure 5-2 Examples of major transmission routes of helminth egg (HE) relevant to protecting human and stock health from sewage treatment. WWTP = wastewater treatment plant, PMI = Post-mortem inspection, LRV = Log Reduction Value. the intermediate host for F. hepatica (snails) is not shown. Modified from (Stevens et al., 2021b)

5.1.2 Summary of consultation with livestock stakeholders

The AGWR was drafting was overseen by a Joint Steering Committee of state and territory representation from Environmental Protection Authority (EPA), Health departments and other relevant government departments. The steering committed utilised two risk working groups, Human Health and Environmental (Farming system were within the environment), to draft the document. As the *T. saginata* life cycle spanned both working groups (human and cattle), each group understood that the other would consider this risk. This oversite was not recognised until near the completion of the draft. Therefore, the risk management for helminth eggs was derived nearing the end of the drafting, with limited time for consultation or development of new control measures suitable for Australia.

Post drafting, the AGWR was available for public comment and feedback via the steering committee and working groups.

5.1.3 Public health hazards mitigated, focusing on stock related hazards

The AGWR focuses on controlling risk related helminth via four major exposure pathways. The first exposure pathway is not stock related (*Ascaris lumbricoides*, an indicator for human risks, and *Trichuris*) (PW1 of Figure 5-3). The other helminth related risks identified by the AGWR are *T. saginata* and *T. solium* (PW2 and PW3 of Figure 5-3). The 4th pathway is not explicitly mentioned in the AGWR. However, it potentially poses a risk if there is a stockyard and abattoirs in the sewer catchment where cattle related helminth could be exposed to other cattle.

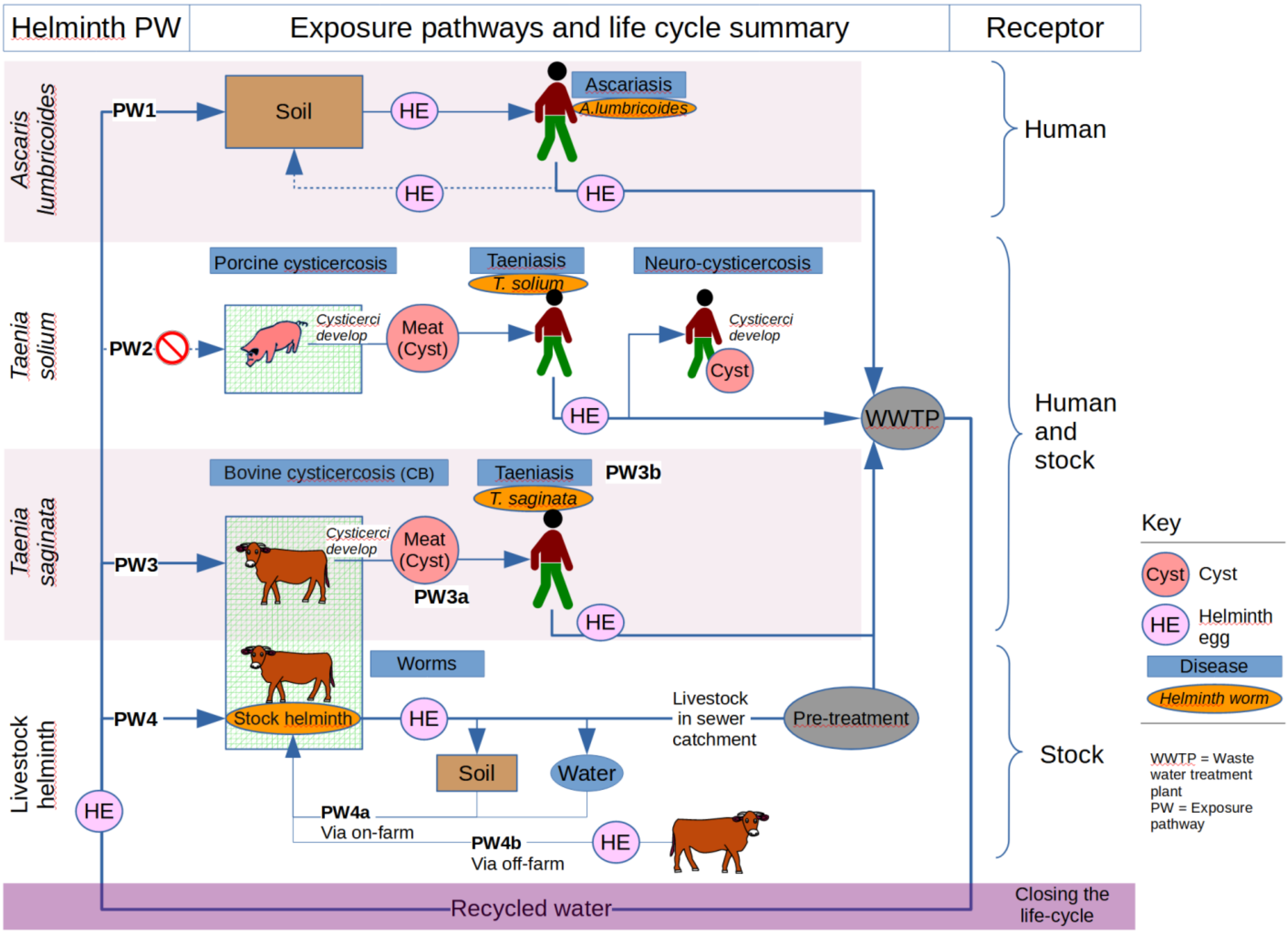

Figure 5-3 The four major pathways of helminth egg (HE) exposure possible to humans and livestock from wastewater treatment plants (WWTP) via the production and use of recycled water and the related human and animal diseases. Subcomponents of each pathway (PW) are designated with a and b. An example of a stock helminth is Fasciola hepatica (PW4). (Stevens et al., 2021a)

5.1.4 The concept of fit-for-purpose and preventive management of risks via approved treatment processes or on-site restrictions

The risk management approach outlined in the AGWR incorporates the concept of identifying and producing recycled water of a quality that is 'fit-for-purpose'. The central principle of the guidelines is that all recycled water schemes require a proactive risk management plan to assure safety and sustainability. The risk management plan is developed to ensure that recycled water quality is maintained to acceptable levels, using control measures that can confidently be applied and maintained and ensure all residual risks are low (i.e. at acceptable levels). The final step in implementing a recycled water scheme is to verify that the management system consistently provides recycled water of a quality that is fit for the intended use (i.e. 'fit-for-purpose'). For example, no *T. saginata* eggs in recycled water, or no C. bovis cysts are identified in cattle from a PMI.

The core of the risk assessment process assesses risk:

- without control measures (maximum risk) and

- with control measures (residual risk), based on control measure and confidence in the efficiency of the control measure.

The AGWR use critical control points (CCP) for managing the system. The system is based and standard risk assessment and concepts used in drinking water guidelines (IEC/ISO, 2009; NHMRC and NRMMC, 2011; WHO, 2017). Such a system is similar to principles used in HACCP for food safety [1], adapted for the nuances of recycled water.

As outlined above, the management of helminths in the AGWR specifies two treatment process steps to manage helminth eggs:

- Secondary treatment with helminth reduction (>25 days of lagoon detention or an equivalent filtration process) and disinfection, or
- Primary treatment with >50 days of lagoon detention and disinfection.

From research published in 1992, the AGWR indicate that a mean hydraulic retention time of 25 days equates to approximately 4 LRV of helminth ova (Ayres et al., 1992; NRMMC et al., 2006). Therefore, this is the target that alternative treatment processes to waste stabilisation ponds should meet if *T. saginata* requires specific management. Such a target would ensure the recycled water is fit for the purpose of exposure to cattle and minimise the risk of contracting C. bovis.

There are no on-site controls detailed in the AGWR. However, a recent estimation of a dose-response curve for infection of cattle with C. bovis has allowed the consideration of these for LRV equivalents (Section 5.1.5.2).

5.1.5 Treatment technologies and frequency of their use in WWTPs in Australia

5.1.5.1 Accepted standard treatment processes

The AGWR recognised at the time of publication that a limitation in approaching the management of livestock health risks associated with recycled water use is that virtually no dose-response models are available for infection in animals. Therefore, water quality objectives cannot be derived using quantitative risk assessment tools. Consequently, the AGWR adopted a practical approach to overcome this limitation. This approach assumed that the livestock industry has traditionally used specific controls to manage key hazards. Since these controls have been effective, it was proposed that they continue to be adopted.

The most common technology used for helminth controls in Australia is 25 days hydraulic retention in a lagoon system after secondary treatment (e.g. activated sludge plant – ASP) (Figure 5-4). These WWTPs are a historical legacy of low cost, low maintenance and effective WWTPs used for sewage treatment across Australia for many decades. However, as populations increase and flow to WWTPs increases, the hydraulic retention for 25 days in many WWTPs is being challenged. To maintain this recognised control measure for helminths, alternative treatment or upgrades to WWTPs are required. Advance filtration can provide this treatment (e.g. reverse osmosis, micro disc filtration or media). However, this is usually cost prohibitive and rarely used directly for this purpose in Australia.

A specific sand filtration process is approved by the Chief Veterinary Officer (CVO) in Victoria. The CVO specifies a sand filtration method or an equivalent microfiltration system that excludes particles greater than 20 microns diameter. The minimise diameter of a helminth egg is 25 microns. The sand filtration must pass through a sand filter having a depth of sand not less than 600 mm, and the sand have an effective size not greater than 0.5 mm and a uniformity coefficient not greater than 4 (EPAV, 2021a).

[1] https://www.foodsafety.com.au/blog/the-seven-principles-of-haccp

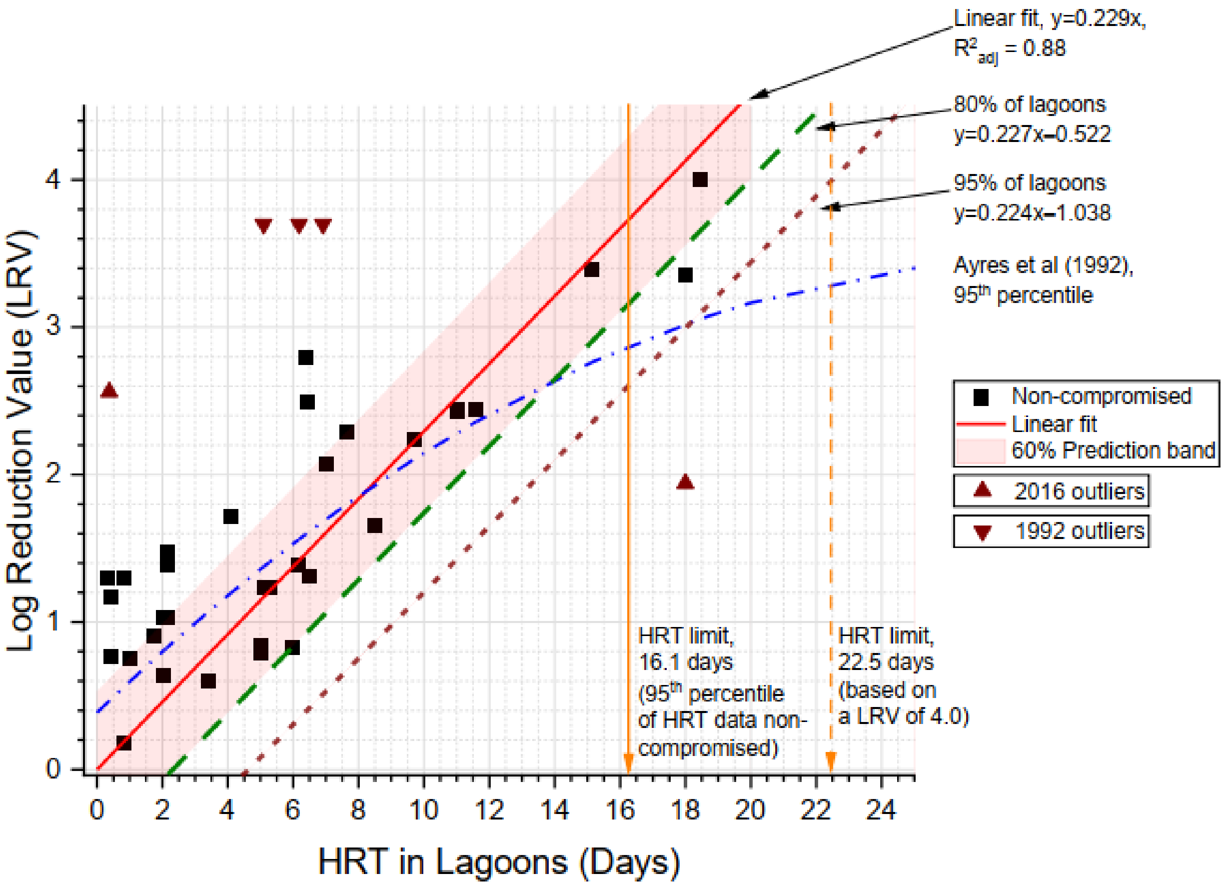

Figure 5-4 Log reduction value (LRV) design equation proposed for lagoons designed for wastewater stabilisation. The green long-dashed line represents what 80% of lagoons would achieve (i.e. the lower 60% Prediction band) and is proposed for lagoons with a high level of design and management; data from Stevens et al. (2017). The LRV equation for 95% of lagoons (brown short-dashed line) was the design equation originally proposed by Stevens et al. (2017). The blue dot-dash line is the 95th percentile design equation originally proposed (Ayres et al., 1992). Hydraulic retention time (HRT) limits are discussed in the text.

5.1.5.2 Approval for non-standard risk-based treatment processes

Recent estimates of HE concentration in sewage, possible outbreak concentrations and an estimated dose-response curve for infection of cattle with C. bovis have indicated that additional controls measures to those currently in the AGWR may be appropriate. These control measures include a range of system attributes that can ensure the risk of C. bovis infection is minimised to acceptable levels (Stevens et al., 2017, 2021b, 2021a). For example, there is adequate data now to recognise that well-operated ASPs should provide some removal of helminth eggs (Figure 5-5). The HRT is one method of assessing the effectiveness of achieving the accredited LRVs.

Heat treatment can also be used to destroy helminth (Figure 5-6). Yet heat is rarely used as a sewage treatment step, most likely due to the energy cost of heating large volumes of water from approximate 20ºC to 45ºC for a day to ensure *T. saginata* eggs are inactivated (Figure 5-6).

Stevens et al. (2021a) also indicate that various site and catchment attributes can lower the risk of exposure, such as:

- Larger WWTPs – providing a buffering and dilution factor from outbreaks in the community.
- Provision of other water sources for cattle drinking water, limiting the direct ingestion of recycled water by cattle – cattle can drink on average 22 to 70 L/day (FutureBeef, 2019).

- Less than one year of exposure to plant biomass irrigated with recycled water – the risk is lowered if not exposed for a lifetime.
- Fodder cut and removed for feeding off-site – removes exposure to drinking water and soil ingestion and potential enhancement of thermal deactivation of the egg.
- Monitoring sewage for outbreaks – allows cessation of supply or other action to limit the exposure or exposure time.

These parameters are not yet approved in any guideline. However, the recently updated Victoria guideline for recycled water indicates that alternatively to the standard acceptable treatment systems, a risk-based assessment and derivation of the level of reduction required can be separately agreed with the CVO and EPA. The guideline notes that where the objective is to protect human health directly (for example, no livestock involved in the transmission process), the helminths' treatment requirements can be different to, and potentially be less stringent than, where the recycled water will be supplied to cattle or livestock. Therefore, risks associated with direct human exposures and the related health impacts on humans can be assessed separately from risks associated with exposures of livestock. This type of risk management approach will become more common as the data is collated over time to support it.

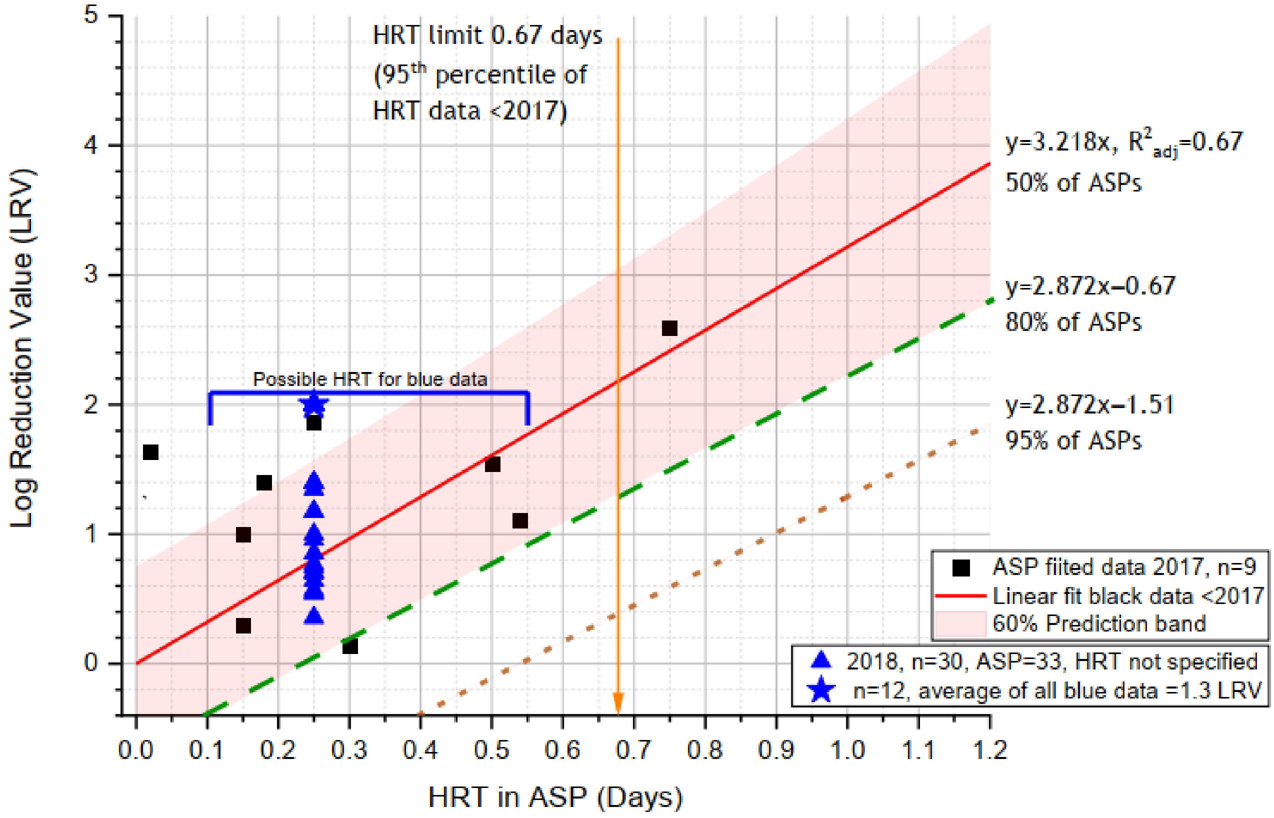

Figure 5-5 Log reduction value (LRV) design equation proposed for Activated Sludge Plants (ASPs). The red long-dashed line represents what 80% of ASPs would achieve (i.e. the lower 60% Prediction band) and is proposed for ASPs with a high level of design and management; data from Stevens et al. (2017). The LRV equation for 95% of ASPs (red short-dashed line) was the removal equation originally proposed by Stevens et al. (2017). Blue data points are from the 2018 publications.

2

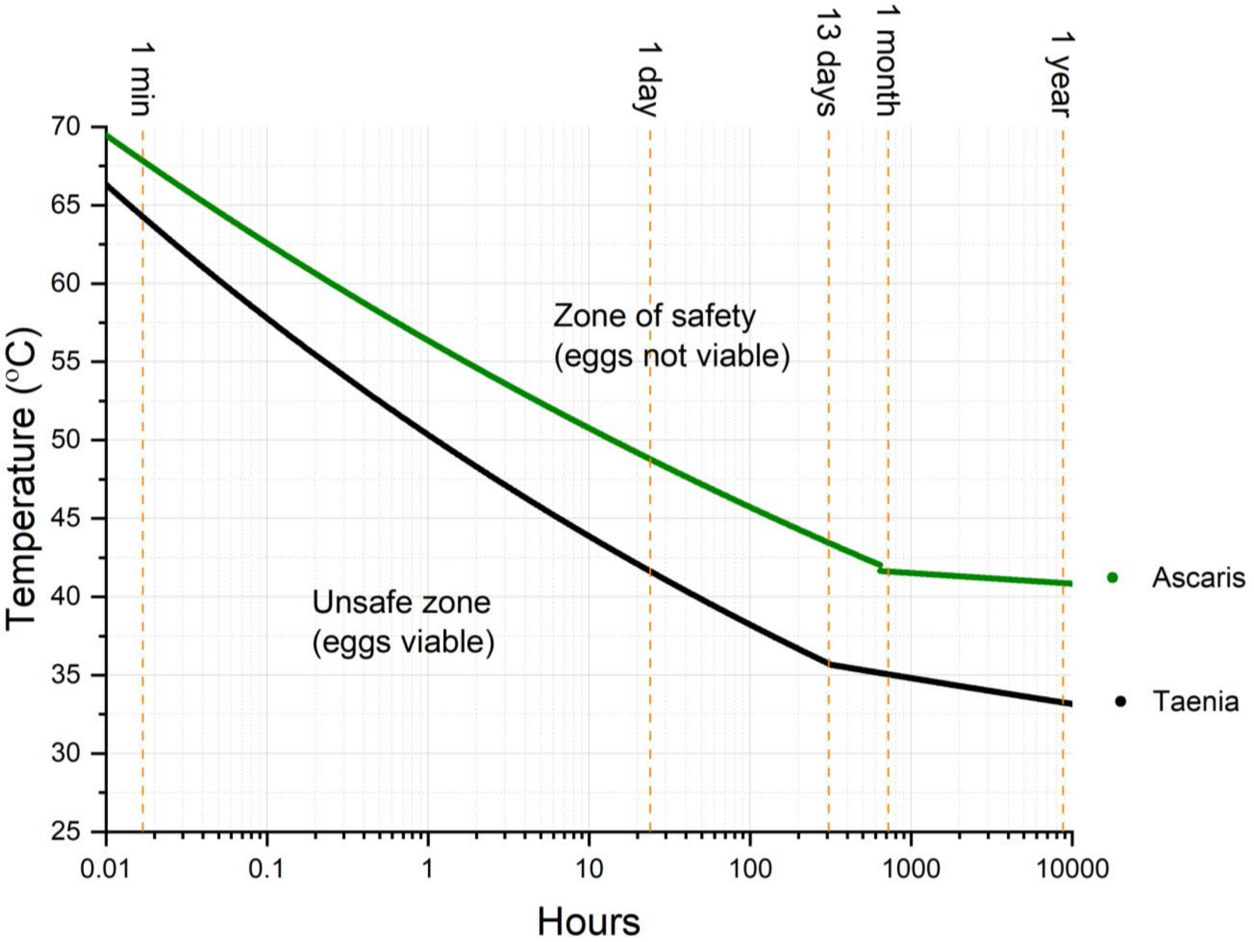

Figure 5-6 The influence of time and temperature on Taenia eggs viability. Adapted from Feachem et al. (1983). Lines fitted represent an upper boundary for eggs becoming non-viable.

5.2 Performance criteria of the relevant guideline to manage *T. saginata*

5.2.1 Log Reduction Value (LRV) specified for helminth eggs in wastewater

The LRV describes a reduction in concentration from pre- to post-treatment (1). A similar concept is also used to indicate the equivalent reduction in exposure from on-site restrictions or other attributes of the exposure pathway.

$$\mathbf{LRV} = -\mathbf{log_{10}}\frac{\mathbf{C_2}}{\mathbf{C_1}} \quad \textbf{(1)}$$

Where: LRV = Log Reduction Value for a specified treatment process or end-use restriction equivalent
C_1 = pre-treatment concentrations (HE/L)
C_2 = post-treatment concentration post-treatment (HE/L)

Typically the LRV for a treatment process to remove a pathogen would be verified by measuring the pre and post-treatment concentrations of the pathogen. However, for the case of recycled water, sewage influent to WWTPs typically have concentrations lower than routine methods for measurement or limit of reporting (LOR) (1 HE/L) (Stevens et al., 2021a). Consequently, HE detection pre and post-treatment is challenging to achieve, and so is the validation and verification of the treatment process. Therefore, treatment processes rely on achieving the LRV based on a design and operational parameters such as hydraulic retention time (HRT). Other indicators can be monitored within the treatment process as control points if they indicate the effective operation of the treatment system and theoretical achievement of the defined LRV (Sections 5.1.5.1 and 5.1.5.2).

Such a low sewage concentration of HE in Australian WWTP sewage samples was estimated to require a LRV of 2.2 via sewage treatment to maintain the baseline risk of C. bovis equivalent to background levels in Australia (Stevens et al., 2021a). However, to protect against potential future detectable outbreaks of taeniasis in the human population and all potential exposure scenarios considered (Stevens et al., 2021a):

- a 3.5 LRV for WWTP was considered appropriate with confirmation by appropriate sewage monitoring
- LRV credits (0.5 to 2.0 LRV) could decrease the required LRV for wastewater treatment based on the size of the WWTP
- on-site management strategies (e.g. restriction of recycled water use for livestock drinking water, the years of exposure for cattle to sites irrigated with recycled water, and the use of fodder off-site)

Without such measures, a HE LRV of 4.0 was recommended for WWTPs to ensure adequate protection of systems with no on-site controls.

5.2.2 *T. saginata* egg concentrations in raw sewage entering WWTPs (Stevens et al., 2017)

Historical detection of C. bovis in cattle indicates that up to the 1990s, there has been some presence of *T. saginata* eggs in sewage influent (Fewster, 1967; Collins and Pope, 1990). However, a more recent analysis of sewage from a total of eleven sewage treatment plants in Victoria and NSW from 2010 to 2019 did not detect any *T. saginata* eggs (554 samples) (Stevens et al., 2021a). This study provides evidence that the prevalence of *T. saginata* in the community of these sewer catchments is low and probably typical of many parts of Australia currently.

5.2.3 Viability, infectivity and dose-response of *T. saginata* eggs in recycled water

5.2.3.1 Technical summary – viability, dose-response and infectivity

In a country where *T. saginata* is not endemic (i.e. Australia), the use of a Quantitative Microbial Risk Assessment (QMRA) to determine the probability of C. bovis infection of cattle (cysticerci from *T. saginata*) is required. To build QMRA model, two important components:

1. characterisation of HE concentrations and viability in sewage and effluent, and
2. a dose-response curve to describe ingestion of eggs *T. saginata* (HE) by cattle and the probability development and detection of cysticerci due to the infection (Figure 5-7).

These two components have now been estimated and combined with an understanding of the viability, dose-response, and infectivity of *T. saginata* eggs and the cattle production environment. There is now sufficient information to characterise the risk of C. bovis infection in cattle using QMRA principles in a detailed model. The models still require verification of C. bovis detection versus predicted, and the sewage treatment industry has not had time to adopt the QMRA model approach.

Therefore, they still rely on total HE concentration in sewage to manage the risk. For example, the World Health Organisation (WHO) specifies a limit of ≤1 HE/L for the safe use of recycled water in agriculture (WHO, 2006; Stevens et al., 2021b). WHO indicates the LRV to achieve this should be based on an appropriate LRV relative to the HE concentration in sewage (Table 5-1). If this logic is used to put the AGWR into context, the HE concentration in sewage in Australia is approximately 1 HE/L (or less), and the treatment process achieves 4 LRV, therefore the recycled water concentration would be 0.0001 HE/L. This recycled water concentration refers to total helminth eggs, and *T. saginata* helminth egg concentrations in sewage are typically lower than the more common *Ascaris* *lumbricoides.* A concentration of 0.06 times was the median estimate of (Stevens et al., 2021a). Therefore, the *T. saginata* egg concentration in recycled water would be 0.000006 HE/L for the current baseline.

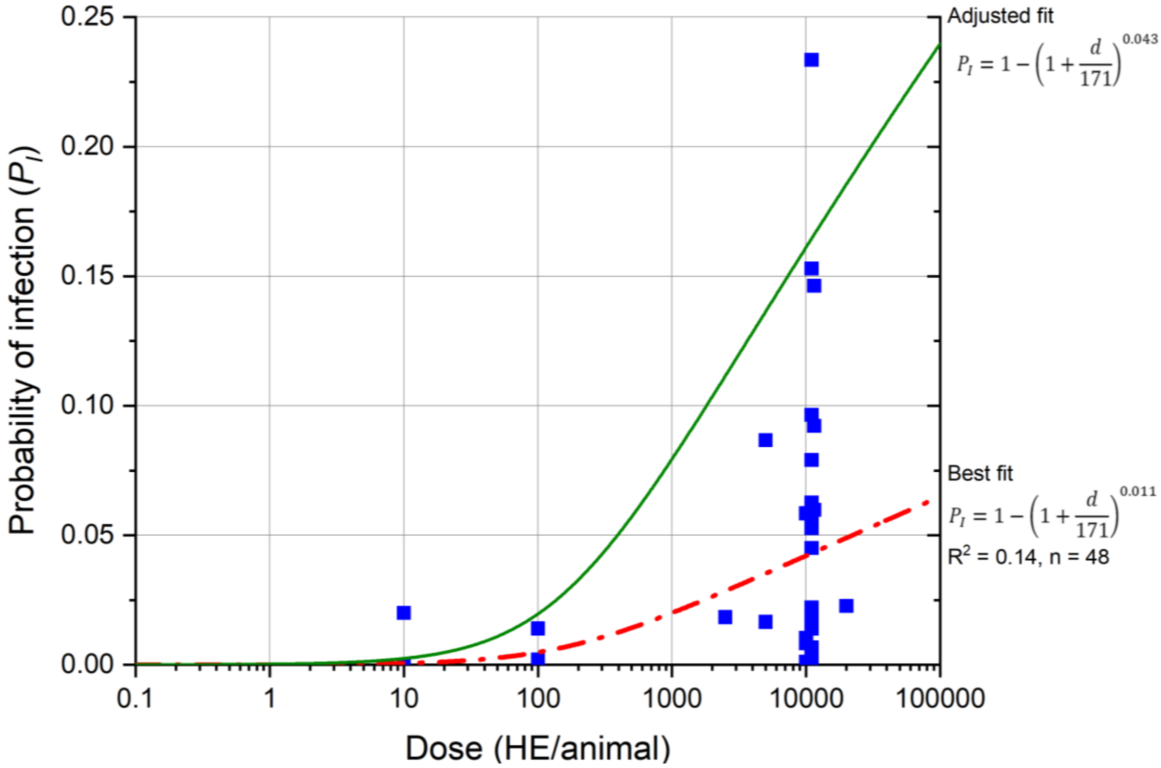

Figure 5-7 Dose-response curve for HE dosed to cattle (d) and probability of a C. bovis infection in cattle (n = 48). The dot-dash line is the best fit, and the solid line is the adjusted fit used as a conservative estimate (Stevens et al., 2021a).

Table 5-1 Options for the reduction of helminth eggs in sewage and verification concentrations recommended by the World Health Organisation

Number of helminth eggs in sewage (HE/L)	Required HE reduction by treatment ($\log_{10}$ units or LRV)	Verification monitoring for recycled water (HE/L)	Comments
1,000	3	≤ 1.0	Treatment should be shown to achieve this concentration reliably
100	2	≤ 1.0	
10	1	≤ 1.0	
≤ 1.0	none, see comments column	≤ 1.0	The target of ≤ 1.0 HE/L is automatically achieved

HE = Helminth egg, adapted from (WHO, 2006).

Measurements and guideline values typically refer to total helminth egg concentrations. Yet the vital component of the egg is its viability, as not all eggs visually counted are viable. Viability can be tested for also, however, it is rarely done as it is time-consuming, complex and relatively expensive, as it involves visual identification and counting by the well-trained analyst using a microscopic (Stevens et al., 2021b).

The viability of the egg is considered in a dose-response curve. Recently, the first approximation of a dose-response in the world has been proposed for *T. saginata* eggs exposure to cattle and the probability of infection. There was a considerable variation in the relationship between the dose of *T. saginata* eggs and the formation of C. bovis in cattle (Figure 5-7). This variation is probably due to several reasons: the low detection limits for routine analysis of C. bovis in carcasses, variation in the viability of the egg, and the variability in the infectivity of HE due to their genetic diversity and climatic conditions the egg is exposed to (Stevens et al., 2021a).

5.2.3.2 Non-Technical summary – viability, dose-response and infectivity

The viability, dose-response and infectivity have now been sufficiently characterised to allow a conservative estimate of the probability of C. bovis infection in cattle. This allows comparison of measured C. bovis cysts identified via PMI (Historical data) with the probability of infection of the cattle from the use of recycled water. Consideration of these parameters allows a historical baseline of C. bovis infection to be compared to an infection rate from recycled water sources. For example, a comparison of historical data on the measured probability of C. bovis cyst detection (Scenario 1 = S1) with estimates from exposure to recycled water scenarios (S2 and S3) (Figure 5-8). This comparison highlights the probability of cyst detection is:

- Low in Australia compared to many parts of Europe (S1)
- Correctly treated the use of recycled water ensures a lower probability of cyst detection (S2)
- The quantifiable probability, limited by the easily obtainable detection limit for helminth eggs (S3), is similar to the measured background in Australia.

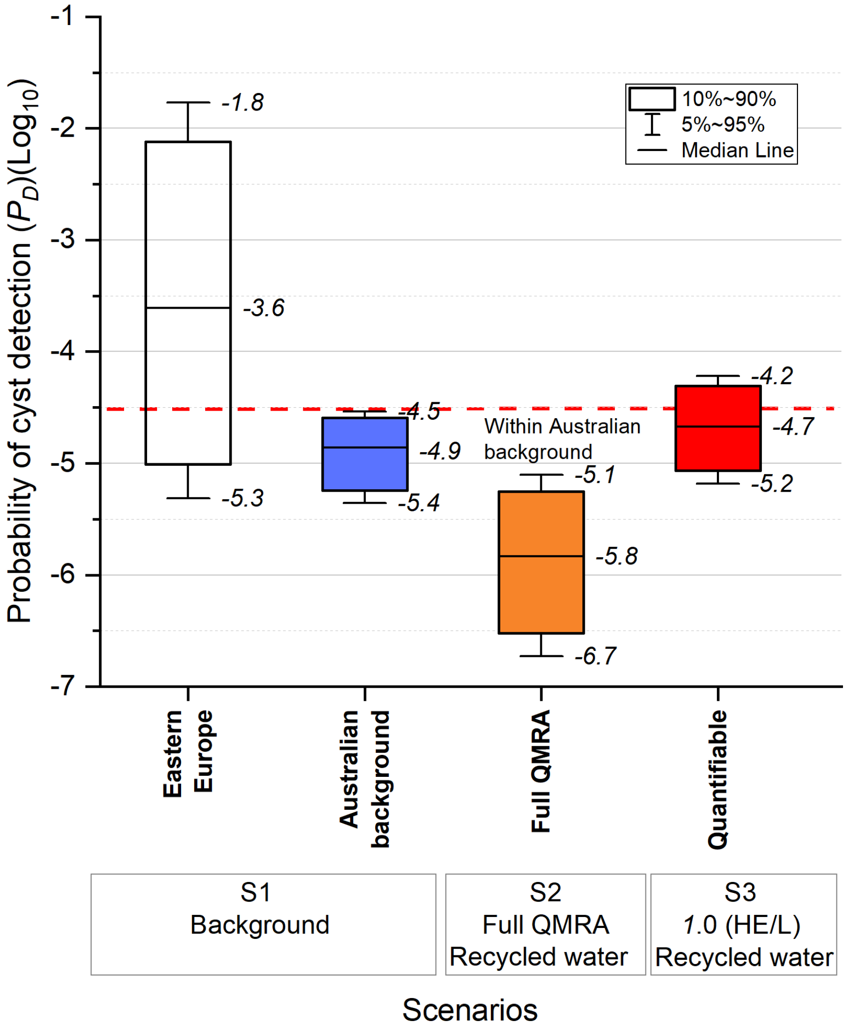

Figure 5-8 The probability of detecting a cyst from Taenia spp. in Eastern Europe and Australia (S1), and for recycled water exposure to cattle assuming the Full QMRA (S2), and a sewage helminth egg concentration for the baseline set at a quantifiable limit of 1 HE/L (S3). Modified from Stevens et al. (2021a).

5.2.4 The technical basis for withholding period for not grazing at-risk land (under Australian conditions)

The AGWR does not define a withholding period for grazing after sewage or recycled water that is not treated to acceptable standards are applied to land. Several state and territory guidelines make no mention of it.

The logic for the two years is not defined in these guidelines. It is most likely based on the recognised survival periods of *T. saginata* eggs in the soil. Our recent best estimate was that 99% of eggs degrade in 180 (90, 360) days (Stevens et al., 2021a), and 720 days would provide a conservative approach.

Time and temperature effects also suggest fodder production may lower the eggs' viability if the fodder experiences higher temperatures for extended periods. For example, 13 days at 35ºC should make the egg not viable (Figure 5-6). The average temperature in silage varies considerably on external factors. However, if there is a 9°C increase in the silage temperature compared to prevailing ambient temperatures, as indicated by Green et al. (2009), this equates to 13 days above an ambient temperature of 24°C. A temperature easily achievable across most of Australia in summer. However, it does not consider the impact of diurnal temperature variations.

One method for managing soils contaminated with eggs (lowering withholding periods) might be to restrict irrigation of the soil infected with *T. saginata* eggs over summer. For example, 20 days greater than 30ºC could inactivate eggs in the upper soil profile. Research is required to confirm if this is an effective method for lowering exclusion periods for cattle from pasture potential contaminated with *T. saginata* egg as soil temperatures vary considerably across Australia and are dependent on a range of climatic, soil moisture and physical properties (Horton et al., 2011; Brownmang onwuka, 2018; Zhang et al., 2022). Current information suggests that if the soil temperature at 5 cm can be estimated by the 5 or 7-day average ambient temperature, many soils in summer could reach 35ºC at the peak of the day. Although, the daily average may be lower due to buffering capacity of the soil and cooling overnight (Horton and Horton, 2012). This research also indicates that temperature at or near the surface is higher than that measured at a 5cm depth, supporting deactivation in soil. Conversely, soil temperatures would be lowered by the cooling effect of soil moisture (from rainfall or irrigation), which has been observed in models as expected (Horton and Horton, 2012).

5.3 Implementation of guidelines and national use

5.3.1 Overview of helminth guidance in Australia

Most state and territory guidance for producing pasture or fodder for cattle in Australia now refer to, or are based on, the AGWR and the defined risk management within this guideline (NRMMC et al., 2006) (Figure 5-9, Table 5-2). Since the publication of the AGWR, the guidance for helminth egg management in recycled water (Risk management rating) has improved in documented guidelines for the ACT, NSW, Qld and Tas (Figure 5-9). In comparison, it has remained high in Vic and WA. The exceptions to the current high management ratings are for NT, where there is no mention of helminth egg management, and SA, where the guideline is confusing and outdated as the document referred to for helminth egg control is no longer accessible. In comparison, the previous SA guideline (1999) achieved a higher risk management rating (Figure 5-9). Unfortunately, the quality of management recommended in the SA guidance has decreased (Figure 5-9).

The improvement in the Tasmania guideline was due to the low base caused by an update of the Tasmanian guidelines neglecting to include any helminth management guidance for using recycled water with cattle (DPIWE, 2002). Due partly to the extensive training conducted across Australia as part of the role-out of the AGWR and ongoing training via the IWES courses[2], TasWater has updated this guidance (TasWater, 2011, 2021) and now achieved a high-risk management rating (Figure 5-9).

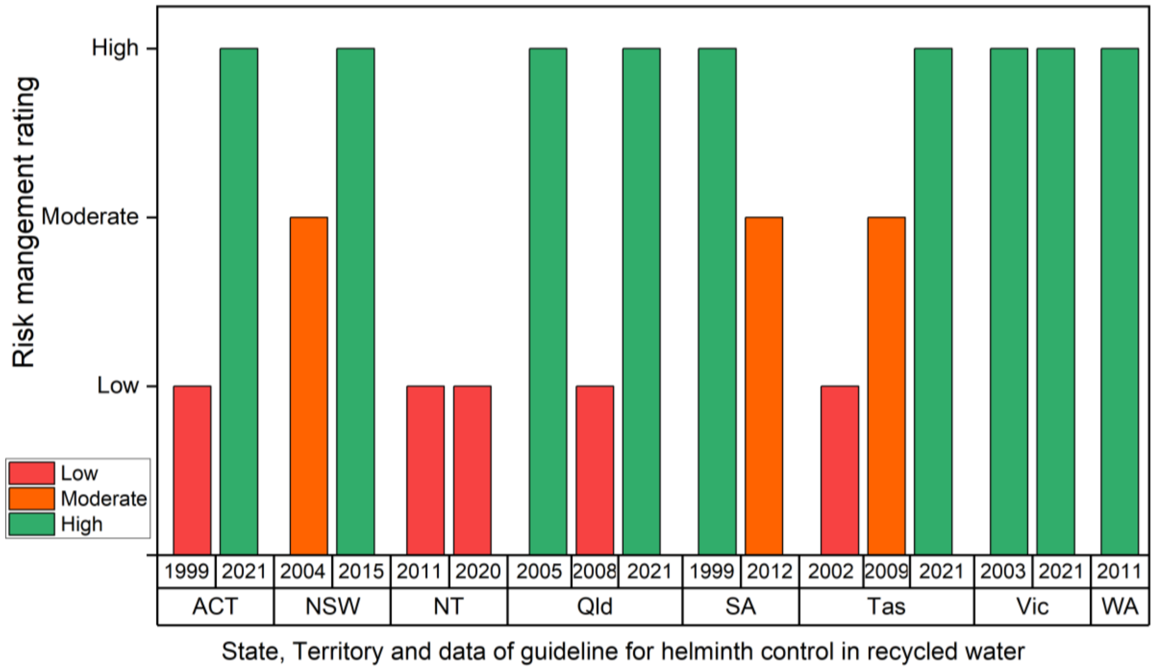

Figure 5-9 Risk management ratings for guidelines for helminths in recycled water for states and territories of Australia and year of publication (Table 5-2).

Table 5-2 Summary of state and territory guidance for managing Taenia saginata eggs in sewage to produce recycled water and the risk management rating (RMR) allocated.

State Terr.	Treatment specified for HE control	Reference	RMR
ACT	The related ACT now refers directly to the **AGWR**. That is secondary treatment with helminth reduction (>25 days of lagoon detention or an equivalent filtration process). A mean hydraulic retention time of 25 days equates to approximately 4-log removal of helminth ova. Therefore, this is the target that alternative treatment processes to waste stabilisation ponds should meet if *T. saginata* requires specific management.	(ACTG, 2021; McIntrye (pers.comm.), 2021) (NRMMC et al., 2006).	High
	Controls for pasture and fodder for grazing animals (except pigs). Drying or ensiling of fodder. Helminth control. For food crops - A minimum of 25 days ponding or equivalent treatment (e.g. sand filtration) for helminth control. Helminth control is not defined for cattle exposure. No recent guidelines or this guideline could be found on the internet. There does not seem to be any supply of recycled water to cattle in the ACT (IconWater, 2021).	(ACTG, 1999)	Mod-erate
NSW	The control of *T. saginata* in treated sewage that is to be used in contact with cattle can be achieved through either 25 days of detention in waste stabilisation ponds or 4-log removal of helminth ova by an alternative treatment refers to the **AGWR** (NRMMC et al., 2006). Refers to and is based on the AGWR (NRMMC et al., 2006).	(NSW DPI, 2015)	High
	Some pathogens (e.g. Cryptosporidium parvum and the helminth Taenia saginata) can infect both humans and animals, and appropriate precautions must be taken. Helminths controls include removal by treatment, veterinary inspection, cattle husbandry, or a withholding period prior to grazing. Other options may be used to control helminth infection in grazing animals for pasture and fodder applications if acceptable to the NSW Department of Primary Industries. For vegetable production, a minimum of 25 days ponding or equivalent treatment (e.g. sand filtration) for helminth control. One must assume this is suitable for cattle also.	(NSW DEC, 2004)	Mod-erate
NT	The Code of Practice for Water Recycling (the Code) indicates that in cases where there may be a risk to livestock or animal health, the assessment may include Specialist Department of Department and Primary Industry (DPIR) livestock or animal health specialists. If applicable, part of the	(DH NT, 2020)	Low

[2] https://iwes.com.au/courses/recycled-water-management/

State Terr.	Treatment specified for HE control	Reference	RMR
	assessment team should be specialist DPIR animal health or livestock officer. AGWR is not mentioned concerning livestock and helminth management. Yet the Code is a process document and provides proponents of recycled water schemes with advice on how to demonstrate compliance with the **AGWR** for low exposure and high exposure recycled water schemes.		
	Helminths were identified as a potential hazard, but no other information was provided.	(DH NT, 2011)	Low
Qld	All recycled water providers are also obliged to supply recycled water that is 'fit for use' and does not represent a 'public health risk', as defined in the Public Health Act, which refers to the **AGWR** (NRMMC et al., 2006).	(QH, 2021a)	High
	Recycled water schemes that supply recycled water for the irrigation of pasture and fodder crops should be capable of removing or inactivating helminths. The AGWR lists secondary treatment, disinfection and greater than 25 days of lagoon detention as an acceptable treatment train for inactivating helminths. Alternative treatment trains may be employed provided it can be demonstrated that the treatment train can remove helminths	(QH, 2021b) Download date, no publication date (2008 to 2021)	High
	The only mention of helminths is the use of *Clostridium perfringens* as a surrogated for HE removal for Class A+ and potable water	(DEWS Qld, 2008)	Low
	Consideration needs to be given to biological and chemical hazards and physical parameters. Biological hazards may include viruses, bacteria, protozoa, helminths, algae and Cyanobacteria.	(NRW Qld, 2008)	Low
	The stock should not be exposed to recycled water that may contain helminth (tapeworm) eggs. If the source water may contain helminth eggs, it should not be used for stock, or further treatment must be undertaken to achieve helminth removal. Helminth removal can be achieved by a minimum of 25 days of pondage detention or filtration via sand or membranes.	(Qld EPA, 2005)	High
SA	Specific removal of viruses, protozoa and helminths will be required in addition to bacteria. The Victorian Department of Primary Industries has developed Agriculture Notes on recycled water use in livestock and cattle production, which apply to recycled water use in South Australia. The www link provided no longer exists. The table referred to indicated that specific removal of viruses, protozoa and helminths will be required in addition to bacteria. But no guidance is provided. Section 7.6 notes that for additional guidance on appropriate treatment processes and additional control for the use of recycled water in agricultural applications, see Table 3.9 in Phase 1 of the Guideline. There is no Table 3.9 of the SA guideline, but this should refer to the AGWR. The SA guidelines use phases one and two of the **AGWR** as the scientific reference for the supply, use and regulation of recycled water. (NRMMC et al., 2006, 2009a, 2009b; EPHC et al., 2008). The reference to helminth control is confusing.	(SA Health, 2012)	Mod-erate
	Use processes that ensure helminth removal when reclaimed water is associated with pasture or fodder for cattle. This can be achieved by ensuring a minimum of 25 days detention in a lagoon or holding pond or by appropriate filtration as approved by the EPA.	(DHS SA and EPA SA, 1999)	High
Tas	Recycled water must be stored to allow for 25 days settlement prior to irrigation (As their sewage treatment plants typically have this). There is a 2 year with holding period restriction. These restrictions apply to direct grazing situations and where the fodder is harvested for hay or silage.	(TasWater, 2011, 2021)	High
	Recycling Scheme suppliers and users should also be familiar with the **AGWR** (NRMMC et al., 2006). In contrast, the Tasmanian guidelines may satisfactorily assess an application for effluent reuse of Class B recycled water for irrigation (DPIWE, 2002).	(EPA Tas, 2009)	Mod-erate
	Taeniasis in cattle can be a major veterinary problem and a nuisance parasite in humans. The best practice measure to control risks from the micro-organisms is to ensure that infective doses of a pathogen are not found in wastewater and an infective dose cannot reach a human host.	(DPIWE, 2002)	Low
Vic	Applies to schemes with ≥ 5 KL/day of helminth reduction requirements are up to 4 $\log_{10}$ and can include lagoon detention of primary treated effluent for ≥ 50 days or secondary treated effluent for ≥ 25 days, or some other equivalent Chief Veterinary Officer (CVO) and EPA approved processes, such as media or membrane filtration. Alternatively, a risk-based assessment and derivation of the level of reduction required can be separately agreed upon with the CVO and EPA. Note that where the objective is to protect human health directly (for example, no livestock involved in the transmission process), the helminths' treatment requirements can be different to, and potentially less stringent than, where the recycled water will supply livestock. Therefore, risks associated with direct human exposures and the related health impacts on humans can be assessed separately from risks associated with exposures of livestock. It builds on the **AGWR** (NRMMC et al., 2006) by allowing alternative risk-based assessment.	(EPAV, 2021a, 2021b)	High
	The specified treatment measures to reduce helminth numbers are: (i) at least 25 days detention in treatment lagoons (this may include either primary, secondary, or maturation lagoons provided the	(EPA Victoria, 2003)	High

State Terr.	Treatment specified for HE control	Reference	RMR
	helminth settling process is not disturbed by processes such as mixing, aeration, or any other process), or a storage facility where all reclaimed water must be detained for at least 25 days from the time of the last discharge into the storage facility (further information on storage lagoons is provided in Section 7.1.4); or (ii) an approved method of filtration, such as sand or membrane filtration.		
WA	The specified treatment measures to reduce helminths numbers include at least 25 days detention in treatment lagoons (this may include either primary, secondary, or maturation lagoons provided the helminth settling process is not disturbed by processes such as mixing, aeration, or any other process) or a storage facility where all recycled water must be detained for at least 30 days from the time of the last discharged into the storage facility, or an approved method of filtration, such as sand or membrane filtration. These guidelines were designed to provide a planning and implementation framework aligned with the **AGWR**.	(WU EHD, 2011)	High

Low - needs to be improved or investigated further, Moderate - acceptable management. However, it needs confirmation from EPA, or equivalent, to how the guidelines are actioned, and High - documented controls and management are ideal. If implemented correctly, there should be a low risk of T. saginata egg exposure to cattle.

5.3.2 Number of relevant sewage effluent treatment plants

Hundreds of sites around Australia recycled water from centralised sewage treatment facilities (Approximately 355) (Figure 5-10). The recycled water is used in the urban and rural environment for various uses ranging from home gardens, sports fields, and urban street scapes to a range of primary production sectors (detailed in Section 5.4). The primary production sector relevant for this report is 'pastures and animal husbandry', and the volumes of recycled water used are some of the largest in this sector (32,502 and 22,580 ML/year, for 'Sheep, beef and others', and 'Dairy cattle', discussed later in Section 5.4).

In 2001 the number of on-site treatment systems across Australia was approximately 1 million (Gunady et al., 2015). This equates to a total of approximately 16,740 ML/year of treated sewage (assumptions defined in Section 5.3.6). Given the discussion in Section 5.3.6, only a small fraction of this volume would be exposed to cattle.

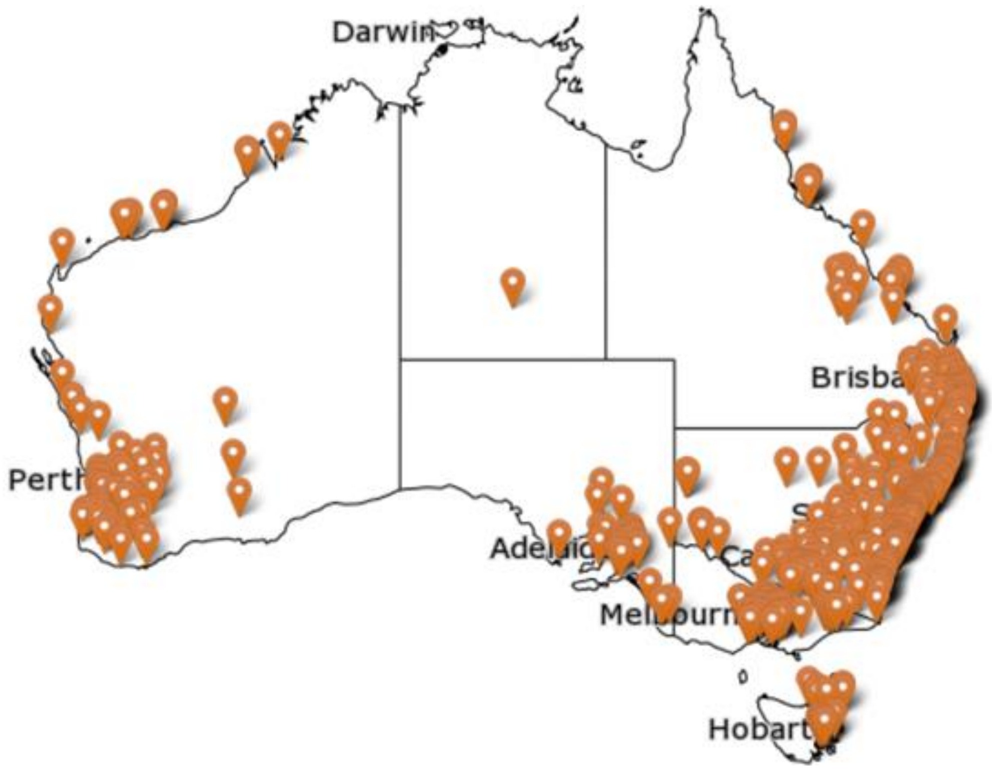

Figure 5-10 Water recycling sites in Australia (2014-2015). Water sources are wastewater, treated effluent, industrial wastewater and not specified (BOM, 2015). End-uses selected were: Urban, environment and irrigation, and not specified.

5.3.3 Regulation, approval and auditing arrangements for WWTPs for each state against the guidelines

The only state with a low rating for auditing was SA. All other auditing requirements were documented well and obtained a high rating, except for Tasmanian, which was moderate (Figure 5-11). These observations of the current guidelines in each state and territory indicate that the documented management and auditing of helminth in the NT and SA are of low quality, and auditing documents for Tas could be improved (Figure 5-11). The Department of Health in the NT and Qld have rated pasture and fodder production considered low exposure (from a human health perspective, we assumed). A recycled water management system is not mandatory. This could lead to a lower audit quality related to *T. saginata* management.

In Qld, a recycled water management plan is not mandatory but encouraged for low-risk schemes (i.e. irrigation of pasture and fodder). Some health departments (i.e. human health) are starting to rate recycled water schemes as low risk if they irrigation pasture and fodder. These low-risk schemes do not require management plans which are what is typically used for the auditing process. These types of changes could lead to *T. saginata* management oversites in the future.

Guidelines in each state and territory are underpinned by regulations and state acts related to environmental and human health protection, which define the approval process (Table 5-3). The legislative documents and guidelines allow the enforcement of best practices described in the related guidelines and underpin the approval processes.

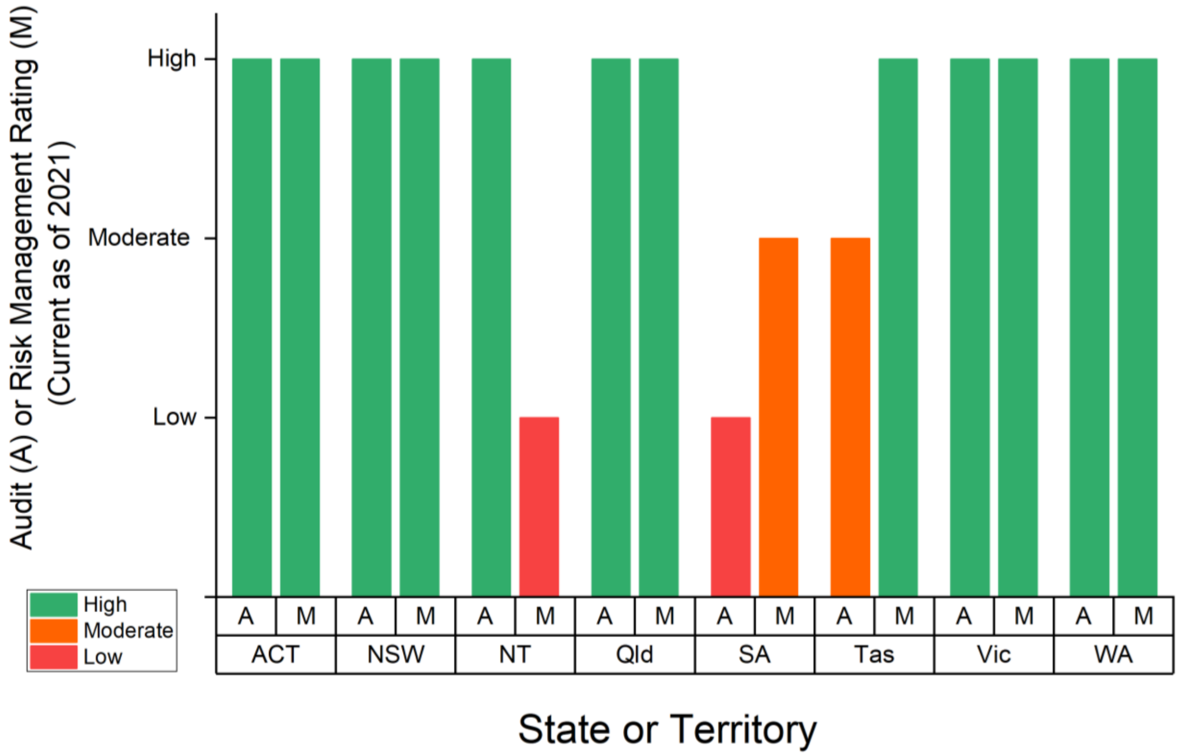

Figure 5-11 Comparison of most current (as of 2021) audit or risk management rating for states and territories of Australia (Table 5-2 and Table 5-3). High = Acceptable, Moderate = should be improved, Low = not appropriate.

Table 5-3 Recycled water management and auditing requirements specified in the most recent guidance documents

State Terr.	Managed by [A]	Audit requirements	Audit frequency	Quality of audit rating	Risk management rating [B]	Most recent guideline	Permit, licensing, or approval
ACT	Icon Water (IconWater, 2021) is a public utility owned by the ACT Government	Refers to the AGWR (NRMMC et al., 2006).	AGWR Section 2.11.2	High	High	(ACTG, 1999)	EPA ACT [3], (ACTG, 2021)
NSW	Two major urban water utilities (Sydney Water and Hunter Valley Water) and several regional state-owned operators	Preliminary internal audit is quarterly (critical control points) and annually (Controls), depending on how the control points are defined. The frequency of external audits of the recycled water management plan should be determined in consultation with the NSW Office of Water (NOW) and the local Public Health Unit.	Follows logic in AGWR	High	High	(NSW DPI, 2015)	NSW Office of Water (NOW) recommends a recycled water management plan, per two state Acts (DWE NSW, 2007; NSW DPI, 2015)
NT	Power and Water (Territory owned)	Preliminary internal audit is monthly (critical control points), quarterly (calibrations), and annually (Controls,) depending on how the control points are defined. The frequency of external audits of the recycled water management plan should be determined in consultation with the Department of Health and local Public Health Unit.	Follows logic in AGWR	High	Low, not mentioned	(DH NT, 2020)	Department of Health (DH NT, 2020). Pasture and fodder production are considered low exposure, and a recycled water management system is not mandatory
Qld	Several state-owned operators servicing the city and regional council	A recycled water provider's compliance with the guideline values should be assessed monthly concerning the previous 12 months' results. However, water should meet helminth's treatment requirement if used to irrigate pasture and fodder crops for beef and dairy cattle.	Yearly	High	High, may not be enforced for helminths?	(QH, 2021b) Refers to (DEWS Qld, 2008)	If prescribed by regulation for low-risk schemes, Queensland Water Supply Regulator, Department of Energy and Water Supply [4]. (QH, 2021b, 2021a)
SA	SA Water (State-owned)	No indication of auditing requirements. However, these guidelines are intended to be used with the AGWR to guide the best water recycling practices.	Best practice AGWR Section 2.11.2	Low	Moderate, guideline confusing	(SA Health, 2012)	Department of Health and Ageing (SA Health, 2012)
Tas	TasWater, a utility owned by 29 local governments	Annually based on the 2002 guideline, and 2011 act refers to AGWR (DPIWE, 2002; NRMMC et al., 2006; TasWater, 2011).		Moderate, not clear in documents	High	(TasWater, 2011, 2021)	Department of Primary Industries, Water and Environment (DPIWE, 2002)
Vic	Various water corporations (18)	Regular audit of user site management plan, independent for >1ML/day. Auditing of schemes should take place periodically to confirm operation is in alignment with the operating Procedures – focus on *E. coli.*	As per AGWR Section 2.11.2	High	High	(EPAV, 2021a, 2021b)	
WA	Water Corporation (State-owned)	Audit required once every 3 years for agricultural irrigation of non-edible crops. Internal and external audits.	Follows logic in AGWR	High	High	(WU EHD, 2011)	Department of Health (WU EHD, 2011)

[A] adapted from Radcliffe (2021), (UU, 2021), [B] Risk management for helminth described in the guideline. See Section 4.2 for definitions of ratings.

[3] https://www.accesscanberra.act.gov.au/s/article/environment-protection-tab-overview
[4] https://www.business.qld.gov.au/industries/mining-energy-water/water/industry-infrastructure/industry-regulation/recycled-water/management-plan

5.3.3.1 Adoption of the AGWR for auditing

All states and territories have adopted the AGWR to guide and audit recycled water schemes (Table 5-2 and Table 5-3). However, the clarity and direct referral to *T. saginata* egg management are unclear for NT and SA. The NT guidance implies compliance with the AGWR and refers to the consideration of the scheme by the Department and Primary Industry (DPIR) animal health or livestock officer – if applicable. The SA guidelines refer to "…Table 3.9 in Phase 1 of the Guidelines" without defining the "Guidelines" and refer to the Victoria Primary Industries document that is no longer accessible. That is, the guidance in the documentation is confusing.

Comparison of the audit requirements and risk management of helminth between states and territories indicate that the risk may not be managed well in the NT and SA, and the auditing could be improved in SA and Tas (Table 5-3).

5.3.3.2 Other state, council and regional guidance and requirements for auditing

Several states and territories manage water recycling by a single entity (ACT, NT, SA, Tas, WA). Three states (NSW, Qld and Victoria) use several state-owned bodies to manage recycled water use in different regions. In Victoria, the state-owned bodies are water corporations specialising in water supply and wastewater treatment. In Qld and NSW, there are several large water corporations and several regional councils. Typically the relevant water management identity should ensure compliance with the state or territory guidance. In some cases, the state also provides additional technical guidance for the use of recycled water, which should be used in conjunction with associated guidelines for water recycling.

These technical guidance documents generally have no mention of audit requirements related to helminth controls, as this is contained in the relevant recycled water guidelines.

For example, Queensland provides additional technical guidance for disposal of effluent via irrigation and provide a model (MEDLI) to assess sewage effluent reuse schemes (both municipal and on-site), intensive livestock industries and agri-industries (DES QLD, 2015; Tennakoon and Ramsay, 2020). The MEDLI model is described as addresses all the facets of effluent reuse; the quality and quantity of effluent available, climate, storage and treatment, irrigation frequency and amount, the flow paths of water, nitrogen, phosphorus and salt components and plant growth[5]. However, it does not consider the pathogens and focuses on sustainable effluent disposal/reuse practices via irrigation and the growing of crops. The guidance for effluent disposal via irrigation indicates that this type of activity is environmentally relevant and in Queensland requires environmental approval to operate (Tennakoon and Ramsay, 2020). However, it does not indicate how this is obtained. Any sewage treatment plant treating human faeces would be require to comply with the Queensland Health guidelines and the associated auditing (QH, 2021b, 2021a)

Similar to Queensland, in addition to the Victorian guidelines for recycled water use, there is also reference to the wastewater irrigation guidelines (EPA Victoria, 1991) (currently being updated), which provide guidance on the technicalities of appropriate irrigation practices when using recycled water to ensure it is environmentally sustainable.

5.3.4 Permit and recording systems for the use of recycled water to irrigate pastures – Requirements for recycled water use in agriculture

For centralised WWTP and the recycled water produced, the logic and concepts in the AGWR have, in most part, been adopted across Australia. The permits required to use recycled water are summarised in Section 5.3.3. From an Australian state and territory perspective, the permitting, auditing and recording system often requires the interaction of various departments related to human health, environmental protection and agriculture (water supply, CVO). The department's interaction varies based on the associated responsibilities and phase of the recycled water

[5] https://science.des.qld.gov.au/government/science-division/medli

scheme (e.g., development, operations and maintenance), with a specific department leading the initial and ongoing approval for operation (Table 5-3).

An example of a well-structured approval process is shown diagrammatically from the Victorian guidelines (Figure 5-12). Where all applications and inquiries related to recycled water schemes within the scope of this guideline should be made through the EPA. Depending on the wastewater source, treatment level and use, the application process may also involve the CVO (Figure 5-12). This type of process is undertaken in all states and territories, with various departments taking the lead (Table 5-3).

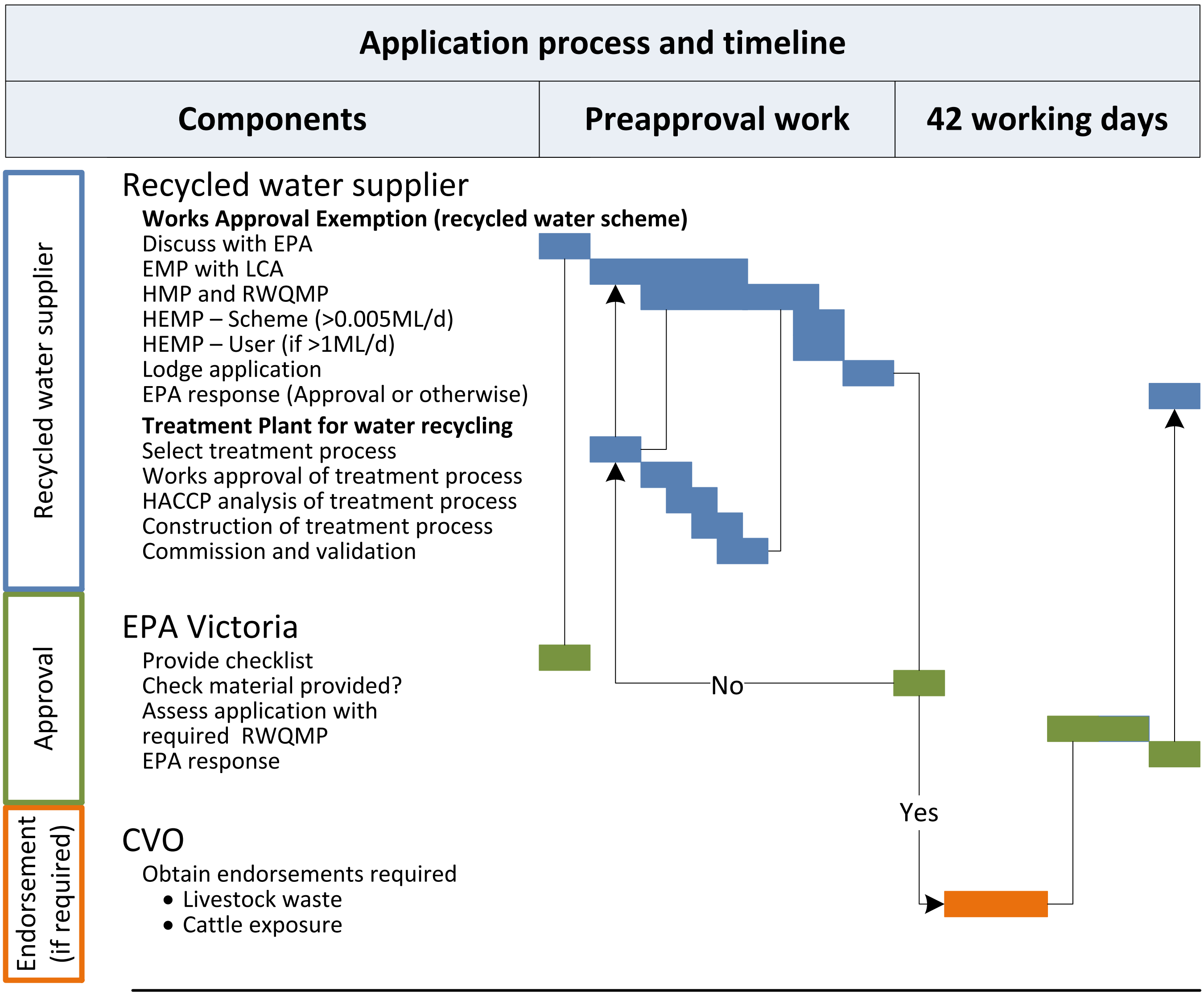

Figure 5-12 Indicative scheme development process for application, endorsement and approval for the Victorian Environmental Protection Authority (EPA) and Chief Veterinary Officer (CVO) (EPAV, 2021a).

5.3.5 Centralised WWTP obligations (Water supplier)

Most recycled water guidance encourages, or requires, a recycled water management plan that incorporates a recycled water management plan (RWMP or the like) that includes the management of helminth if identified in the risk assessment undertaken to develop the RWMP. In the context of the RWMP, health relates to human health and all environmental risk (including the agricultural environment) are managed under the environmental risks. However, helminths are complicated by their impact on humans and the agricultural environment (e.g. cattle).

For *T. saginata* eggs, the risk is managed for the agricultural environment to protect animal health, product quality, and for human health, via product quality. The RWMP components to manage this risk can relate to the appropriate WWTP management plan or on-site management (Section 5.3.5), both part of the overall RWMP.

5.3.5.1 Centralised WWTP management plan – content

Where appropriate, the WWTP management plan for helminth egg controls follow the risk management frame and preventive measures (i.e., control measures) outlined in the AGWR. This should include target criteria and critical limits set for treatment processes accredited to the removal of the helminth from sewage (Figure 5-13). If this target or critical limits are exceeded, corrective action should be to cease the recycled water supply until they are not exceeded. How well this approach has been adopted for helminth management needs to be verified with local authorities.

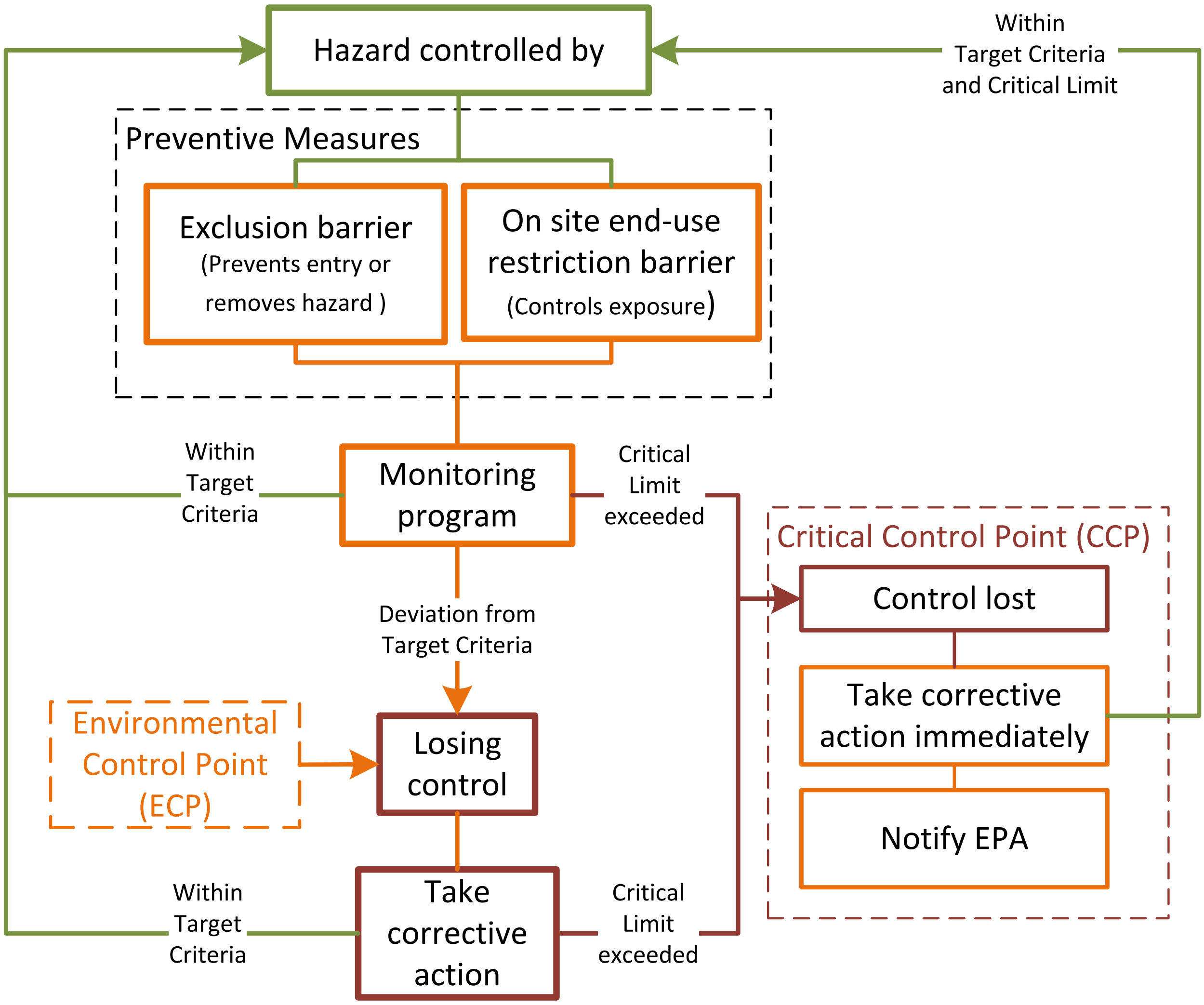

Figure 5-13 Relationship of preventive measures (On-site and exclusion barriers) with the monitoring program, environmental control points (ECP) and critical control points (CCP) (modified from (NRMMC et al., 2006) (EPAV, 2021b)).

5.3.5.2 Site management plan – content

With respect to *T. saginata* exposure controls, if on-site restriction barriers are used these will be identified and reported on in the site management plan, which feeds into the scheme RWMP. For example, one large WWTP in Victoria is currently using a restriction of cattle for drinking recycled water as part of a multi-barrier approach to their management strategy.

5.3.6 On-site sewage management

The focus of the report is based around larger volumes of water recycled by centralised WWTP to be fit for the intended purpose, such as irrigation of pasture and fodder grazed or fed to cattle and recycled water used for cattle drinking water. There are also other wastewater sources with human sewage input, such as greywater, septic tanks, and on-site treatment systems.

Greywater is water sourced from household wastewater (showers, washing machines, etc.) not combined with toilet water (Black water). However, there can be some incidental faecal contamination of greywater, for example, from washing dirty nappies or showering (NSW Health, 2000; NRMMC et al., 2006). These volumes are usually small and used within a domestic garden and covered under the AGWR (NRMMC et al., 2006). Therefore greywater is unlikely to be exposed to cattle.

Septic tanks and on-site treatment of individual sites are typically disposed of within the domestic property boundaries with limited access (Table 5-4). As such, exposure to cattle from water recycled from on-site systems is unlikely if well maintained. The number of on-site treatment systems irrigate above ground is also limited, as it is typically not encouraged in the guideline. If they are operated as per on-site guidance across Australia (Table 5-4), the likelihood of exposure to cattle is low. However, where maintenance is not binding, or auditing is inadequate, accidental exposure is possibly (e.g. ACT and Qld; Table 5-4).

On-site treatment is designed based on wastewater volumes of 155 (80,220) L/day (AS/NZS, 2012). Therefore daily volumes per property would irrigate small areas. Based on an irrigation rate of 2 ML/ha/year and 3 people in a household, this equates to an irrigation area of approximately 84 (43,119) m^2/year.

Table 5-4 Septic tanks and on-site treatment of wastewater

State Terr.	Volumes applied to	Permit	Maintenance	Water exposure	Helminth or cattle	References
Vic	< 5,000 L/day	Required from Council	By occupier of premises as per Council requirements.	Usually on-site with disposal or recycling options below ground or trenches with limited access to disposal area.	No mention.	(EPA VIC, 2016)
NSW [A]	< 2000 L/day, max of 10 people	LGA	Local councils should ensure householders have maintenance contracts.	Trenches, drainage beds, subsurface drippers and drainage beds must not be exposed to grazing animals. Surface irrigation areas must be protected from livestock.	No mention.	Best practice (WaterNSW, 2019) of (DOL NSW et al., 1998)
Qld	<21 EP	LGA for facility,	Not defined.	Avoid the likelihood of contamination of soils, groundwater, and waterways.	No mention.	(QG, 2019) and Business Qld [6]
SA	Households	LGA	Owners/operators of on-site wastewater systems ensure maintenance and service contracts under the conditions of approval.	The land application area must be dedicated to the sole use of receiving recycled water. It must be landscaped, preferably with shrubs and trees, and should be designed to discourage pedestrian and vehicle access.	No mention except for greywater.	(SAHealth, 2013)
WA	Where reticulated sewerage is not available. Department of Health approval if > 540 L/day	All applications must be lodged to the LGA in the first instance. [B]	Signed maintenance agreement between the owner and the service provider.	Commercial permitted for irrigation of pasture, WA.	No mention of helminth control. Site soil evaluation indicates avoidance of contamination of food sources.	[7], (AS/NZS, 2012)
Tas	up to 100 KL/day	Director of Building Control	A binding agreement for the pumping, management, monitoring, and maintenance of the pump-out system.	Various methods of irrigation. Protect the land application area if the property contains stock.	No mention, comply with AS1546.3 and 1547.	(CBOS, 2017), (AS/NZS, 2001, 2012) [C]
NT	Unsewered areas	Department of Health	Operation and maintenance servicing contract arrangements are vital and must be maintained for the life of the waste management system.	Subsurface drip irrigation is preferred to surface spray irrigation.	No mention.	(DoH NT, 2014) replaced by (DH NT, 2020)
ACT	Septic/Sub-soil Sewage Disposal Systems	EPA ACT possibly, but not clear if required	Not specified.	As per the range discussed in AS 1547 (AS/NZS, 2012).	comply with AS1547 [C].	(AS/NZS, 2012; EPA ACT, 2012)

EP = Effective people, LGA = Local Government Authority.

[A] > 11,000 on-site wastewater systems in the catchment across 15 local government areas.

[B] The LGA will process your application if the proposed apparatus will treat less than 540 L/day of wastewater OR the building to be serviced is a single dwelling. If the wastewater volume received by the system is more than 540L/day and the building being serviced is not a single dwelling, the LGA will assess your application and prepare a local government report.

[C] AS1547 indicates that the disposal area be used only for effluent application and spray irrigation systems have no casual access or allow the drift to be exposed to animals or humans. These standards are typically designed for domestic wastewater flows up to 14,000 L/week from a population equivalent of up to 10 persons.

[6] https://www.business.qld.gov.au/industries/building-property-development/building-construction/plumbing-drainage/on-site-sewerage

[7] https://www.legislation.wa.gov.au/legislation/statutes.nsf/RedirectURL?OpenAgent&query=mrdoc_44070.pdf, https://ww2.health.wa.gov.au/Articles/F_I/Guidance-on-applying-for-approval-of-installation-of-a-commercial-onsite-wastewater-system https://ww2.health.wa.gov.au/~/media/Files/Corporate/general-documents/water/Wastewater/Site-Soil-Evaluation.pdf

5.4 Use of recycled water by the primary production sectors

Analysis of data from the Australian Bureau of Statistics (ABS) indicated that variation in recycled water use for all agricultural commodity groups from 2000 to 2019 did not change significantly. Any variation in use was most likely from seasonal demands for each commodity group (Figure 5-14 and Figure 5-15).

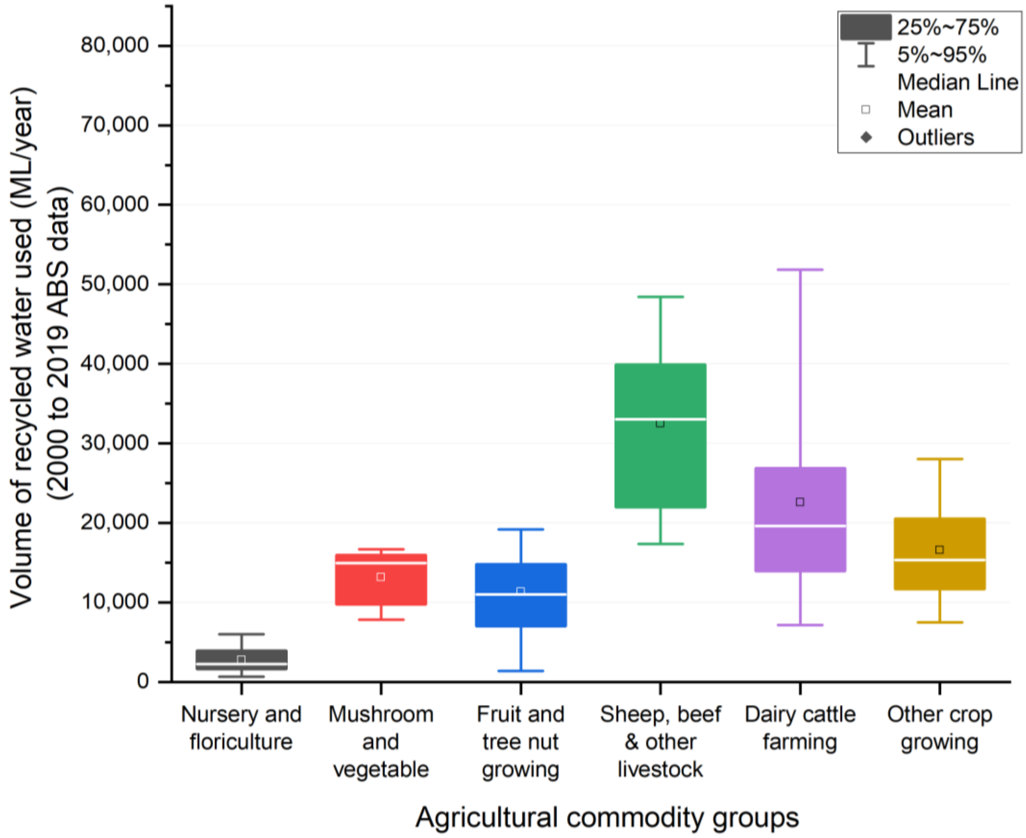

Figure 5-14 Recycled water use by various agricultural commodities groups in Australia (2000 to 2019, (ABS, 2021)). Note Agricultural commodity group category 'Sheep, beef & other livestock' is listed in the ABS as ' Sheep, beef, cattle, grain growing and other livestock farming' for 2008 to 2019. Outliers identified in Figure 5-15 were included.

The outliers in the commodity group 'Dairy cattle farming' (2004) for Australia were a combination of Vic and NSW data. This value was for 'Agriculture Dairy farming', a category used from 2001 to 2004. This category was updated and consolidated in 2008 to those listed in Figure 5-14 (i.e., Dairy cattle farming). The larger recycled water volume in 2004 was predominantly from Victoria (76,042 ML/year). If this volume was used, it equated to approximately 10,000 ha of dairy cattle pasture irrigated with recycled water (Assume 7 ML/ha/year). This is very unlikely and could be a systematic error due to the changes in categories during this time. As data from 1993 to 1996 for Australia varied from 29,066 to 38,118 ML/year) for the commodity group 'Livestock, pasture, grains and other agriculture' (there were no other categories listed), it is unlikely the outlier value (79,136 ML/year) was correct. Therefore, the value has been excluded from any statistical analysis.

For the commodity group 'Sheep, beef and other livestock', the mean volume of recycled water used across Australia was 32,502 (17,362 to 48,406; min to max) ML/year. However, as beef are only a portion of this commodity group, volumes of recycled water exposed to be beef will be lower. For a more direct comparison, it was assumed that the fraction of beef in the category average 0.8, ranging from 0.5 to 1.0, as cattle a more typically used for feed production on the irrigated pastures across Australia. The average volumes of recycled water used for 'Dairy cattle farming' were lower 22,580 (7,176 to 51,855) ML/year, with a greater range (Figure 5-14) than 'Sheep, beef and other livestock' commodities group.

Future use of recycled water for livestock will increase as populations grow and recycled water volumes available increase. However, conversely as more highly treated recycled water (Class A) is produced from upgrades to WWTPs, the recycled water may also be used for higher values crops and opportunities (Radcliffe, 2021).

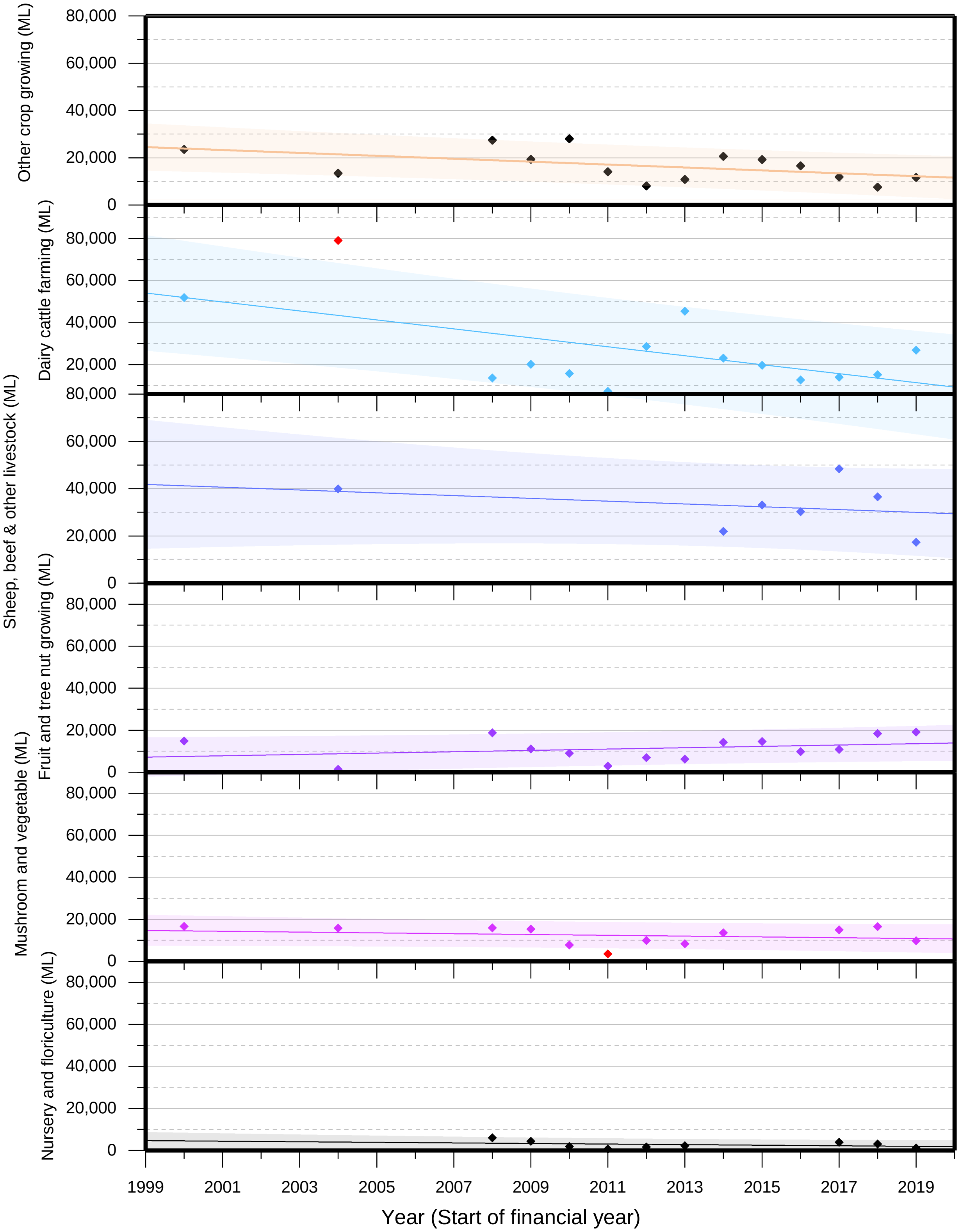

Figure 5-15 Uses of recycled water across Australia from 2000 to 2019 (ABS, 2021). Outliers identified as red points (studentised residual > ± 2.0). All slopes are not significantly different from zero (ANOVA) (OriginLab, 2021).

5.4.1 Horticultural food crops eaten raw

The average volumes of recycled water used for food crops eaten raw, commodity groups of ‘Mushroom and vegetables’ and ’Fruit and tree nuts’ average 13,158 and 11,326 ML/year, respectively (Figure 5-14). Both these industries have embraced recycled water to overcome threatened water supplies in expanding industries in several states and territories of Australia. The produce grown in both commodity groups is normally readily accepted by wholesalers and consumers. The consumer will have little idea if the produce is grown with or without recycled water as there are no labelling requirements. Primarily as the recycled water is treated to a level fit for this purpose. In many cases, recycled water has a higher quality assurance standard than other rain-fed water systems used to supply irrigation water.

5.4.2 Processed food crops

No category was identified that used recycled water specifically for processed food crops. However, the processing step (e.g., cooking) can also provide a level of protection from helminth eggs as they are destroyed at a temperature greater than 65ºC (Figure 5-16).

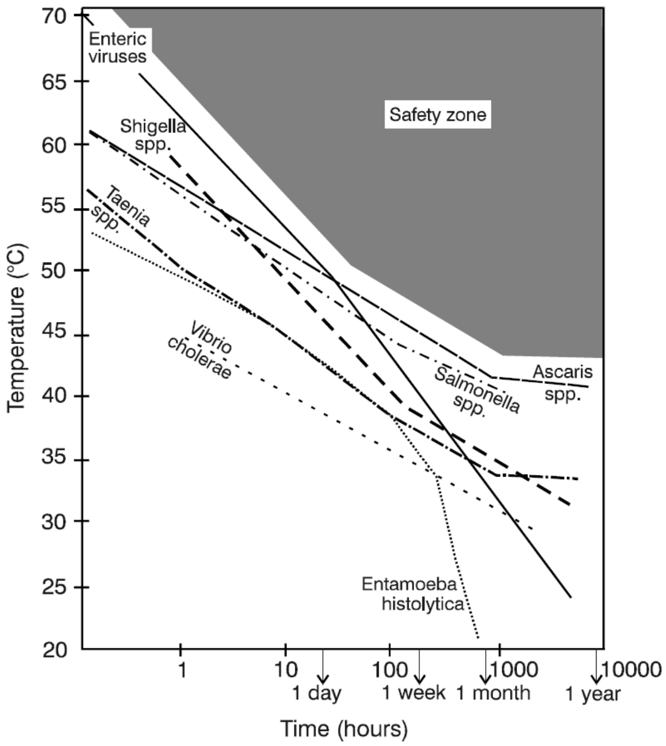

Figure 5-16 Temperature and contact time for inactivation of helminth eggs (Feachem et al., 1983; Strauch, 1991; Smith, 2008).

5.4.3 Pastures and animal husbandry

The total number of cattle with potential exposure to recycled water from centralised treatment systems was considerably lower than the total cattle population (Figure 5-17). The fraction of cattle potential cattle exposed to recycled water annually varied from 0.0070 (0.0032; 0.0160) (Calculated using a simple Monte Carlo model derived; Figure 5-18). This represented a median of 180,390 (79,004; 418,288) head of all cattle/year potential exposure to recycled water. This was approximately 92,570 (40,336; 212,744) head of beef/year exposed to pasture or fodder grown with recycled water.

Exposure to on-site wastewater systems would be much lower given the volume produced, area irrigated, and restrictions that apply (5.3.6).

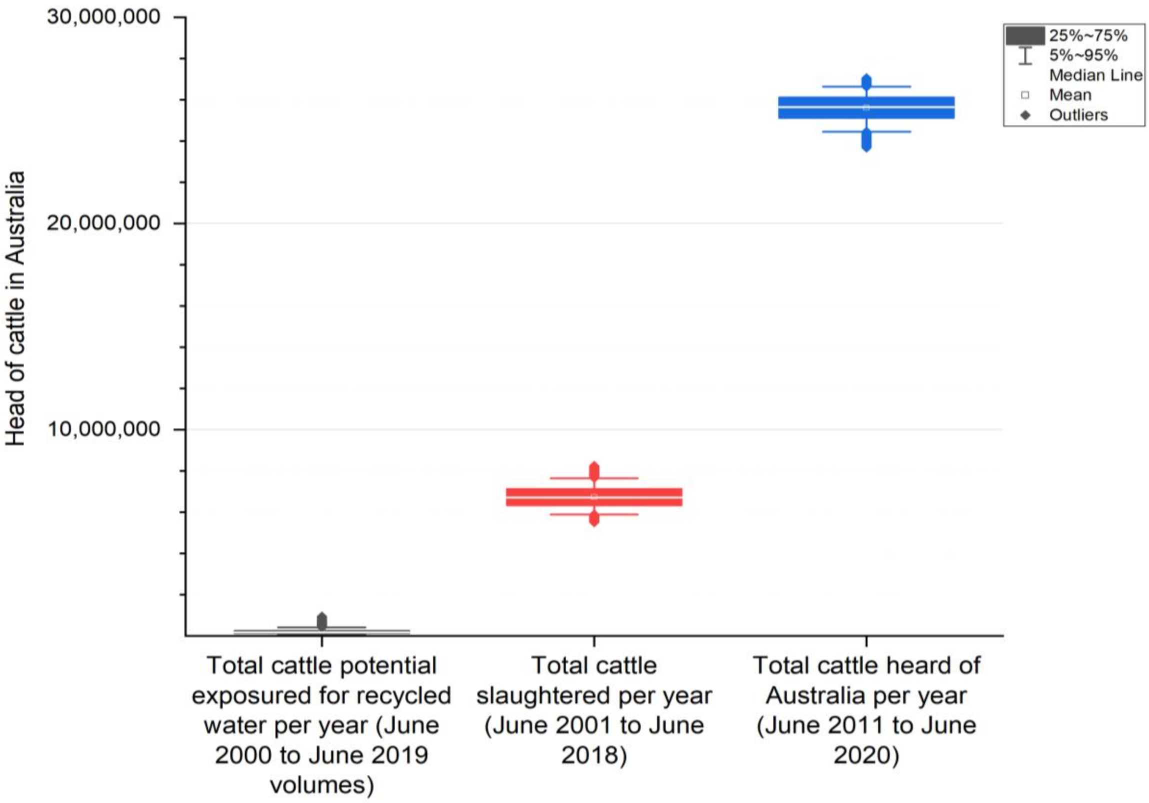

Figure 5-17 Head of cattle potential exposed to pasture or fodder irrigated with recycled water from centralised wastewater treatment plants, total cattle slaughtered and the total cattle herd in Australia. Recycled water exposure was based on irrigation rates of 2.62 (1.00, 6.82) ML/year (Stevens et al., 2021a), cattle stocking rates of 9 (5, 20) head/ha[8], the fraction of recycled allocated to sheep, beef and other livestock (Figure 5-14) allocated to be beef was assumed to 0.8 (0.5, 1.0). Total cattle refer to beef and dairy cattle, exposed to similar mean volumes.

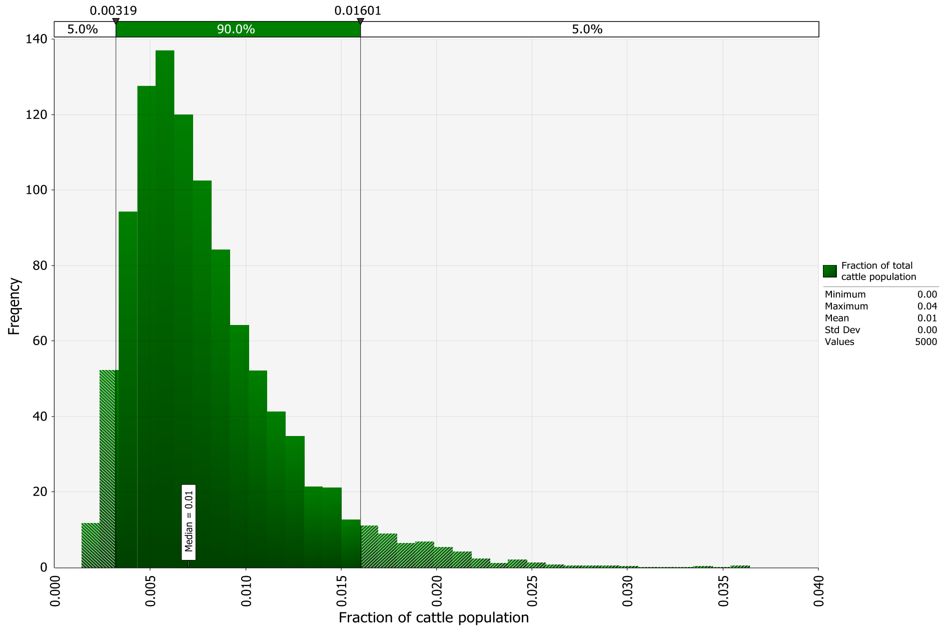

Figure 5-18 Fraction of cattle (beef and dairy) potentially exposed to recycled water in a year (2010 to 2020 cattle population[9])

[8] https://etools.mla.com.au/src/?v=4&r=18&linking=1#/beef

[9] https://www.abs.gov.au/statistics/industry/agriculture/agricultural-commodities-australia/latest-release#livestock

5.4.4 Perception of recycled water used to produce foods

The concept in the AGWR is that the water is fit for the purpose it is used for it, then it re-enters the natural water cycle post the primary exposure site. Recycled water used for pasture and fodder production (feed) is this primary exposure site, and perception of recycled water use often focus on this. From a feed perspective, cattle and the meat product are a secondary exposure site, one step removed from the primary exposure. However, recycled water use for cattle drinking water is primary exposure.

From a retailer's perspective, the name of the water used to produce the food product must not imply sewage. In addition, an independent advisory panel should oversee the product safety, and the product's safety is explained well (Furlong et al., 2019).

From a public perception recognition and acceptance perspective, people in Australia can be receptive to drinking recycled water when the relative situation is worse (Fielding et al., 2015; Adapa, 2018). Australian households support wastewater recycling and are willing to pay more for it; however, they prefer recycled wastewater be used in commercial and industrial processes rather than in their houses and backyards (Bennett et al., 2016). Several studies have indicated that the closer the risk of personal contact or ingestion, the less acceptable (Lease et al., 2014). The psychological research on contagion can explain higher opposition to recycled water for uses with human contact. Contagion refers to the idea that once two objects come into contact with each other, that contact can influence the properties of the objects and can extend beyond the period of contact (Fielding et al., 2015).

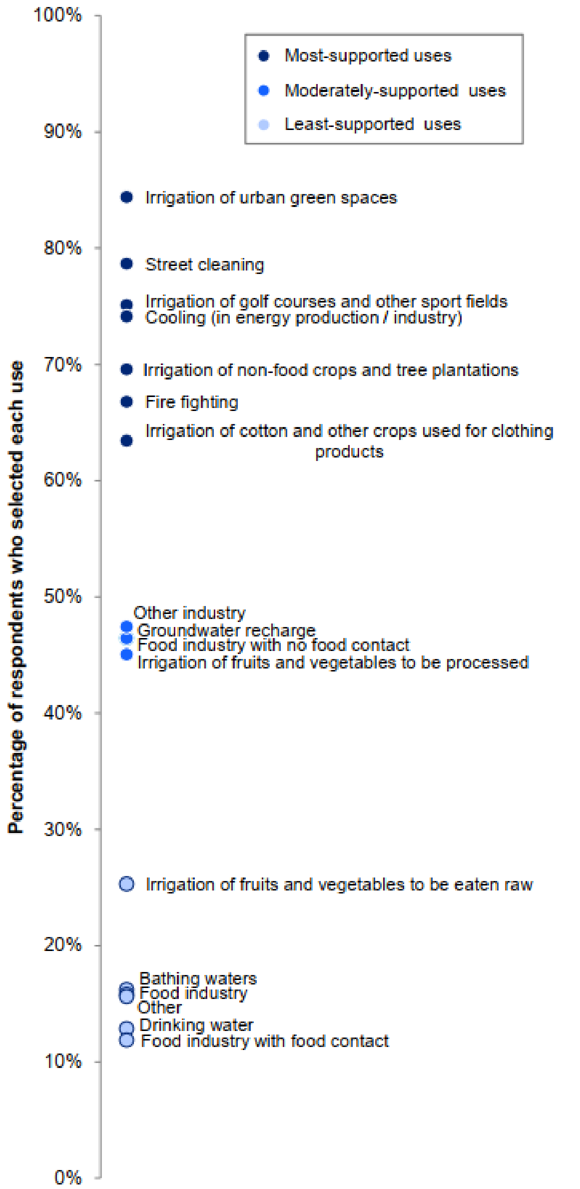

Figure 5-19 Proportion of respondents considering a given use of recycled water as appropriate (EU, 2015)

Studies in Australia have shown perceptions and acceptance of recycled water from different sources and uses to be similar to those in Europe (Figure 5-19) (Po et al., 2005; Syme and Nancarrow, 2006).

Acceptance studies for uses of recycled water and produce grown generally focus on food for humans, not feed for animals that are then consumed as food for humans. This secondary exposure for meat products removes the direct contact (if the animal does not drink the recycled water) and should increase acceptance of this use. As the water supplied for pasture and fodder production should be fit for the intended use, there have been no historical requirements to label this product as grown with recycled water. As meat is often consumed cooked, this would be expected to increase acceptance as a processing step also provides a barrier to direct exposure to the consumer.

The discussion above indicates that acceptance would be relatively high for meat production from pasture and fodder grown with recycled water. However, it is also essential to quickly provide positive factual information about the benefits and safety of recycled water used for cattle production when retailers or consumers request it.

5.5 C. bovis in Australia

5.5.1 Taeniasis (Humans - evidence for local infection)

Humans are the primary host of the tapeworm *T. saginata*, and the tapeworm eggs are passed in human faeces (Kiermeier et al., 2019). In Australia, *T. saginata* is not endemic in the human population (Kiermeier et al., 2019). Additionally, it is not a requirement to notify medical authorities of *T. saginata* infection in Australia (Health Victoria, 2017). Hence, evidence around human infection rates in the country are limited. According to Kiermeier et al. (2019), there are 0.56 to 0.97 illnesses per year from the consumption of Australian beef. Additionally, Stevens et al. (2017) determined that the risk of *T. saginata* infection within Australia is low as there should not be any significant source releasing HEs to the sewer. Control measures, such as HE removal via sewage treatment processes, cooking of meat, hand hygiene, meat inspection, availability of medication and restrictions on the supply of recycled water directly or indirectly to animals and food crops, also work to reduce the risk of human exposure to *T. saginata* (Stevens et al., 2017).

The risk of human *T. saginata* infection from consumption of Australian beef is very low (0.37 cases per 1 billion portions consumed in the domestic and top five export markets – USA, Japan, Korea, China and Canada)(Kiermeier et al., 2019). The likelihood of infection within Australia may be low. However, infected people could enter the country by visiting or returning travellers and migration from endemic countries. For example, a total prevalence of 14.1% for *T. saginata* taeniasis was detected during 2002-04 in people from two areas around Denpasar in Bali (Wandra et al., 2006). It is not surprising that with the high frequency and ease of travel between endemic and non-endemic regions, sporadic infection can occur in people who would otherwise be considered at no or very low risk of infection (Forster et al., 2020). Infected travellers or immigrants are known to increase the incidence of helminth-associated diseases in developed countries (Gordon et al., 2017) (Section 5.5.2).

Current health screening for immigrants does not include testing for parasites and focuses on notifiable diseases such as tuberculosis and HIV/AIDS. Since STH infections are not notifiable, it is possible that there are autochthonous and returned traveller cases occurring in Australia that are not identified or reported (Gordon et al., 2017; Stevens et al., 2021b).

5.5.2 Disease burden and sources of C. bovis in Australia.

Extensive studies over the last decades (554 samples from 11 WWTPs) have indicated that the *T. saginata* egg is not present in raw sewage in southern Australia (Stevens et al., 2017, 2021a). This indicates that the current disease burden in Australia is very low. However, the travellers and immigrants could impact the current disease burden (Section 5.5.1).

5.5.3 Carcass condemnation from C. bovis – 2001 to 2018.

Recent data for C. bovis infection in cow/bulls and heifer/steers across Australia indicated that condemnation rates from C. bovis infection are very low (Pointon et al., 2022). This data allowed the comparison of carcasses condemned due to C. bovis from 2001 to 2018 with the introduction of the AGWR (NRMMC et al., 2006; Matthews, 2020). There was a significant ($p = 0.05$) difference in means for AGWR and the maturity of cattle (cow/bull and heifer/steer) and interaction between these (ANOVA (OriginLab, 2021). The difference between pre and post the AGWR was significant (Tukey test), indicating that there has been a decrease in C. bovis detected. This significant decrease could be due to the publication of the AGWR contributed to improvements in preventing the incidence of C. bovis in cattle (Discussed further in Pointon et al., 2022). Improvements to most guidelines at the state and territory levels indicate the adoption of the AGWR (Section 5.3.1 and 5.3.3).

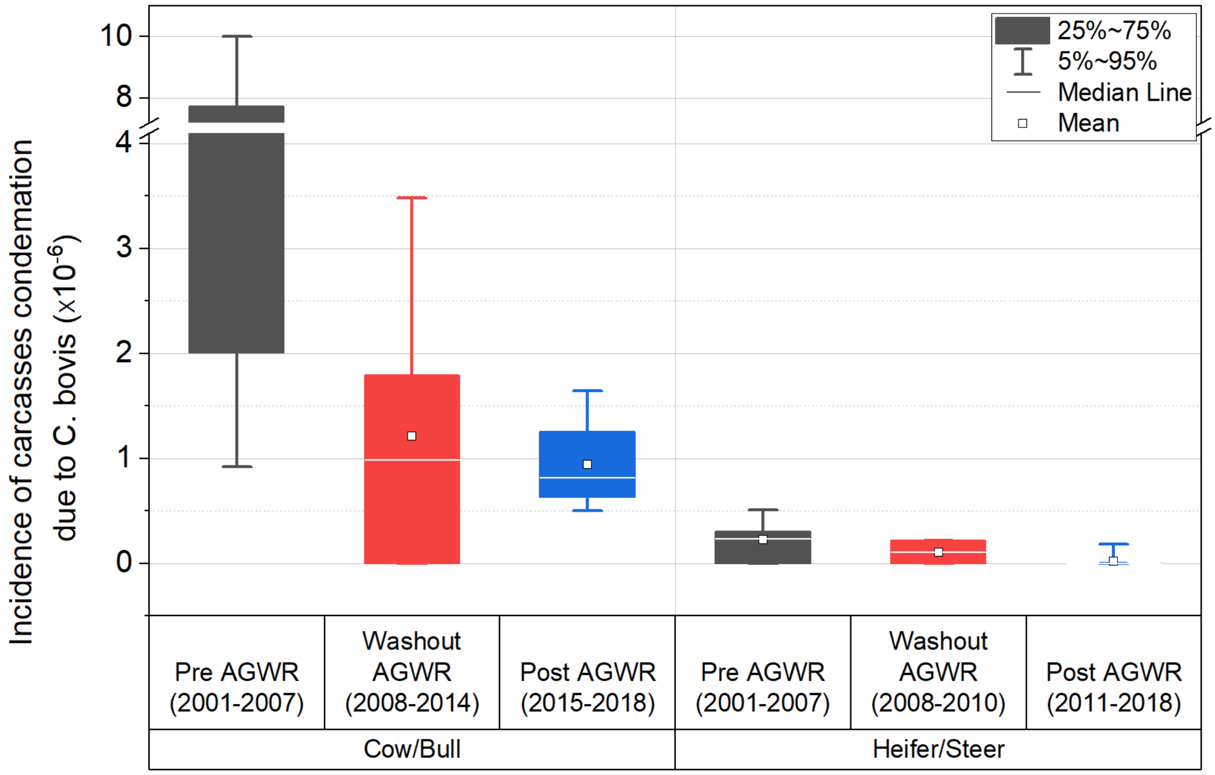

Figure 5-20 Incidence of carcasses condemned in Australia from C. bovis cyst detection relative to the publication date of the Australian Guideline for Water Recycling (AGWR) and maturity of the cattle. (Matthews, 2020)). Excludes 2010 data due to an identified contamination event not associated with recycled water use (Brown et al., 2010; NSW Industry and Investment, 2010; Jenkins et al., 2013).

6 Discussion

6.1.1 Summary of outcomes

The management of recycled water quality and minimising the risk of C. bovis in cattle meat represents the first stage of this supply chain (Figure 2-1). The AGWR provide the fundamental guideline for managing this risk in Australia. They provide a precautionary approach for removing the helminth egg from sewage, based on experience in Australia and that translated from countries around the world and experience in Australia. The guideline for management of *T. saginata* eggs ensures a treatment system or equivalent that will remove 99.99% of helminth eggs from the sewage (4 LRV) to minimise the risk to cattle exposed to the recycled water. As *T. saginata* eggs have not been detected in Australian sewage for the last decade, the AGWR represents an over-protective approach for the baseline exposure (Stevens et al., 2017, 2021b, 2021a). However, these guidelines also protect against any unforeseen outbreaks entering the sewer. Even though, recent historical data suggests this is unlikely.

Detection of C. bovis via PMI (2001 to 2018) and estimates for the likelihood of contracting taeniasis support the findings that taeniasis and C. bovis are very rare in Australia (Kiermeier et al., 2019; Pointon et al., 2022). However, C. bovis has been detected from contamination events and some unknown sources. Identification of contamination events is often complicated, and unknown sources are difficult to trace. Some of the unknown source could be from poorly designed or managed centralised or on-site wastewater treatment systems. Therefore, it is essential to understand how the state and territory guidelines are implemented and audited, on the ground, to ensure that the necessary control measures are in place, maintained and verified.

During development of the AGWR, two limitations to the approach taken for managing helminth in recycled water were identified: i) the risk assessment that supported the development of new management strategies for *T. saginata* egg was limited by the lack of an exposure model (NRMMC et al., 2006), and ii) the associated control measures (treatment or on-site) described in it relied on historical experience, as a precautionary approach due to the first limitation. Recently, research has overcome these limitations and developed a comprehensive exposure model that has identified additional treatment and on-site control measures to manage the *T. saginata* egg risk (Stevens et al., 2021a). However, the verification of these new measures is complicated by the low concentration of helminth eggs in Australia's raw sewage. Regardless, this type of complication is inherent with helminth egg management and design equations for HE removal or exposure models are often relied on to minimise the associated risk. However, these new management strategies could be validation using PMI for C bovis.

Since the publication of the AGWR all state and territory guidance for centralised treatment systems have been updated and indicate that their guidance for water recycling reflects the risk and controls from the AGWR. However, review of these published guidelines indicated that this may not be precisely the case for *T. saginata* egg control and the associated risk from both an establishment and auditing perspective. For example, in NT and SA, specific guidance is poor to moderate (respectively), and auditing specifications are poor to moderate in SA and Tas (respectively). Such observations indicate that there could be some improvement to these guidelines directly, or by adding amendments, or fact sheets for the guidelines, like those issued by the water supplier in Tasmania (TasWater, 2011). How these published guidelines are used practically requires verification.

Where the controls and auditing are rated high and used appropriately, due to the protective approach for helminth egg management related to cattle exposure and the supply of recycled water fit-for-purpose, the recycled water should not require ongoing livestock traceability (e.g. National Livestock Identification System (NLIS)) as part of the risk management. However, cyst detection (PMI) combined with choosing to use traceability could be another risk management method used for the verification process. For example, the cost to treat water to an acceptable level (4 LRV) may be prohibitive for the wastewater treater. Consequently, the water will be deemed unsuitable for cattle production, restricting access to the water for the cattle industry or increasing the cost of irrigation water unnecessarily. However, an integrated approach could use a QMRA to determine a 3 LRV from the treatment of the sewage is required. This could be verified with the cattle traceable and additional PMI for C. bovis cysts during processing, if no cysts are detected this would verify the QMRA. The PMI for C. bovis cysts could also be used to verify *T. saginata* egg control for any recycled water scheme where cattle are fed with pasture or fodder irrigated with recycled water. To our knowledge, this verification approach has not been assessed directly in Australia. These types of investigations can help determine the optimal cost-effective approach for water managers and beef producers.

On-site treatment systems and related guidance have also adopted the general principles of the AGWR. In most cases, these systems do not allow access to the irrigation area, which is encouraged to be subsurface. However, specific mention of helminths and livestock exclusion from the area is not commonly noted. Areas of irrigation for on-site wastewater treatment systems are typically small, but the number of on-site treatment systems large. Therefore they potentially pose a risk that is not controlled well. Amendments to these state and territory guidelines should specifically mention excluding livestock or cattle like that document in the NSW guidance.

To determine if the alternate PMI is appropriate for cattle produce using recycled water, the next step is to confirm that recycled water guidelines are practised and to verify that the obligations associated with enforcement and auditing of the guidance comply with the appropriate guidance. This will involve state/territory guidance EPA and other auditors for centralised or on-site wastewater treatment systems. This step is crucial to ensure the entire supply chain is protected when producing cattle with recycled water and modifications to PMI are to be relied on the equivalence case to overseas beef export markets.

6.1.2 Uncertainties

Some uncertainties identified were the:

- Lack of presence in raw sewage makes quantifying the actual risk posed by *T. saginata* eggs in sewage difficult. Improvements to detection limits may overcome this or verify cattle as C. bovis free during PMI.
- Inland release of sewage effluent to freshwater systems (primary exposure) with no defined helminth controls. Yet the freshwater system could supply water to farms for irrigation water and livestock drinking water, i.e. exposure to cattle (Secondary exposure site). The risk from this exposure route has not been quantified and relies on dilution and settling or deactivation of helminth eggs in the freshwater environment. To date, there has been no exposure recorded in Australia via this route.
- A definitive cause-and-effect regarding the AGWR and C. bovis incidences is difficult to make. However, the data analysed suggest the AGWR may be one factor that has lowered C. bovis (PMI) incidences.

6.1.3 Future risk

Future updates to guidelines can change helminth guidance as risks perceived to be insignificant can be removed, often to simplify the guidance. There is already some evidence of this in some states and territories for centralised and on-site wastewater treatment guidance. Therefore, awareness of the helminth risk management that the guidance provides to protect cattle from *T. saginata* must be maintained in future revisions of guidelines to ensure this risk continues to be managed. The current baseline may be low for C. bovis incidence and *T. saginata* egg concentrations in sewage. However, protection against unexpected loads from community outbreaks, travellers and migrants are essential to maintain management of the risk.

7 Conclusions / Recommendations

7.1.1 Conclusions

The regulatory arrangements (through the supply chain) to prevent *T. saginata* egg exposure of cattle from recycled water (from sources of human sewage) have been documented for centralised WWTP and on-site treatment systems. Overall guidance for both treatment systems typically provides a robust system for managing helminth egg exposure to cattle in Australia. However, some gaps in this guidance were identified for some states and territories.

The C. bovis condemnation data assessed suggested that publication of the AGWR have helped lower the incidence rate of C. bovis detected via PMI. Promoting this benefit to maintain helminth egg control via centralised and on-site wastewater treatment systems is essential to ensure those who regulate recycled water use are aware of the importance of this control measure.

7.1.2 Recommendations

Recommendations from this report are:

1. There is a trend for health departments (i.e. human health) to rate recycled water schemes that irrigation pasture and fodder as low risk (to humans). As a low-risk scheme, management is then simplified by not requiring management plans. These plans are typically used for the auditing process that determines if appropriate helminth egg management is in place and maintained. Such a trend could lead to *T. saginata* egg management oversites in the future. The potential for these oversights need to be brought to the attention of relevant government departments to ensure the controls for helminth egg management is maintained in the future. For example, if recycled water that is fit-for-purpose was an integral part of the production quality assurance guideline for cattle produciton, this could trigger requirements for recycled water guidelines to be maintained.
2. Amendments should be made to all on-site treatment guidelines for states and territories across Australia that do not specifically mention excluding cattle from irrigation areas. Or, excluding all livestock from the irrigation area to maintain the soil structure and manage livestock helminth risks.
3. How well the documented guidance in states and territories of Australia are implemented practically by the responsible government authority (e.g. Department of Health, EPA) for all relevant exposure pathways for cattle needs to be verified. This verification should assess how well recycled water schemes are maintained and audited concerning minimising the risk of C. bovis in cattle.
4. Verification of the control measures for *T. saginata* egg management in the AGWR (current or improvements) integrated with PMI for C. bovis cysts via traceability should be explored futher. Current research suggests that helminth controls may be over-protective, leading to increased water treatment costs prohibiting access to recycled water for some sectors of the cattle industry.
5. Consideration of grazing history is not relevant for recycled water if the AGWR guidance is followed, verified, and audited, for the management of helminth, as the recycled water should be fit for the intended purpose. However, if this quality assurance system for recycled is not implimented, the risk of C. bovis detection in cattle may not be managed appropriately. In this case, the grazing history related to recycled water exposure may be of use. The integration of the recycled water quality assurance system into the whole supply chain should be explored as an alternative C. bovis management system.

8 Bibliography

ABS (2021) Water Account, Australia | Australian Bureau of Statistics. Aust Bur Stat Available at: https://www.abs.gov.au/statistics/environment/environmental-management/water-account-australia [Accessed November 23, 2021].

ACTG (1999) ACT Wastewater Reuse for Irrigation — Environment Protection Policy, Environment ACT. Canberra, ACT, Australia: Environment Protection Legislation and Policies, Department of the Environment, Climate Change, Energy and Water. Available at: http://www.environment.act.gov.au/environment/epa_legislation_and_policies.

ACTG (2021) Environment Protection Act 1997. Updated 2021. Canberra, ACT, Australia: Australian Capital Territory Government. Available at: https://www.legislation.act.gov.au/a/1997-92/default.asp.

Adapa S (2018) Factors influencing consumption and anti-consumption of recycled water: Evidence from Australia. J Clean Prod 201:624–635 Available at: https://www.sciencedirect.com/science/article/pii/S0959652618324193 [Accessed October 27, 2021].

AMRG (2020) Fact Sheet 2.7: Alternative risk management for C. bovis in cattle and buffalo inspection. AMRG Guideline 2020:1. PostMortem Meat Inspection – Alternative techniques to Schedule 2 and 3 of AS 4696:2007. Australian Meat Regulators Group. Available at: https://www.mintrac.com.au/page.asp?p=175 [Accessed June 29, 2021].

ARMCANZ, ANZECC, NHMRC (2000) Guidelines for sewerage systems. Use of reclaimed water, Paper 14. Canberra, Australia.: National Water Quality Management Strategy. Agriculture and Resource Management Council of Australia and New Zealand. Australian and New Zealand Environment and Conservation Council. National Health and Medical Research Council. Available at: http://www.environment.gov.au/water/publications/quality/index.html.

AS4696 (2007) AS 4696-2007 Hygienic production and transportation of meat and meat products for human consumption. Available at: https://infostore.saiglobal.com/en-au/standards/as-4696-2007-121579_saig_as_as_255139/ [Accessed January 10, 2022].

AS/NZS (2001) AS/NZS 1546.3:2001 : On-site domestic wastewater treatment units -Aerated wastewater treatment systems. Standards Australia/Standards New Zealand, Sydney and Wellington: Standards Australia/Standards New Zealand. Available at: http://www.saiglobal.com/shop/Script/Details.asp?DocN=AS900502987057.

AS/NZS (2012) On-site domestic wastewater management. AS/NZS 1547-2012. Available at: https://www.standards.org.au/standards-catalogue/sa-snz/waterandwasteservices/ws-013-1/{designation} [Accessed January 11, 2022].

Ayres RM, Alabaster GP, Mara DD, Lee DL (1992) A design equation for human intestinal nematode egg removal in waste stabilization ponds. Water Res 26:863–865.

Bennett J, McNair B, Cheesman J (2016) Community preferences for recycled water in Sydney. Australas J Environ Manag 23:51–66 Available at: https://doi.org/10.1080/14486563.2015.1129364 [Accessed October 27, 2021].

BOM (2015) Climate Resilient Water Sources. Clim Resilient Water Sources Available at: http://www.bom.gov.au/water/crews/site-explorer/.

Brown G, Dennis M, Slapeta J, Thompson A (2010) Letter to the Editor - Prevalence of Cysticercus bovis (beef measles) in Australian cattle. Aust Vet J 88.

Brownmang onwuka BM (2018) Effects of soil temperature on some soil properties and plant growth. Adv Plants Agric Res Volume 8 Available at: https://medcraveonline.com/APAR/APAR-08-00288.pdf [Accessed December 22, 2021].

CBOS (2017) Building Act 2016. Director's Guidelines for On-site Wastewater Management Systems. v2.0. Consumer, Building and Occupational Services Department of Justice, Government of Tasmania. Available at: https://www.cbos.tas.gov.au/__data/assets/pdf_file/0020/405056/Directors-guidelines-for-Onsite-wastewater-management-systems.pdf.

Collins G, Pope S (1990) Cysticercus bovis in cattle in New South Wales. Aust Vet J 67:228–229 Available at: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1751-0813.1990.tb07768.x [Accessed November 23, 2021].

DES QLD (2015) MEDLI - Software for effluent reuse schemes. Version 2. Available at: https://science.des.qld.gov.au/government/science-division/medli.

DEWS Qld (2008) Water quality guidelines for recycled water schemes. Brisbane: Department of Energy and Water Supply, Queensland Government, Australia. Available at: https://www.dews.qld.gov.au/__data/assets/pdf_file/0019/45172/water-quality-guidelines.pdf.

DH NT (2011) Guidelines for Management of Recycled Water Systems. Casuarina, NT, Australia: Department of Health, Northern Territory Government. Available at: http://www.health.nt.gov.au/Environmental_Health/Wastewater_Management/index.aspx#RecycledWaterSystems.

DH NT (2020) Code of Practice for Water Recycling. Darwin, NT, Australia: Department of Health, Northern Territory Government. Available at: https://nt.gov.au/property/building/health-and-safety/wastewater-management/recycled-water.

DHS SA, EPA SA (1999) South Australian Reclaimed Water Guidelines. Adelaide, South Australia: Department of Human Services and Environment Protection Agency, Government of South Australia.

DoH NT (2014) Code of practice for small on-site sewage and sullage treatment systems and the disposal or reuse of sewage effluent. Darwin, Northern Territory, Australia.: Department of Health, Northern Territory Government. Available at: https://nt.gov.au/__data/assets/pdf_file/0008/228833/code-of-practice-onsite-wastewater-management.pdf.

DOL NSW, EPA NSW, DoH NSW, DLWC NSW, DUAP NSW (1998) Environment & Health Protection Guidelines. On-site Sewage Management for Single Households. Sydney: NSW Departments of Local Government, Health, Land and Water Conservation, Urban Affairs and Planning, and NSW Environment Protection Authority. Available at: https://www.olg.nsw.gov.au/wp-content/uploads/Onsite-sewage-management-guide.pdf.

DPIWE (2002) Environmental Guidelines for the use of Recycled Water in Tasmania. Hobart, Tasmania: Department of Primary Industries, Water and the Environment. Tasmanian Government.

DWE NSW (2007) Best-Practice Management of Water Supply and Sewerage Guidelines. Department of Water and Energy, Government of NSW. Available at: https://www.industry.nsw.gov.au/water/water-utilities/best-practice-mgmt.

EPA ACT (2012) Water quality environment protection policy Environment Protection Authority, ACT. Available at: https://www.legislation.act.gov.au/DownloadFile/ni/2012-324/current/PDF/2012-324.PDF.

EPA Tas (2009) Guide to the EPA Regulatory Expectations for Wastewater Treatment in Tasmania. Environmental Protection Authority, Tasmania, Australia. Available at: http://epa.tas.gov.au/epa/document?docid=59.

EPA VIC (2016) Code of practice – onsite wastewater management. Publication 891.4. Available at: https://www.epa.vic.gov.au/our-work/publications/publication/2016/july/891-4 [Accessed May 3, 2019].

EPA Victoria (1991) Guidelines for wastewater irrigation. Publication no 168. Melbourne: EPA Victoria. Available at: http://epanote2.epa.vic.gov.au/EPA%5CPublications.nsf/PubDocsLU/168?OpenDocument.

EPA Victoria (2003) Guidelines for environmental management. Use of reclaimed water. Southbank, Victoria 3006, Australia: EPA Victoria. Available at: http://epanote2.epa.vic.gov.au/EPA/Publications.NSF/PubDocsLU/464.2?OpenDocument.

EPAV (2021a) 1910.2: Victorian guideline for water recycling. Melbourne, Victoria, Australia: EPA Victoria. Available at: https://www.epa.vic.gov.au/about-epa/publications/1910-2 [Accessed April 22, 2021].

EPAV (2021b) 1911.2: Technical information for the Victorian guideline for water recycling. Melbourne, Victoria, Australia: EPA Victoria. Available at: https://www.epa.vic.gov.au/about-epa/publications/1911-2 [Accessed April 22, 2021].

EPHC, NHMRC, NRMMC (2008) Australian Guidelines for Water Recycling. Managing Health and Environmental Risks. Phase 2. Augmentation of Drinking Water Supplies. National Water Quality Management Strategy 22. Canberra, Australia.: Environment Protection and Heritage Council, National Health and Medical Research Council, and the Natural Resource Management Ministerial Council. Government of Australia. Available at: https://www.nhmrc.gov.au/about-us/publications/australian-guidelines-water-recycling#block-views-block-file-attachments-content-block-1.

Feachem RG, Bradley DJ, Garelick H, Mara D (1983) Ascaris and Ascariasis. In: Sanitation and disease. Health aspects of excreta and wastewater management World Bank Studies in Water Supply and Sanitation 3. World Bank 1983.

Fewster GE (1967) The Incidence of Cysticercus Bovis in Cattle in Victoria and Tasmania. Aust Vet J 43:450–453 Available at: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1751-0813.1967.tb08873.x [Accessed November 23, 2021].

Fielding KS, Gardner J, Leviston Z, Price J (2015) Comparing Public Perceptions of Alternative Water Sources for Potable Use: The Case of Rainwater, Stormwater, Desalinated Water, and Recycled Water. Water Resour Manag 29:4501–4518 Available at: https://doi.org/10.1007/s11269-015-1072-1 [Accessed October 27, 2021].

Forster D, Ko D-K, Koehler AV, Kranz S, Goh C, Fleming B, Awad M, Johnson D, Gasser RB, Mahanty S (2020) Case Report: Neurocysticercosis Acquired in Australia. Am J Trop Med Hyg 103:2318–2322.

Furlong C, Jegatheesan J, Currell M, Iyer-Raniga U, Khan T, Ball AS (2019) Is the global public willing to drink recycled water? A review for researchers and practitioners. Util Policy 56:53–61 Available at: https://www.sciencedirect.com/science/article/pii/S0957178718300092 [Accessed October 27, 2021].

FutureBeef (2019) FutureBeef, Knowledge centre articles. Water requirements for cattle. Future Beef Available at: https://futurebeef.com.au/knowledge-centre/water-requirements/ [Accessed September 16, 2019].

Gordon C, Kurscheid J, Jones M, Gray D, McManus D (2017) Soil-Transmitted Helminths in Tropical Australia and Asia. Trop Med Infect Dis 2:56 Available at: http://www.mdpi.com/2414-6366/2/4/56 [Accessed July 24, 2018].

Green O, Nadimi ES, Blanes-Vidal V, Jørgensen RN, Storm IMLD, Sørensen CG (2009) Monitoring and modeling temperature variations inside silage stacks using novel wireless sensor networks. Comput Electron Agric 69:149–157 Available at: http://www.sciencedirect.com/science/article/pii/S0168169909001513 [Accessed March 6, 2017].

Gunady M, Shishkina N, Tan H, Rodriguez C (2015) A Review of On-Site Wastewater Treatment Systems in Western Australia from 1997 to 2011. J Environ Public Health 2015:1–12.

Health Victoria (2017) Taeniasis (tapeworm). HealthVic Available at: https://www2.health.vic.gov.au/public-health/infectious-diseases/disease-information-advice/taeniasis-tapeworm [Accessed July 18, 2018].

Horton B, Corkrey R, Horton B, Corkrey R (2011) A weighted coefficient model for estimation of Australian daily soil temperature at depths of 5 cm to 100 cm based on air temperature and rainfall. Soil Res 49:305–314 Available at: https://www.publish.csiro.au/sr/SR10151 [Accessed December 21, 2021].

Horton B, Horton B (2012) Models for estimation of hourly soil temperature at 5 cm depth and for degree-day accumulation from minimum and maximum soil temperature. Soil Res 50:447–454 Available at: https://www.publish.csiro.au/sr/SR12165 [Accessed January 10, 2022].

IconWater (2021) Sewage Reuse Projects | Icon Water. Available at: https://www.iconwater.com.au/Water-education/Water-and-sewerage-system/Sewage-Treatment/Sewerage-reuse-projects.aspx [Accessed December 9, 2021].

IEC/ISO (2009) AS/NZS ISO 31010:2009 Risk management — Risk assessment techniques. Geneva, Switzerland: International Organization for Standards and International Electrotechnical Commission.

ISO (2018) ISO 31000:2018 Risk management - Guidelines. SAI Global.

Jenkins DJ, Brown GK, Traub RJ (2013) “Cysticercosis storm” in feedlot cattle in north-west New South Wales. Aust Vet J 91:89–93.

Kiermeier A, Hamilton D, Pointon A (2019) Quantitative risk assessment for human Taenia saginata infection from consumption of Australian beef. Microb Risk Anal Available at: http://www.sciencedirect.com/science/article/pii/S2352352218300355.

Lease HJ, Hatton MacDonald D, Cox DN (2014) Consumers’ acceptance of recycled water in meat products: The influence of tasting, attitudes and values on hedonic and emotional reactions. Food Qual Prefer 37:35–44 Available at: https://www.sciencedirect.com/science/article/pii/S0950329314000597 [Accessed October 27, 2021].

Lucas J (2021) Revision of AS4696-Post Mortem Inspection and Disposition. Canberra, ACT: Department of Agriculture, Water Resources and Environment.

Matthews DB (2020) Common and Emerging conditions resulting in fell carcase condemnation at slaughter. Eagle Farm, Queensland, Australia.

McIntrye (pers.comm.) S (2021) Recycled water guidelines for the ACT.

NHMRC, NRMMC (2011) Australian Drinking Water Guidelines 6 (2021 update to 2011) V. 3.6. Commonwealth of Australia, Canberra.: National Health and Medical Research Council, National Resource Management Ministerial Council. Available at: https://www.nhmrc.gov.au/about-us/publications/australian-drinking-water-guidelines#block-views-block-file-attachments-content-block-1 [Accessed June 27, 2016].

NRMMC, EPHC, AHMC (2006) Australian Guidelines for Water Recycling. Managing Health and Environmental Risks. Phase 1. National Water Quality Management Strategy 21. Canberra, Australia: Natural Resource Management Ministerial Council. Environment Protection and Heritage Council, Australian Health Ministers’ Conference, Government of Australia. Available at: https://www.waterquality.gov.au/media/83.

NRMMC, EPHC, NHMRC (2009a) Australian Guidelines for Water Recycling. Managing Health and Environmental Risks. Stormwater Harvesting and Reuse. National Water Quality Management Strategy 23. Canberra, Australia.: Natural Resource Management Ministerial Council. Environment Protection and Heritage Council, Australian Health Ministers’ Conference. Government of Australia. Available at: https://www.waterquality.gov.au/media/90.

NRMMC, EPHC, NHMRC (2009b) Australian Guidelines for Water Recycling. Managing Health and Environmental Risks. Volume 2C - Managed Aquifer Recharge. Canberra, Australia.: Natural Resource Management Ministerial Council, Environment Protection and Heritage Council, and the National Health and Medical Research Council. Government of Australia. Available at: www.ephc.gov.au/taxonomy/term/39.

NRW Qld (2008) Recycled water management plan and validation guidelines. Brisbane: Natural Resources and Water. Queensland Government, Australia. Available at: https://www.rdmw.qld.gov.au/__data/assets/pdf_file/0020/45164/rwmp-and-validation.pdf.

NSW DEC (2004) Environmental Guidelines: Use of effluent by irrigation. Sydney, Australia: New South Wales Department of Environment and Conservation, Incorporating the New South Wales Environmental Protection Authority. Available at: www.environment.nsw.gov.au/resources/effguide.pdf http://www.environment.nsw.gov.au/water/effluent.htm.

NSW DPI (2015) Recycled water guidance document. Recycled water management systems. Parramatta, NSW, Australia: New South Wales Department of Primary Industries, Office of Water. Available at: https://www.industry.nsw.gov.au/__data/assets/pdf_file/0010/180478/Section-60-NSW-Guildeines-for-Recycled-Water-Management-Systems.pdf.

NSW Health (2000) Greywater Reuse in Sewered Single Domestic Premises. Gladesville, NSW, Australia: New South Wales Health. Available at: http://www.health.nsw.gov.au/public-health/ehb/general/wastewater/greywater_policy.pdf.

NSW Industry and Investment (2010) Animal Health Surveillance. Available at: www.industry.nsw.gov.au.

OriginLab (2021) OriginPro. OriginLab Corporation, Northampton, MA, USA. Available at: www.originlab.com.

Pearse B, Traub R, Davis A, Cobbold R, Vanderlinde P (2010) Prevalence of Cysticercus bovis in Australian cattle. Aust Vet J 88:260–262 Available at: http://onlinelibrary.wiley.com.ezproxy.lib.rmit.edu.au/doi/10.1111/j.1751-0813.2010.00593.x/abstract [Accessed April 18, 2016].

Po M, Nancarrow BE, Leviston Z, Porter NB, Syme GJ, Kaercher JD (2005) Predicting community behaviour in relation to wastewater reuse what drives decisions to accept or reject? Perth: CSIRO Land and Water, Commonwealth of Australia. Available at: http://www.cmis.csiro.au/healthycountry/reports/PredictingReuseBehavior.pdf.

Pointon A, Matthews B, Stevens DP (2022) Association between AGWR and total carcase condemnation for C. bovis. DRAFT. Sydney NSW: Australian Meat Processor Corporation.

QG (2019) Queensland Plumbing and Wastewater Code. Queensland Government. Available at: https://www.hpw.qld.gov.au/__data/assets/pdf_file/0019/3943/queenslandplumbingandwastewatercode_26march2019.pdf.

QH (2021a) Guidelines and information about supplying and using recycled water in Queensland. Recycl Water Qld Health Qld Gov Available at: https://www.health.qld.gov.au/public-health/industry-environment/environment-land-water/water/quality/recycled-water [Accessed December 8, 2021].

QH (2021b) Guideline for low exposure recycled water schemes. Brisbane, Qld, Australia: Queensland Health, Queensland Government. Available at: https://www.health.qld.gov.au/__data/assets/pdf_file/0029/892604/guideline-low-exposure-recycled-water-schemes.pdf.

Qld EPA (2005) Queensland Water Recycling Guidelines. Brisbane: Queensland Government Environmental Protection Agency.

Radcliffe JC (2021) Current status of recycled water for agricultural irrigation in Australia, potential opportunities and areas of emerging concern. Sci Total Environ:151676 Available at: https://www.sciencedirect.com/science/article/pii/S0048969721067528 [Accessed November 23, 2021].

SA Health (2012) South Australian Recycled Water Guidelines. Adelaide SA: SA Health, Government of South Australia. Available at: https://www.sahealth.sa.gov.au/wps/wcm/connect/public+content/sa+health+internet/resources/policies/south+australian+recycled+water+guidelines.

SAHealth (2013) On-site wastewater system code. SA Health, Government of South Australia. Available at: https://www.sahealth.sa.gov.au/wps/wcm/connect/public+content/sa+health+internet/resources/on-site+wastewater+systems+code.

Smith S (2008) The implications for human health and the environment of recycling biosolids on agricultural land. London: Imperial College London and Icon Consultants Ltd. Available at: http://www.biosolids.com.au/Review%20of%20implications%20of%20agricultural%20recycling%20of%20biosolids%20Final.pdf.

Stevens D, Anderson J (2013) Irrigation of crops in Australia. In: Milestones in water reuse: the best success stories (Lazarova V, ed). London New York: IWA Pub.

Stevens D, Surapaneni A, Deere D, O'Connor N, Crosbie N, Keegan A, Stackpole L, Robards M (2021a) The probability of cysticercus bovis detection in livestock from exposure to recycled water in non-endemic countries. Microb Risk Anal 18:100164 Available at: https://www.sciencedirect.com/science/article/pii/S2352352221000062 [Accessed September 10, 2021].

Stevens DP, Daniel V, Shahsavari E, Aburto-Medina A, Soni SK, Khudur LS, Khallaf B, Surapaneni A, Schmidt J, Keegan A, Crosbie ND, Blackbeard J, Hampton J, Deere D, O'Connor N, Ball AS (2021b) Improvement of Log Reduction Values Design Equations for Helminth Egg Management in Recycled Water. Water 13:3149 Available at: https://www.mdpi.com/2073-4441/13/22/3149 [Accessed November 10, 2021].

Stevens DP, Surapaneni A, Thodupunuri R, O'Connor NA, Smith D (2017) Helminth log reduction values for recycling water from sewage for the protection of human and stock health. Water Res 125:501–511 Available at: https://authors.elsevier.com/sd/article/S0043135417307200 [Accessed September 1, 2017].

Strauch D (1991) Survival of pathogenic micro-organisms and parasites in excreta, manure and sewage sludge: -EN- -FR- -ES-. Rev Sci Tech OIE 10:813–846 Available at: http://doc.oie.int:8080/dyn/portal/index.seam?page=alo&aloId=25321 [Accessed December 2, 2016].

Syme G, Nancarrow BE (2006) Social psychological considerations in the acceptance of reclaimed water for horticultural irrigation. In: Growing food crops with reclaimed wastewater, pp Chapter 13. Melbourne: CSIRO Publishing.

TasWater (2011) Recycled water and livestock. TasWater. Available at: https://www.taswater.com.au/ArticleDocuments/244/Recycled%20Water%20and%20Livestock.pdf.aspx.

TasWater (2021) Recycled Water. TasWater - Recycl Water Available at: https://www.taswater.com.au/customers/businesses/recycled-water/recycled-water [Accessed December 8, 2021].

Tennakoon S, Ramsay I (2020) Disposal of effluent using irrigation. Technical guideline. Brisbane, Qld, Australia: Brisbane: Queensland Department of Environment and Science, Queensland Government. Available at: https://www.publications.qld.gov.au/dataset/disposal-of-effluent-using-irrigation-technical-guideline.

UU (2021) Urban Utilities. Who we are. Available at: https://urbanutilities.com.au/about-us/who-we-are [Accessed December 9, 2021].

Wandra T, Sutisna P, Dharmawan NS, Margono SS, Sudewi R, Suroso T, Craig PS, Ito A (2006) High prevalence of Taenia saginata taeniasis and status of Taenia solium cysticercosis in Bali, Indonesia, 2002-2004. Trans R Soc Trop Med Hyg 100:346–353.

WaterNSW (2019) Designing and installing on-site wastewater systems. A WaterNEW current recommended practice. Available at: https://www.waternsw.com.au/__data/assets/pdf_file/0003/58251/Designing-and-Installing-On-Site-Wastewater-Systems-WaterNSW-CRP-2019.pdf.

WHO (2006) Guidelines for the safe use of wastewater, excreta and greywater: Volume II Wastewater use in Agriculture. Geneva, Switzerland: World Health Organization. Available at: https://www.who.int/water_sanitation_health/publications/gsuweg2/en/.

WHO ed. (2017) Guidelines for drinking-water quality, 4th edition, incorporating the 1st addendum. World Health Organization. Available at: https://www.who.int/publications/i/item/9789241549950 [Accessed September 10, 2018].

WU EHD (2011) Guidelines for the Non-potable Uses of Recycled Water in Western Australia. Water Unit, Environmental Health Directorate, Government of Western Australia. Available at: http://www.public.health.wa.gov.au/cproot/2280/2/Guidelines%20for%20the%20Non-potable%20Uses%20of%20Recycled%20Water%20in%20WA.pdf.

Zhang T, Huang J-C, Lei Q, Liang X, Lindsey S, Luo J, Zhu A-X, Bao W, Liu H (2022) Empirical estimation of soil temperature and its controlling factors in Australia: Implication for interaction between geographic setting and air temperature. CATENA 208:105696 Available at: https://www.sciencedirect.com/science/article/pii/S0341816221005543 [Accessed December 22, 2021].