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Prepared by: Karen Pither
Viridis Consultants Pty Ltd

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Meat and Livestock Australia Limited
PO Box 1961
NORTH SYDNEY NSW 2059

Wastewater Recycling Risk Assessment

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Executive summary

Safe wastewater recycling requires potential health risks to be reduced to acceptable levels. Health-based targets set the benchmarks for establishing the safety of water at the point of use. This Wastewater Recycling Risk Assessment quantifies the risk associated with options for the reuse of abattoir process water by applying the principles of quantitative microbial risk assessment (QMRA) to a range of theoretical scenarios to identify actions required to meet health based targets.

The first stage of the risk assessment involved a screening level risk assessment, estimating the level of risk associated with the reuse of abattoir process water from a range of points within the meat production process. A literature review identified a number of pathogens relevant to beef production. Initially, in the absence of actual pathogen data from abattoir process water sources, a range of pathogen concentrations were adopted and the risk associated with a range of uses was calculated to provide a basis for further investigation. Pathogen reduction requirements were estimated to give an indication of the treatment required to make the process water suitable for the use. Using generic pathogen reductions achieved by treatment technologies, options for treatment can be identified.

The second stage of the risk assessment was to undertake a monitoring program to quantify levels of pathogens in a range of process water streams. The results have been complied into a site-specific risk assessment and guidance of establishment of a hazard analysis and critical control point (HACCP) framework to manage risk.

The results of this assessment can be used to identify the options that are available to abattoirs and can be further investigated through site specific assessment.

Table of Contents

Tables

1. Introduction

The Australian red meat processing industry is a significant consumer of water, used primarily to ensure food safety and hygiene during operations. Water is used across almost all stages of meat processing, as well as being used to ensure facilities achieve adequate health requirements and to provide workers with a safe and hygienic work environment. Drought and resulting water restrictions have put enormous pressure on processing plants to reduce water consumption (MLA 2008).

Water consumption by the food industry is coming under increasing scrutiny by authorities in Australia, which has led to the consideration of water recycling. The use of recycled water and reusing water in the food industry raises several issues, including possible food safety concerns, consumer acceptance and market access. Food safety concerns can be addressed by Hazard Analysis and Critical Control Point (HACCP) and the use of modern water recycling technology (AQIS 2008). In addition to water consumption, the discharge of process water to the environment must meet strict water quality requirements and other options such as discharge to sewer can be costly. Reuse of process water is an opportunity to reduce consumption of potable water, which may result in a:

- reduction in cost for purchase and discharge of water
- reduction in the burden on council water supplies and sewer services
- reduced discharge of wastewater, both to the sewer and the environment.

Regardless of the benefits, the reuse of process water must be implemented in a safe manner to ensure the protection of human health, both for workers and consumers of meat, the livestock and the environment.

1.1. Goals

1.1.1. Stage 1 Risk screening and estimation

Stage 1 of this project comprised of identifying potential hazards and undertaking a preliminary risk screening to estimate the risk associated with the reuse of process water for a range of uses.

This is the first step in understanding the options for reuse, the risks associated with reuse and the requirement for implementing reuse in an abattoir. In the absence of site specific data, this estimation has adopted a range of reference pathogens, pathogen concentrations and options for reuse, to make estimations on the risks associated with different sources and exposure types.

Once reuse opportunities have been identified and the pathogen concentrations in sources water have been identified, the findings of this risk assessment can be used to determine:

- suitable uses for the process water
- level of treatment required to make the process water suitable for the use.

The outcomes of this project formed the basis of a site-specific reuse risk assessment that included targeted monitoring, risk assessment and identification of critical control points using the HACCP approach.

1.1.2. Stage 2 Site specific assessment

Stage 2 of the project investigated site-specific process water reuse opportunities for a subject site and included:

- characterisation of risk through monitoring program and simple QMRA techniques
- identification of opportunities for reuse
- guidance on preparing a site-based risk management plan.

This report focuses on risk associated with relevant pathogens and does not include assessment of the physical suitability of water for use in abattoir systems (e.g. physically suitable for use in boilers) or reconfiguring infrastructure to establish a reuse program.

1.2. Background

Wastewater used as a source to produce high-quality recycled water for potable uses can contain a wide range of agents that pose potential risks to human health, including chemicals and pathogenic (disease-causing) microorganisms.

High exposure uses of water, such as food processing, require correspondingly high levels of control, and a commitment to ongoing management and continuous monitoring to ensure safety. Measures used to control risk usually start with reducing hazards in source waters, followed by application of multiple advanced treatment processes. Implementing the use of recycled water for high risk uses is a difficult, challenging and highly technical task. It requires high levels of skill, and there can be no short cuts (NHMRC & NRMMC 2006).

Safe wastewater recycling requires potential health risks to be reduced to acceptable levels. Health-based targets set the benchmarks for establishing the safety of water at the point of use. Typically, they take the form of performance targets for microorganisms and guideline values for chemicals.

Safety is defined as 'ensuring that microbial health risk complies with the definition of tolerable risk'. This is achieved by meeting performance targets whereby concentrations of pathogens in wastewater are reduced to concentrations below those that would produce 10^{-6} disability adjusted life years (DALYs) per person per year. The DALYs approach has been adopted by the World Health Organisation (WHO) and is considered the benchmark for assessing risks to public health (the application of DALYs is detailed in subsequent sections of this report).

The multiple barrier approach is the foundation for ensuring safe recycled water. The approach applies no matter what the initial source of water. The need for highly reliable barriers and control measures is essential for both microbial and chemical hazards. No single barrier is effective against all conceivable hazards or is completely effective at all times. Having multiple barriers protects against variations in performance of individual barriers (NHMRC & NRMMC 2006).

A number of standards and guidelines are relevant to the reuse of abattoir wastewater, however, there is some ambiguity in relation what reuse is acceptable within an abattoir due to the difference between how recycled water and potable is defined in the AQIS Meat Notice and AS 4696. The AQIS Meat Notice includes current approved uses for water recycling in abattoirs, which have been assessed by AQIS and are considered acceptable.

Table 1 provides a summary of potential options for reuse, as identified in the various guidelines and literature. Appendix A contains a detailed summary of the provisions of the following standards and guidelines:

- AQIS Meat Notice 2008/06 Efficient Use of Water in Export Meat Establishments
- AS4696:2007 Hygienic Production and Transportation of Meat and Meat Products for Human Consumption
- Australian Guidelines for Water Recycling (AGWR)
- Australian Drinking Water Guidelines (ADWG).

Table 1 Summary of potential reuse options

Current recycled water uses	Source
Open space irrigation	AGWR
Dust suppression	AGWR
Toilet flushing	AGWR
Cold water laundry	AGWR
Washdown of outdoor surfaces	AGWR
Irrigation of cattle fodder	AGWR
Irrigation pasture	AGWR
Coolers	AGWR
Boilers	AGWR
Steriliser and hand-wash water collected and used to wash cattle yards	Meat Notice
Carcase decontamination wash water collected, coarsely filtered, and reused immediately for the same purpose whilst maintaining a temperature that is lethal to pathogens	Meat Notice
Steriliser water collected from clean end on the viscera table and used for the initial viscera table wash	Meat Notice
Steriliser water collected and used to wash moving dry landing area (hide on area)	Meat Notice
Tertiary treated effluent water used as the initial wash in the ante mortem yards and as an initial wash of stock	Meat Notice
Chlorinated tertiary treated water used as final wash in ante mortem yards and as final wash of stock.	Meat Notice
Water from knife and equipment sterilisers to wash cattle and yards	Meat Technology Update Feb 2005
Viscera-table steriliser and cooling water used for paunch initial emptying or initial viscera-table rinse	MLA

1.3. Current knowledge

A review of the available literature was undertaken to gain an understanding on the current knowledge about water use and recycling in abattoirs. In general, the literature review found that pathogen loads are often quite high in process water, and practical constraints, such as configuration of piping and volumes of water available have limited the establishment of reuse projects. Appendix B provides a details literature review that was used to inform this project.

2. Stage 1 Reuse exposure assessment

A review of the available literature on the risk of utilising recycled water in meat processing indicated that there has been very little quantification of risk, and very little data available on the concentrations of pathogens in abattoir process water.

Due to the limited data available, theoretical calculations of risk were undertaken using generic data available in the literature to inform a point estimate of the probability of infection and disease burden from the pathogens of concern.

The definition of risk is broadly described as:

Risk = chance + hazard + exposure + consequence

Risk is the likelihood of identified hazards causing harm in exposed populations in a specified timeframe and the severity of the consequences. Point estimates of probability of infection and disease burden have been undertaken using a Quantitative Microbial Risk Assessment (QMRA) framework outlined by Hass, Rose and Gerba (1999) as broadly summarised in Table 2.

QMRA is a framework and approach that brings information and data together with mathematical models to address the spread of microbial agents through environmental exposures and to characterize the nature of the adverse outcomes.

Table 2 Summary of QMRA Process

Risk Assessment Step	Action
Identify the problem	State the problem and the scope of the risk assessment
Hazard Identification	Identification of the microbial agent and the spectrum of human illness and disease
Dose Response	The dose response analysis provides a quantitative relationship between the likelihood of adverse effects and the level of microbial exposure. The dose response assessment phase is arguably the most important phase in the QMRA paradigm.
Exposure Assessment	The exposure assessment identifies affected population, determines the exposure pathways and environmental fate and transport, calculates the amount, frequency, length of time of exposure, and estimates dose or distribution of doses for an exposure.
Risk Characterisation	The risk characterization integrates dose-response analysis and exposure assessment to estimate the magnitude of risk, uncertainty and variability of the hazard. This step requires the integration of the information from previous steps into a single mathematical model to calculate risk - the probability of an outcome like infection, illness or death.
Risk Management	Risk can be managed using many different strategies and is most effective when it is informed through risk characterization. The identification and evaluation of risk management strategies based on cost and effectiveness are integral parts of the process. In addition to quantitative evaluation, an understanding of risk perception and a plan for risk communication are also pertinent risk management activities.

2.1. Methodology

To gain an overall understanding on the risk associated with the reuse of abattoir process water a screening level risk assessment was undertaken as follows:

- identify hazards and selection of reference pathogens for further investigation
- estimate exposure volumes and a range of pathogen concentrations to be investigated

- point estimation of risk of infection and disease burden
- estimate the pathogen reduction required to make process water fit for the use
- review treatment technologies capable of achieving the required pathogen reduction.

At this stage, the point estimation of risk was considered suitable, due to the lack of actual pathogen concentration data and to give a broad overview of the risk associated with various reuse options.

2.2. Limitations

This screening level risk assessment and estimation is based on theoretical values for concentration and exposure volume and is limited to a point estimate of disease burden. Actual risk should be quantified when specific pathogen data becomes available. WSAA (2015) also identify the following limitations due to uncertainty for QMRA:

- the inability to fully determine the infectivity or human pathogenicity of pathogen isolates
- the uncertainty of pathogen recovery from environmental samples
- the uncertainty of pathogen data which reflects concentrations at a fixed temporal and spatial point in a relatively small volume, against a highly variable true concentration.

2.3. Opportunities for recycling

Abattoirs are particularly intensive users of waters, as meat processing requires heavy usage of water for preparation and hygiene purposes. According to Meat & Livestock Australia (MLA), 8,000 ML of potable water was used over a year at medium to large abattoirs (GHD 2011). Compared to the total Australian water consumption over 2013-2014, which was 19,000 GL (ABS 2015), it can be estimated that roughly 0.04% of total Australian water consumption can be attributed to cattle slaughter.

It is difficult to specifically characterise water usage in abattoirs because of high variation between individual plants and the requirement for water flow metering to collect the information (Ecowise Environmental 2008). With this in mind, the ranges typical abattoir water usage volumes were estimated by Ecowise Environmental (2008) on behalf of Meat & Livestock Australia, Table 1. Note that these ‘typical’ values are for general meat processing plants and not specific to cattle. Most water is utilised directly for process use, with water also used for stockyards, chillers, boiler and amenities. It is likely that these non-direct uses will present the most opportunity for water reuse, as the water does not come into direct contact with the meat as it is processed.

Table 1 Summary of Predicted Water Usage (Ecowise 2008)

Area of Usage	Estimated fresh water consumption (%)
Stockyards (mostly washdown)	7 – 24
Slaughter, evisceration	44 – 60
Boning	5 – 10
Offal processing	7 – 38
Casings processing	9 – 20
Renderings	2 – 8
Chillers	2
Boiler losses	1 – 4
Amenities	2 – 5

Pathogen concentrations in human sourced sewage are well characterised, making the assessment of risk from exposure to sewage sources recycled water reasonably straight forward. The literature review conducted for this project indicates that pathogens and their concentrations in abattoir process water are not well characterised, with little data available on the concentrations generated specific process steps.

It is not feasible or practical at this stage to characterise pathogen concentrations at every step in the meat production process, therefore based on the breakdown of water volumes above, and the uses identified in various guidelines, the following uses were selected for further investigation. Exposure of the recycled water to staff and the consumer is a factor in the risks assessment and was also considered in the selection. Exposure volumes were adopted from the most relevant uses outlined in the guidelines, which are:

- Cleaning - high water usage and opportunities to limit reuse water to areas within the abattoir that do not contact meat or meat products. This use is considered to have a high exposure for abattoir workers, with the exposure volume similar in the worst case to fire fighting.
- Slaughter floor – high water usage and potential to use recycled water for applications that do not contact with meat or meat products however for this assessment, volumes for drinking water were adopted for this use to meet requirements for drinking water (assuming recycled water could come into contact with meat or meat products).
- Cattle yards – whilst reported usage volumes were low compared to other uses, dust suppression in the cattle yards was considered in this risk assessment, as the low exposure volumes may allow for a lower quality of water to be supplied. To assess risk for cattle yards, the exposure volumes for municipal irrigation (ingestion of sprays) was adopted.
- Truck wash – as for cattle yards, the overall usage volume was not reported to be high, however this was considered for further investigation as specific volume data was available from car wash, and the low exposure volume may allow for a lower quality water to be supplied safety for truck wash. The exposure volumes from the literature were adopted. (It is acknowledged that the truck wash is used to wash manure from the vehicles and is likely to generate aerosols containing faecal contamination. It may appear counter intuitive to require a very high quality of water to reduce inhalation of pathogens within water that is used to clean up manure, however there are no standard methods to consider this in the risk assessment).

- Cooling towers – consideration of the risk associated with cooling towers has been included to investigate options for using recycled water in cooling towers. Whilst *Legionella* risk is the main focus of cooling tower risk management with well establishment management practices, recycled water from abattoirs may contain *Coxiella burnetii*, which has a mode of transmission through the inhalation of dust particles and potentially aerosols.

The redirection of process water from the 'clean' processes for reuse in the 'unclean' processes presents the best opportunity for reuse as the clean processes are expected to have low concentrations of pathogens and may need little if any treatment to make it suitable for reuse. Current uses that employ this concept have been captured in the Meat Notice as identified in Table 1.

2.4. Inherent risk

The occupational risk associated with animal husbandry and meat production is well established (SFA 2014, ASCC 2006, LeJeune and Kersting 2010). Vaccination, standard and additional precautions (also known as universal precautions), hand-washing, education and training and the use of personal protective equipment where appropriate are the main control strategies for the prevention of occupationally-related infection. Vaccination of at-risk workers is the most effective approach when the risk of exposure is significant, the disease can be serious and an effective vaccine is available (ASCC 2006). Asano et al 1992 demonstrated that the probability of infection can be mitigated by controlling exposure to reclaimed wastewater in the use area.

Due to the nature of meat production and the level of training and awareness that is the standard for the food processing industry, abattoir employees are expected to have experience in implementing PPE to reduce exposure to pathogens from recycled water, as they are already using the equivalent PPE to reduce exposure to faecal and digestive matter when dealing with both livestock and animal products.

According to FAO (1985) the main hygiene principle in meat processing is that 'clean' and 'unclean' operations are efficiently separated. The application of that principle separates the lairage, stunning, slaughter and bleeding and skinning as 'unclean' and subsequent processing from evisceration onwards as 'clean'. 'Unclean' processes would also include the use of water in cattle yards, truck wash and cleaning of areas used prior to evisceration.

The inherent risk in unclean areas is expected to be equivalent to or higher than the risk associated with reuse of process water. Additional pathogens in recycled process water that are not already being managed at an animal husbandry and meat production level are not expected to increase risk. The application of on-site exposure reductions (PPE and irrigation controls) can be applied to reduce the volume and frequency of exposure, mitigating occupational risks.

Whilst the inherent risks are recognised, to progress this project and better understand risk associated with reuse this project, the QMRA and risk estimations focussed on maximum risk. Maximum risk is the risk associated with the use in the absence of preventive measures, such as PPE and other occupational exposure reductions.

2.4.1. Cleaning

A significant opportunity for water recycling in abattoirs is cleaning, particularly in areas prior to evisceration, that are considered 'unclean'. These areas are expected to have a high level of pathogens, due to the occurrence of faecal and digestive materials, and the risk associated with reusing process water is expected to be less than or equal to the risk associated with dealing with the faecal or digestive matter in these areas.

Whilst hygiene goals need to be achieved, reusing process water for the first wash down of surfaces would not be expected to increase the risk or pose a risk greater than the materials being removed by the cleaning process.

In terms of using process water for cleaning, to undertake a theoretical assessment of maximum risk, the exposure volumes for firefighters identified by Deere and Davidson (2004) may be considered representative of the worst-case scenario (2 mL median and 100 mL 99 percentile per event).

2.4.2. Slaughter floor

Water usage in the slaughter floor is expected to be carcass wash, head wash, wash down of viscera tables. Water use in this area can be broken down into two stages, initial wash down to remove faecal matter, urine, blood, dirt and other materials followed by a sanitation step to disinfect

The AQIS Meat Notice has established reuse in this area where process water, for example from hand wash, sterilisers and basins is used for the initial wash of materials from surfaces, followed by a cleaning process for example at high temperatures or with a disinfectant. In addition, use of process water in the tripe room for the initial wash of matter from tripe is established as an acceptable use.

Whilst contact with meat or meat products during the first wash would be unlikely and subsequent decontamination or 'cleaning' would remove remaining pathogens, should this use result in direct contact with the carcass and reuse of process water for this purposes may not be considered appropriate unless it is treated to a potable standard in accordance with ADWG. To understand maximum risk for reuse on the slaughter floor and other associated areas, risk estimations assuming drinking water (potable) quality is required. For the assessment of this risk the exposure volume adopted from the AGWR is 1.4 litres per day. This does not assume that 1.4 litres of reuse water is consumed or reflect volumes of water retained on meat or meat products, but assists in setting the standard for potable water, which is based on the consumption of 1.4 litres per day.

2.4.3. Cattle yards

Water usage in the cattle yards is primarily for dust suppression, therefore it is assumed that the main route of exposure is to staff managing the holding and movement of cattle from the ingestion of sprays (assumed to be similar to municipal irrigation exposure as per AGWR). The use of recycled water on the cattle yards is current common practice at abattoirs. Prior to slaughter animals may be treated to remove any visible dirt from their hides or pelts. Cattle are normally washed, either manually or with fixed sprays. The amount of water used for washing depends on the type and cleanliness of the stock, increasing significantly if they are received in a dirty condition (AMPC undated).

As previously discussed, the inherent risk in cattle yards, associated with the presence of livestock, manure and urine would be greater than the risk associated with process water, which can be managed through occupational exposure reductions. To determine the maximum risk, in the absence of occupational exposure reductions, an ingestion volume equivalent to municipal irrigation was adopted from the AGWR.

2.4.4. Truck wash

Trucks used to transport cattle to abattoir sites are washed prior to leaving the site to remove build-up of manure and dirt to reduce the potential for spreading waste onto roads and along transport routes. As with cattle yards, the inherent risk of the faecal matter being removed by the process water is expected to be greater than or equal to the risk associated with the process water. The maximum risk associated with truck wash was included as reliable data on exposure volumes exists for this use.

2.4.5. Cooling towers

Mechanical and natural draft cooling towers are routinely used to condition air and water for power plants and air conditioning systems. The management of cooling towers focuses on reducing the risk to the public from *Legionella*. The design and maintenance guidelines for controlling the growth and proliferation of *Legionella* within cooling towers have been well established. When considering using abattoir process water in cooling towers, the risk associated with *C. burnetii* must also be understood. *C. burnetii* falls into a similar size range as *Legionella* and the main route of exposure for *C. burnetii* is inhalation of spores, entrained in dust and potentially aerosols.

There is very little information available regarding the risk of *C. burnetii* from cooling towers, however there is extensive information on *Legionella*. The main management action for *Legionella* is chlorination of the cooling tower water, which is very effective in inactivating *Legionella*, however *C. burnetii* is highly resistant to environmental stresses such as high temperature, osmotic pressure and ultraviolet light treatment with biocide such as chlorine (Voth and Heinzen 2007, Ortells and Medema 2011, La Scola and Raoult 2000).

Whilst the concentration of pathogens in recirculated waters of cooling towers using reclaimed water is reduced somewhat by the treatment to prevent biofouling (US EPA 2012), the effectiveness of these techniques in inactivating *C. burnetii* is not established therefore reducing exposure to aerosols should be the focus of managing *C. burnetii* risk from cooling towers at abattoirs.

Water droplets become entrained in the air stream as it passes through the tower. When a small amount of circulating water in a cooling tower is entrained and carried aloft by the air stream in the form of droplets, which vary from a few to several thousand microns in diameter, the droplets are referred to as drift (Meroney 2004).

Investigations into *Legionella* outbreaks indicate that cooling tower aerosols can travel up to 10 km from the source, depending on climatic conditions (Nguyen et al 2006, Nygård et al 2008, US EPA 2012, Bartram 2015, Bull et al 2012).

Information about ingestion volume of aerosols is not readily available, therefore a QMRA for this use was not developed, however a worked example on reusing process water for cooling towers is presented in 9.1.2.

2.5. Hazard identification

To understand the risk associated with the reuse of abattoir process water, the relevant hazards must be identified and understood. The primary sources of pathogens in abattoir process water are pathogens that can be harboured in the gastrointestinal tract, and exposed during evisceration and the pathogens adhered to livestock, the hide such as faecal matter and dirt.

MLA commissioned an investigation in 2003 to quantify microbial emissions from abattoirs (Jain et al 2003). This investigation identified pathogens relevant to meat production. Fifty-two pathogens were reviewed and six (*Campylobacter sp*, *Cryptosporidium*, *Escherichia coli*, *Salmonella* sp, *Listeria monocytogenes* and *Coxiella burnettii*) were selected for further study based on their relevance to the Australian meat processing industry and their potential to pose a risk to human health. The results of Jain et al were reviewed against current literature and were found to be current and relevant to this project. The pathogens selected for further consideration for this risk screening, based on the rationale presented in Table 3.

Table 3 Reference Pathogens

Pathogen	Rationale
Campylobacter jejuni and *Campylobacter coli*	*Campylobacter* are microaerophilic gram-negative curved or spiral rods with a polar flagellum. *C. jejuni and C. coli* are common causes of gastroenteritis. It can cause acute self-limiting diarrhea in healthy humans with an incubation period of 2-3 days, and appears very common worldwide (CAMRA). *C. jejuni* is most often isolated from chickens, but can be found in the intestinal tract of a wide variety of wild or domesticated animals such as healthy cattle, birds and even flies (Jain et al 203). The *Campylobacter* bacteria have been isolated from cattle manure.
Escherichia coli (certain serotypes)	*Escherichia coli* resides as a commensal gram negative bacterium in the mammalian and bird intestinal tract and is excreted in faeces. Enterohemorrhagic *E. coli* (EHEC; particularly serotype O157:H7) is a highly pathogenic variant which can cause life-threatening disease and has been the cause of many major outbreaks from faecally contaminated food (e.g., ground beef) and drinking water as evidenced by the outbreak in Walkerton, Ontario following heavy rains EHEC is technically part of the larger group of Shiga toxin producing *E. coli* (STEC), many of which cause little or no disease. EHEC attaches to the large intestinal wall and produces 'attaching and effacing lesions', which can cause bloody or non-bloody diarrhea, as well haemorrhagic colitis and haemolytic uremic syndrome (HUS). Its principal reservoir is the bovine intestinal tract. *E. coli* has been isolated from the faeces, hides and oral cavities of cattle. Faeces of cattle has been found to contain *E. coli* O157, but other sites such as the oral cavity and hides of cattle have also been reported to contain *E. coli* O157. In one survey of 100 cattle, *E. coli* O157 was isolated from 44% of hides, 24% of oral cavities and 10% of faeces (Fegan et al., 2005), indicating that oral cavities and hides may have greater potential for transmission of *E. coli* O157 to the carcase than the faeces of animals.
Cryptosporidium parvum	*Cryptosporidium* is considered worldwide in distribution, with human infection mostly originating from contaminated water. The pathogen is known to cause gastrointestinal disease. Whilst cryptosporidiosis has not been associated with the consumption of meat, the gastrointestinal contents of cattle can be a source of infection for workers during the processing of carcasses in abattoirs (Fayer and Xiao 2007).

2.6. Exposure assessment

Exposure at the simplest level is the dose of the pathogen that an individual ingests, inhales, or comes in contact with. Exposure assessment involves the determination or estimation of the magnitude, frequency, duration, and route(s) of exposure. Doses are typically calculated as a function of pathogen density in the exposure medium (e.g., drinking water, reclaimed water, biosolids) and the volume of that medium that is ingested or inhaled. These numbers feed into the dose-response models to predict the probability of infection.

Haas et al (2014) guidance on conducting an exposure assessment has been relied upon for this risk screening. Dose is determined by Haas et al as

$$\bar{d} = \bar{\mu} \times \bar{m}$$

Where:

$\bar{d}$ is the mean expected dose

$\bar{\mu}$ is the average (arithmetic mean) concentration of pathogens in the medium

$\bar{m}$ is the average (arithmetic mean) consumption of the medium per exposure event

For the purpose of this risk assessment, point estimates will be made to give a general estimation of risk. Further statistical analysis can be undertaken once site specific data is available.

2.6.1. Pathogen concentrations

To conduct this risk screening, a number of theoretical concentrations were used to account for a wide range of water quality. The rationale behind these calculations is to allow for the results of a site specific assessment to be compared against the results to determine suitable uses for that quality of water.

2.6.2. Exposure volumes

To make estimates of the risk, generic exposure volumes have been sourced from the relevant literature, with the intention to apply expected exposure volumes to the dose response models. Table 4

identifies the point estimates of exposure volume per event (drinking water/ cross connection is reported per day) used adopted for this risk assessment.

It should be noted that the exposure volume used for potable uses is not based on the expected volume of water that could be consumed as a result of recycled water being used in an abattoir setting or being retained on a meat product. The exposure volume for ingestion of drinking water is used to determine the level of treatment required to achieve a potable standard.

Table 4 Summary of exposure volumes

Exposure Type	Exposure Volume (L)	Reference	Comparable exposures for abattoir reuse	Reference
10 minute car wash ingestion of sprays	0.00379	Sinclair et al	Truck wash down	Sinclair et al
Municipal irrigation - ingestion of sprays	0.001	AGWR	Outdoor irrigation – landscaping, pasture, cattle yards.	AGWR
Firefighting ingestion of water and sprays	0.02	AGWR	Cleaning Repairing a pipe break	AGWR
Ingestion of drinking water	1.4	Haas et al	Slaughter floor (Potable uses) Cross connection	Haas et al

2.7. Dose response assessment

The Center for Advancing Microbial Risk Assessment (CAMRA) has developed resources for undertaking QMRA. The QMRA framework has been used to estimate the risk of a response (for example, infection, illness or death) given a known dose of a pathogen. QMRA wiki developed by CAMRA has been relied on for inputs into the dose response models.

In the QMRA framework, the dose response assessment phase is an essential quantitative element of the risk estimate. It estimates the risk of a response (for example, infection, illness or death) given a known dose of a pathogen, that is estimation of the risk of infection. Dose response models are mathematical functions that describe the dose response relationship for specific pathogens, transmission routes, and hosts.

Exposure to microbiological agents can result in a series of endpoints including infection, illness, severe illness and death (Haas et al 2014).

2.7.1. Probability of infection

Calculation of the probability of infection for the chosen reference pathogens for a range of pathogen concentrations and exposure volumes were undertaken to estimate the chance of infection if a person was exposed to recycled water during reuse.

A dose response function can be used to convert the mean dose of oocysts into a risk of infection. For *Cryptosporidium* and STEC the dose response is described by an exponential model,

$$Risk_{(infection)} = 1 - \exp(-k \times dose)$$

For *Cryptosporidium* k = 0.0572 and for STEC k = 0.000218 as described by CAMRA.

For *Campylobacter*, the dose response is described as a beta-Poisson model where:

$$Risk_{(infection)=}1 - \left[1 + \frac{\left(2^{\frac{1}{\alpha}} - 1\right)}{\mathrm{N50}}\right]^{-\alpha}$$

α = 0.144 and N50 = 890 as described by CAMRA

- Doses were calculated using theoretic concentrations and volumes identified in Table 4.

2.7.2. Disease burden for pathogens

In order to assess the burden of disease related to exposure to microbiological and chemical contaminants or conversely to apply a reference level of tolerable risk, the disease outcomes following each specific exposure and ingestion or infection have to be defined (Havelaar and Mesle 2003). Disease burden is measured in Disability Adjusted Life Years (DALYs).

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

The disease burden of 10^{-6} DALYs is approximately equivalent to a lifetime additional risk of cancer of 10^{-5}(i.e. 1 case per 100 000 people) or an annual diarrhoeal risk of illness of 10^{-3} (i.e. one illness per 1000 people). In comparison, the reported rate of diarrhoeal illness in Australia is 0.8–0.92 cases per person per year.

Disease burden estimates for the reference pathogens were sourced from Havelaar and Mesle (2003) for *Cryptosporidium parvum, Campylobacter jujeni* and Shiga toxin-producing *Escherichia coli* (STEC).

- STEC disease burdens in Havelaar and Melse were based on the severity and duration of a range of outcomes from exposure to STEC, from watery diarrhoea to death of 54.7 DALYs per 1000 cases of gastroenteritis (0.0547 DALYs per infection).
- *Cryptosporidium parvum* disease burdens in Havelaar and Melse were based on the severity and duration of a range of outcomes from exposure to *C. parvum*, including watery diarrhoea and death of 1.47 DALYs per 1000 cases of gastroenteritis (0.00147 DALYs per infection).
- *Campylobacter jujeni* disease burdens in Havelaar and Melse were based on the severity and duration of a range of outcomes from exposure to *C. jujeni*, including gastroenteritis, Guillain-Barre syndrome and reactive arthritis of 4.6 DALYs per 1000 cases of gastroenteritis (0.0046 DALYs per infection).

2.8. Risk characterisation

Risk of infection for each pathogen concentration and exposure volume were multiplied by the DALY score per infection to calculate the DALYs per exposure event. DALYs per year were calculated based

on the assumption that a person undertaking the reuse, works at the site 5 days a week for 48 weeks of the year (240 events per year).

As can be seen from the point estimates of disease burden presented in Table 5, Table 6 and Table 7, process water with relatively low concentrations will need to be treated to be considered suitable for the use and meet the requirements for tolerable risk as noted in red. Once site specific pathogen concentrations are available, the disease burden calculations should be revised and probabilistic risk calculations undertaken.

Table 5 *Cryptosporidium* Disease Burden

Exposure Type	**Disease Burden (DALYs per person per year)**			
Concentration of Pathogen	**0.001 org/L**	**0.1 orgs/L**	**1 org/L**	**100 org/L**
Cattle yards (0.001 mL)	4.8 x 10-6	4.8 x 10-4	4.8 x 10-3	2.6 x 10-1
Truck wash (3.79 mL)	1.8 x 10-5	1.8 x 10-3	1.7 x 10-2	3.5 x 10-1
Cleaning (20 mL)	9.6 x 10-5	9.5 x 10-3	8.4 x 10-2	3.5 x 10-1
Potable uses (1.4 litres/day)	6.6 x 10-3	3.0 x 10-1	3.5 x 10-1	3.5 x 10-1

Table 6 Shiga Toxin producing *E. coli* Disease Burden

Exposure Type	**Disease Burden (DALYs per person per year)**			
Concentration of Pathogen	**0.001 org/L**	**0.1 orgs/L**	**1 org/L**	**100 org/L**
Cattle yards (0.001 mL)	6.9 x 10-7	6.9 x 10-5	6.9 x 10-4	6.9 x 10-1
Truck wash (3.79 mL)	2.7 x 10-6	2.6 x 10-4	2.6 x 10-3	2.6 x 10-1
Cleaning (20 mL)	1.4 x 10-5	1.4 x 10-3	1.4 x 10-2	1.3
Potable uses (1.4 litres/day)	9.6 x 10-4	9.6 x 10-2	9.3 x 10-1	13.1

Table 7 *Campylobacter* Disease Burden

Exposure Type	**Disease Burden (DALYs per person per year)**			
Concentration of Pathogen	**0.001 org/L**	**0.1 orgs/L**	**1 org/L**	**100 org/L**
Cattle yards (0.001 mL)	2.3 x 10-9	2.3 x 10-7	2.3 x 10-6	2.3 x 10-4
Truck wash (3.79 mL)	8.7 x 10-9	8.7 x 10-7	8.7 x 10-6	8.6 x 10-4
Cleaning (20 mL)	4.6 x 10-6	4.6 x 10-6	4.6 x 10-5	4.5 x 10-3
Potable uses (1.4 litres/day)	3.2 x 10-6	3.2 x 10-4	3.1 x 10-3	1.6 x 10-1

2.9. Risk management

Based on the outcomes presented in Table 5, Table 6 and Table 7, process water that is intended to be reused within an abattoir will need to be treated to ensure it is fit for the use, with the possible exception of water used in the cattle yards and landscaping. As required under the AGWR, the treatment selected should meet the log reduction values (LRVs) required to achieve the tolerable risk disease burden of 10^{-6} DALYs.

At present, the most relevant guidance on validation testing is provided in the Victorian Department of Health Guidelines for validating treatment processes for pathogen reduction (2013) and the US

EPA Technical Guidelines. The Australian Water Recycling Centre of Excellence (AWRCE) has developed validation protocols under the WaterVal project, for a number of treatment technologies. These will provide a range of options for validating the LRVs achieved by treatment technologies, including correlating operational monitoring to pathogen removal.

Prior to selecting a treatment technology, the required LRVs should be calculated based on site specific testing. Treatment technologies must be designed to specifically meet the required LRVs and this should be validated through manufacturer or on site challenge testing.

Table 8, Table 9 and Table 10 provide estimations of the pathogen LRVs required to be achieved to make the process water suitable for the identified uses, based on a range of theoretical pathogen concentrations.

Section 7 of this report provides an overview and summary of the available treatment technologies.

Table 8 Cryptosporidium Log Reduction Estimation

Exposure Type	**Estimated pathogen log reductions required**			
Concentration of Pathogen	**0.001 org/L**	**0.1 orgs/L**	**1 org/L**	**100 org/L**
Cattle yards (0.001 mL)	0	2	3	5
Truck wash (3.79 mL)	1	3	4	6
Cleaning (20 mL)	1	3	4	6
Potable uses (1.4 litres/day)	3	5	6	8

Table 9 Shiga Toxin producing *E. coli* Log Reduction Estimation

Exposure Type	**Estimated pathogen log reductions required**			
Concentration of Pathogen	**0.001 org/L**	**0.1 orgs/L**	**1 org/L**	**100 org/L**
Cattle yards (0.001 mL)	0	1	2	4
Truck wash (3.79 mL)	0	2	3	5
Cleaning (20 mL)	1	3	4	6
Potable uses (1.4 litres/day)	2	4	5	7

Table 10 *Campylobacter* Log Reduction Estimation

Exposure Type	**Estimated pathogen log reductions required**			
Concentration of Pathogen	**0.001 org/L**	**0.1 orgs/L**	**1 org/L**	**100 org/L**
Cattle yards (0.001 mL)	0	0	0	2
Truck wash (3.79 mL)	0	0	0	2
Cleaning (20 mL)	0	0	1	3
Potable uses (1.4 litres/day)	0	2	3	5

3. Stage 2 Site specific assessment

3.1. Site description

The subject site is a meat-processing establishment (*Bovine* Slaughterhouse and Beef Processing Plant) with a current kill capacity of approximately 330 000 head per year. The facility includes:

- buildings, including: cold stores, harvest floor and beef boning rooms and rendering plant;
- ancillary equipment to support the site beef processing operations, including a boiler, electricity transformers and equipment repair workshops;
- carparks;
- internal roads;
- cattle yards;
- wastewater treatment systems, including pre-treatment systems (screening), anaerobic and aerobic treatment systems;
- irrigation areas; and
- grazing paddocks.

The water management at the subject site consists of stormwater management, water protection, groundwater management, wastewater management and irrigation management.

3.1.1. Stormwater management

The site operator follows the stormwater management hierarchy, aiming the avoid the contamination of stormwater in the first place. A number of methods are employed in different areas of the site in order to segregate contaminated from non-contaminated stormwater and run-off. These methods include;

- roofing where practicable
- concrete pads with defined drainage
- settling basins
- silt traps
- sumps and drainage from contaminated and/or potentially contaminated areas
- bunding.

Dry cleaning methods are undertaken, where practicable, for the cleaning of spillages, equipment, trucks, floors, areas or structures. Where dry cleaning methods are not considered practicable the cleaning of spillages, equipment, trucks, floors, areas or structures is undertaken using methods which minimise the volume of wash down water produced. Run-off from contaminated or potentially contaminated areas within the property is captured by or diverted to drains, contours or diversionary banks. This captured run-off is captured by or diverted to the wastewater treatment system. Run-off from plant and immediate surrounds is captured by drains that are directed to the wastewater treatment system. Water captured within bunding stormwater structures is also directed to wastewater treatment system.

3.1.2. Wastewater management

There are two streams of wastewater generated by meat processing; red stream and green stream. Both streams undergo primary treatment which involves solids removal and secondary treatment which removes organics and nutrients from the wastewater.

The Red Stream consists of wastewater from:

- kill floor
- rendering
- boning room
- hide wash.

This water is directed to primary treatment which is a contra sheer unit for screening. This cylindrical screener separates the wastewater and the solids. The stream is then directed into a dissolved air flotation (DAF) unit. Here mechanical injection of air encourages binding and flotation of fat particles to the surface. The recovered fats from the 'float' are sent back to rendering for processing. This stage of treatment also allows solids such as dirt and grit to settle to the bottom of the DAF tank (DAF bottom sludge). This sludge is pumped back to the green stream contra sheer where the solids are separated and transported into the paunch removal system for removal off-site. The water is sent to a wastewater mixing tank.

The Green Stream consists of wastewater from:

- cattle holding yards
- pens
- paunch room
- contaminated stormwater pond
- truck wash.

This water is directed to primary treatment which is a contra sheer unit. The solids are dropped out to a paunch truck located underneath the contra sheer and the water is sent to the wastewater mixing tank and combined with the red stream. The mixed wastewater is then pumped to an anaerobic lagoon approximately 300 metres SSW. The anaerobic lagoon is approximately 19 mega litres (ML) in capacity. Wastewater is gravity fed to a series of aerobic lagoons. Aerobic 1 is approximately 12 ML at a length of 78 metres and width of 58 metres. Aerobic 2 consists of two parallel ponds each 39 metres wide by 47 metres in length with approximately 6 ML capacity between them. Water is the fed into a final pond known as the irrigation pond, where treated wastewater is either:

- recycled back into the system to be used for cattle washing, lawns and garden maintenance and yard or road dust suppression, truck wash
- paunch drain flushing and blood plant cooling
- irrigated on site
- disposed of to trade waste to the local council sewer.

3.2. Opportunities for reuse

The kill floor, cleaning and tripe room are with the most significant uses of potable water at the subject site. As these areas are involved in the processing of meat and to ensure that the safety of the product is not compromised, any reused process water should meet the requirements for potable water.

Current uses of recycled water at subject site include dust suppression of cattle lanes, washdown of outdoor surfaces and truck wash. To demonstrate that the water quality used is fit for the purpose and to ensure the ongoing viability of the existing uses, the site specific risk assessment will include these uses.

The operators of the subject site have indicated that using recycled water for the cooling towers is an option for investigation. As the cooling towers have the potential for generating aerosols, the risks associated with inhalation of relevant pathogens, such as *Legionella* and *C. burnetii* must be managed. As previously discussed, QMRA for cooling towers has not been undertaken, due to the lack of availability of exposure volumes necessary to calculate disease burden for *C. burnetii*, however, the reuse of process water from sources that are unlikely to contain *C burnetii* present and opportunity for reuse in cooling towers, therefore a worked example is provided in section 9.1.2.

4. Monitoring Program

The purpose of the site specific monitoring program was to characterise the pathogen risk from a number of abattoir wastewater sources. Due to time and budgetary considerations, the monitoring program could only provide a 'snapshot' of pathogen concentrations and allow for a quantitative analysis of the risk.

4.1.1. Locations

The monitoring locations were selected to give a broad overview of pathogen concentrations in wastewater sources that are considered viable options for reuse:

- WR01 - combined wastewater pre DAF (red and green streams) - to give a measure of worst case scenario
- WR02 - combined wastewater post treatment (red and green streams) – to give a measure of current risk and identify options for reuse using currently available treatment processes
- WR03 – combined paunch/offal/kill floor (red and green streams) - due to high potable water use
- WR04 - boning room (red stream) - due to high potable water use
- WR05 - kill floor (red stream) - due to high potable water use

4.1.2. Monitoring program

The program comprised of 10 days of sampling, during production:

- *E. coli* and faecal coliforms sampled at 5 sites per day for 10 days – total 50 samples
- *Cryptosporidium* sampled at 1 site per day for 10 days – total 10 samples
- *Coxiella burnetii* sampled at 5 sites for 5 days – total 25 samples.

E. coli and faecal coliforms were chosen for each site to give an indication of faecal contamination across a range of process water sources. *Cryptosporidium* was sampled only at WR01 to provide an example of the

worst case scenario for *Cryptosporidium.* This was considered the best use of the budget whilst delivering an estimation of *Cryptosporidium* occurrence in wastewater.

C. burnetii was selected as it is a pathogen of concern for beef production. There is very little information available about the occurrence of *C. burnetii* in abattoir wastewater, but is increasingly considered a potential hazard associated with reuse. *C. burnetii* was included to quantify the actual risk associated with reuse of abattoir wastewater.

The sampling program overview is presented in Table 11. A sample sheet is provided to collect relevant data and indicate the necessary equipment.

Table 11 Proposed Monitoring Program

Parameter	Sample Bottle	Day 1 – 5	Day 5 – 10
E. coli /faecal coliforms	250 mL bottle	One 250 mL sample at each location (WR01, WR02, WR03, WR04, WR05)	One 250 mL sample at each location (WR01, WR02, WR03, WR04, WR05)
Cryptosporidium/giardia	10 L sample (2 x 5 L bottle)	Two 5 L samples at WR01	Two 5 L samples at WR01
C. burnetii	1 L bottle	One 1 L sample at each location (WR01, WR02, WR03,WR04, WR05)	None
Total per day		5 x 250 mL bottle 2 x 5 L bottle 1 x l L bottle	5 x 250 mL bottle 2 x 5 L bottle

4.1.3. Sample collection

The following process was followed for the collection of samples:

- Samples were collected during production. The time of day and estimated production level for the day noted on the sample sheet.
- Relevant details were noted on the bottle label, including site descriptor and date.
- *E. coli*/faecal coliform and *Cryptosporidium*/Giardia samples were sent to Sydney for analysis so were couriered to ALS Brisbane in the early afternoon to ensure receipt in Sydney within the 24-hour timeframe.
- A chain of custody form (template provided) was submitted with each batch of samples sent for analysis.
- Samples were chilled to <4°C or <6°C. as recommended by ALS by placing samples in ice immediately upon sampling for best practice chilling, with either repacking into another cool box or draining of free water and replacement of ice just prior to dispatch.
- *C. burnetii* samples were sent to the Australian Rickettsial Reference Laboratory (Victoria) in one batch at the end of the 5 days of sampling.

4.1.4. Sample analysis

The following samples were collected and analysed:

- Faecal coliforms and *E. coli* (MW006: Faecal Coliforms & *E.coli* by MF)
- *Cryptosporidium* (ALS Method Code: MP546 LOR - 1 oocyst per volume/amount analsysed)

- *Coxiella burnetii* (LOR - 10 organisms per 100ml) This test detects DNA from *C. burnetii*. It is reported as positive when two distinct *C. burnetii* genes (com1 & htpAB) are both detected in the specimen, or when the com1 gene is detected in duplicate reactions.

The results for *C. burnetii* did not include spore infectivity or viability, as at present, there is no current method for this undertaking this analysis for this type of sample, as the concentration of spores in a sample are considered too low to be able to culture an acceptable sample for analysis.

5. Monitoring results

5.1. WR01 - Combined wastewater pre-treatment

WR01 represents the combined wastewater for the whole abattoir site, collected prior to treatment within the onsite DAF and lagoon plant. This site was selected to account for the 'worst case scenario' for recycled water source water in the beef production process. This source is expected to include cow manure, urine, dirt, dust and digestive matter as well as blood and other liquid wastes generated from all parts of the site.

The *E. coli* and faecal coliform results presented in Table 12 indicate that faecal contamination at this location is high. This is expected, as the inputs to the wastewater include manure, paunch contents, washdown of indoor and outdoor surface.

The *Cryptosporidium* analysis indicate that while *Cryptosporidium* is a hazard, in the wastewater, it is at a reasonably low level <50 oocysts/L. The AGWR identify typical *Cryptosporidium* concentrations in raw sewage to be in the range of 0 – 10^4 oocysts per litre. The results indicate that the process water prior to treatment, is at the lower end of this range. It is noted that this analysis did not include oocyst viability.

The results from *C. burnetii* show that one sample out of 5 returned a positive reading. The value of 10.5 organisms per 100mL was on the cusp of the level of detection. *C. burnetii* bacteria are found in the birth products (i.e. placenta, amniotic fluid), urine, faeces, and milk of infected animals, therefore the likely source of *C. burnetii* at this sampling site is most likely faecal matter washed from surfaces and cattle prior to slaughter.

Table 12 WR01 Sampling Results

Parameter	N	Minimum (cfu or orgs per 100mL)	Maximum (cfu or orgs per 100mL)	Average (cfu or orgs per 100mL)	95th percentile (cfu or orgs per 100mL)	No of positive samples
E. coli	10	240,000	520,000,000	201,624,000	520,000,000	10
Faecal coliforms	10	240,000	520,000,000	201,624,000	520,000,000	10
Cryptosporidium	10	<50	<50	<50	<50	10
C. burnetii	5	0	10.5	2.1	8.4	1

5.2. WR02 - Combined wastewater post-treatment

WR02 is the combined treated wastewater, treated via DAF and anaerobic and aerobic lagoon processes. The *E. coli* and faecal coliform results presented in Table 13 indicate that faecal

contamination at this location is highly variable, however it is noted that the average and 95th percentile values are much lower than the pre-treatment stream, by an order of 4. This source is expected to include cow manure, urine, dirt, dust and digestive matter as well as blood and other liquid wastes generated from all parts of the site however some treatment has taken place.

One sample return a positive detection for *C. burnetii*, like WR01, the value was on the cusp of the level of detection. As for WR01, the likely source of *C. burnetii* at this sample point is most likely faecal matter washed from surfaces and cattle prior to slaughter.

Table 13 WR02 Sampling Results

Parameter	N	Minimum (cfu or orgs per 100mL)	Maximum (cfu or orgs per 100mL)	Average (cfu or orgs per 100mL)	95th percentile (cfu or orgs per 100mL)	No of positive samples
E. coli	10	73	100,000	18,238	66,250	10
Faecal coliforms	10	~270	100,000	19,220	68,950	10
C. burnetii	5	0	13.5	2.7	810.8	1

5.3. WR03 – Combined paunch/offal/kill floor

WR03 is the combined paunch/offal/kill floor (red and green streams). The *E. coli* and faecal coliform results presented in Table 14 indicate that faecal contamination at this location is highly variable.

There were no positive detections of *C. burnetii*. The absence of *C. burnetii* in all post slaughter sources is consistent with the assumption that the source of *C. burnetii* is most likely faecal matter washed from surfaces and cattle prior to slaughter and is unlikely to be found in process water sourced from 'clean' areas.

Table 14 WR03 Sampling Results

Parameter	N	Minimum (cfu or orgs per 100mL)	Maximum (cfu or orgs per 100mL)	Average (cfu or orgs per 100mL)	95th percentile (cfu or orgs per 100mL)	No of positive samples
E. coli	10	<2	740,000,000	27,7024,000	668,000,000	10
Faecal coliforms	10	<2	740,000,000	27,7024,000	668,000,000	10
C. burnetii	5	0	0	0	0	0

5.4. WR04 -boning room (red stream)

WR04 is the boning room (red stream). The *E. coli* and faecal coliform results presented in Table 15 indicate that this stream is also highly variable.

There were no positive detections of *C. burnetii*.

Table 15 WR04 Sampling Results

Parameter	N	Minimum (cfu or orgs per 100mL)	Maximum (cfu or orgs per 100mL)	Average (cfu or orgs per 100mL)	95th percentile (cfu or orgs per 100mL)	No of positive samples
E. coli	10	<1	310,000,000	31,016,270	186,048,000	10
Faecal coliforms	10	<1	310,000,000	31,060,128	170,635,000	10
C. burnetii	5	0	0	0	0	0

5.5. WR05 - kill floor

WR05 is the kill floor (red stream). The *E. coli* and faecal coliform results presented in Table 16 indicate that faecal contamination is very low, with an expected maximum pathogen load equivalent to 100 orgs/litre in the QMRA estimations. There were no positive detections of *C. burnetii*.

Table 16 WR05 Sampling Results

Parameter	N	Minimum (cfu or orgs per 100mL)	Maximum (cfu or orgs per 100mL)	Average (cfu or orgs per 100mL)	95th percentile (cfu or orgs per 100mL)	No of positive samples
E. coli	10	<1	10	1.9	5.95	1
Faecal coliforms	10	<1	10	1.9	5.95	1
C. burnetii	5	0	0	0	0	0

6. Site specific data analysis

6.1. E. coli and Cryptosporidium

The QMRA risk estimation calculations detailed in section 2 were rerun using the site specific data presented in section 4.1 to identify maximum risk; the risk in the absence of preventive measures including PPE, vaccinations and safe work methods.

The *E. coli* testing did not quantify the proportion of STEC in the *E coli* samples, however to estimate the LRVs required for each process water source, the calculations have been based on the *E. coli* results rather than specific STEC.

This may result in over conservative outcomes and may over-estimate the risk, however, this approach is considered appropriate for the initial scoping of a reuse project. Further quantification of STEC though PCR testing should be undertaken once a clear option for reuse is identified.

The concentrations of *E. coli* detected in the process water from sites WR01, WR02, WR03 and WR04 result in a probability of infection of 1 (100%) for the four potential uses identified in section 2, resulting in the same disease burden for each site and use as shown in Table 17. The *cryptosporidium* concentration detected at WR01 resulted in a probability of infection of 1 (100%) for all uses other than for inhalation of sprays (0.001 mL) associated with the irrigation of cattle yards.

The disease burden for all sources and uses are considered unacceptable, in reference to the tolerable risk disease burden of 10^{-6} DALYs.

Table 18 identifies the LRVs required to achieve the tolerable risk disease burden. As noted previously, due to the high levels of pathogens within the process water, the probability of infection for all sources and uses except for irrigation of cattle yards was 100%, producing the same disease burden estimates and required LRVs for the majority of uses.

Table 17 Site Specific Disease Burden Estimates

Exposure Type	**Disease Burden (DALYs per person per year)**				
Site	WR01	WR02	WR03	WR04	WR05
E. coli					
Cattle yards (0.001 mL)	13.128	13.128	13.128	13.128	0.041
Truck wash (3.79 mL)	13.128	13.128	13.128	13.128	0.154
Cleaning (20 mL)	13.128	13.128	13.128	13.128	0.792
Potable uses (1.4 litres/day)	13.128	13.128	13.128	13.128	12.960
Cryptosporidium					
Cattle yards (0.001 mL)	0.352	ND	ND	ND	ND
Truck wash (3.79 mL)	0.353	ND	ND	ND	ND
Cleaning (20 mL)	0.353	ND	ND	ND	ND
Potable uses (1.4 litres/day)	0.353	ND	ND	ND	ND

ND – no data available

Table 18 Site Specific LRV Targets

Exposure Type	**LRV Target**				
Site	WR01	WR02	WR03	WR04	WR05
E. coli					
Cattle yards (0.001 mL)	7	7	7	7	4
Truck wash (3.79 mL)	7	7	7	7	5
Cleaning (20 mL)	7	7	7	7	5
Potable uses (1.4 litres/day)	7	7	7	7	7
Cryptosporidium					
Cattle yards (0.001 mL)	5	ND	ND	ND	ND
Truck wash (3.79 mL)	5	ND	ND	ND	ND
Cleaning (20 mL)	5	ND	ND	ND	ND
Potable uses (1.4 litres/day)	5	ND	ND	ND	ND

ND – no data available

6.2. Coxiella burnetii

The monitoring program included a five-day sampling program for *C. burnetii* at all five sample locations. Only two out of 25 samples returned a positive reading. Both readings were very low and on the cusp of the level of detection. These results indicate that the occurrence of *C. burnetii* in abattoir wastewater is very low and it is often not present, even in untreated wastewater. This result may be due to a low level of *C. burnetii* in cattle process over the 5 days of sampling.

The absence of *C. burnetii* in sampling sites WR-03, WR-03 and WR-05 indicate that *C. burnetii* is most likely from wastewater sources prior to slaughter which include wash down of floors and surfaces that could contain manure and urine and the rinse down of cattle prior to slaughter. As discussed in section 2.4, the inherent occupational risk in these areas due to the presence of manure, urine and livestock is expected to be greater than or equal to any risk associated with reuse of process water in these areas.

Due to the characteristics of *C. burnetii* it is unclear which treatment technologies remove or reduce the occurrence or viability of *C. burnetii*, therefore LRVs for *C. burnetii* have not been estimated. The main route of exposure is through inhalation of aerosols or dust generated on a site. This risk is managed onsite through PPE and a comprehensive vaccination program. Offsite impacts can be mitigated through maintenance of soil moisture to reduce dust, maintaining vegetation cover in paddocks and pastures and limiting irrigation during windy conditions.

The monitoring results indicate that there is very little if any *C. burnetii* in a range of abattoir water sources.

7. Treatment options

7.1. Process selection

7.1.1. Technology log reduction values

There are many options for treating process water to make it suitable for reuse. Many abattoirs traditionally undertake primary and secondary treatment of wastewater to make it suitable for pasture irrigation or disposal to sewer. The suitability of treatment technologies will depend on space, infrastructure configuration and budget. To meet the log reductions required to make process water, it may be necessary to use a combination of treatment technologies.

The AGWR provide indicative log reductions achieved by a number of different treatment technologies. Table 19 provides the indicative LRV achieved for a selection of treatment technologies for the selected reference pathogens.

Table 19 Indicative Log Reductions Achieved by Water Treatment Technologies

	Indicative LRV		
Treatment Technology	***E. coli***	***Campylobacter***	***Cryptosporidium***
Membrane Filtration	3.5 - >6.0	3.5 - >6.0	>6.0
Reverse osmosis	>6.0	>6.0	>6.0
Chlorination	2.0 – 6.0	2.0 – 6.0	0.0 – 0.5
Ozonation	2.0 – 6.0	2.0 – 6.0	N/A
UV Disinfection	2.0 – 4.0	2.0 – 4.0	>3.0

LRVs are variable based on makes, models, operational conditions and site specific characteristics therefore site specific validation of LRVs is required.

7.1.2. Technology selection and validation

Using the LRV estimates provided in Table 8,

Table 9 and

Table 10 and the indicative LRVs identified in Table 19, options for treatment can be identified for further investigation.

For example:

Where site specific testing identifies a source of process water, with *E. coli* concentration of 100 organisms/L, *Cryptosporidium* of 1 organism/L and *Campylobacter* of 1 organism/L, that is to be reused for cleaning, the following LRVs need to be achieved.

- *E. coli* – 6 log reductions
- *Cryptosporidium* – 4 log reductions
- *Campylobacter* – 1 log reduction

Based on the indicative LRVs identified in Table 19, a combination of UV disinfection and chlorination may have the capability to make the water fit for the use.

Each treatment step must be evaluated to ensure that the chosen combination of treatment components will achieve the LRVs targets identified in the site-specific risk assessment in section 5. Validation also identifies the operational envelope for the treatment processes to inform the operational control of the treatment processes e.g. setting critical operational limits.

Validation is the process of proving that a treatment process can achieve pathogen removal under a specific operation range. A national framework for validating water treatment technologies has been developed in the form of protocols for specific treatment technologies. The framework is based on the following nine elements:

- identification of the mechanisms of pathogen removal by the treatment process unit
- identification of target pathogens and or surrogates that are the subject of the validation study
- identification of factors that affect the efficacy of the treatment process unit in reducing the target pathogen

- identification of operational monitoring parameters that can be measured continually and are related to the reduction of the target pathogen
- identification of the validation method to demonstrate the capability of the treatment process unit
- description of a method to collect and analyse data to formulate evidence-based conclusions
- description of a method to determine the critical limits, as well as an operational monitoring and control strategy
- description of a method to determine the LRV for each pathogen group in each specific treatment process unit performing within defined critical limits
- provision of a means for revalidation or additional onsite validation where proposed modifications are inconsistent with the previous validation test conditions.

7.2. Technology details

7.2.1. Ultraviolet (UV)

Ultraviolet disinfection is an established, physical method of pathogen deactivation. It works by exposing the wastewater to a source of UV light, thereby exposing the pathogens present in the wastewater to UV (EPA Victoria, 2002). The UV light denatures the DNA of the pathogens exposed (Gray et al. 2015). Unlike chemical dosing (chlorination, AOPs), there are no disinfection by-products (DBPs) formed, however conversely UV radiation does not have lasting effects via residual disinfection and therefore not preventing re-growth of pathogens further downstream (EPA Victoria, 2002). UV is considered effective in the inactivation of all pathogen groups however, higher UV doses are required for virus inactivation, than for bacteria and protozoa.

7.2.2. Chlorination

Disinfection via chlorination is a chemical method of disinfection, using hypochlorite salts or gaseous chlorine to dose wastewater (EPA Victoria, 2002). When the chlorinating chemical is exposed to water, it reacts to form hypochlorous acid (HOCl), monochloramine (NH_2Cl), hypochlorite ion (OCl^-) and dichloramine (NH_2Cl_2), which have oxidising properties, working to deactivate pathogens, in particular HOCl (EPA Victoria, 2002). Chlorination is effective against deactivating bacteria and viruses, whilst protozoa and helminths are more resistant (EPA Victoria, 2002). LRVs achieved for municipal wastewater were reported as 4 for bacteria, 4 for viruses and 0 for protozoa (Gray et al. 2015). Chlorination has an advantage, residual chlorines remaining in the wastewater after dosing providing a level of disinfection and thereby limiting pathogen regrowth (EPA Victoria, 2002).

7.2.3. Pasteurisation

This is a physical disinfection process, used widely throughout the food industry, notably in the product of milk. Pasteurisation of wastewater involves rapidly heating the wastewater to temperatures high enough to deactivate pathogens (temperatures varied depending on the type of pathogen, however Sanciolo et al. (2015) reported on pasteurisation temperatures >50 °C. The pasteurisation of wastewater is not usually done in Australia; however, it has been demonstrated to be effective in a full-scale investigation in California (Sanciolo et al. 2015). LRVs reported are food related, and values for bacteria vary between 1-8 depending on the species of bacteria and temperature of the pasteurisation (Sanciolo et al. 2015). It was reported that protozoa are effected by pasteurisation, with LRVs reported from 1-5, varying depending on the protozoa species, the

temperature and contact time (Sanciolo et al. 2015). LRVs for viruses were reported to be effected by pasteurisation, again varying on the specific species of viruses, with values varying widely from 1-8 (Sanciolo et al. 2015). Although more research is required to gain traction in Australia, pasteurisation has advantages over other treatment methods due to the fact that the turbidity of the water does not affect the efficacy of the disinfection, unlike in chemical dosing and UV radiation (Sanciolo et al. 2015).

7.2.4. Reverse Osmosis (RO)

Reverse osmosis and nanofiltration (RO/NF) membranes have been widely recognised as being capable of achieving LRVs for pathogens including bacteria and viruses. High pressure membranes, such as RO/NF, are comprised of three layers. The first (top) layer is a semi-permeable membrane made of polyamide (PA), which is pH resistant, rough, slightly negatively charged and has hydrophilic properties. This layer is responsible for the passage of water and the rejection of dissolved species and pathogens. The second layer is comprised of nanoporous polysulfone serving as structural support for the first layer and the final layer is a non-woven polyester fabric which gives stiffness and further support to the membrane.

Size exclusion and charge repulsion are the principal removal mechanisms of RO/NF membranes. However, depending on the compound properties, adsorption and diffusion mechanisms can also play a role.

The performance of individual RO/NF systems can vary significantly and high LRVs cannot be arbitrarily credited to any system. Instead, each RO/NF membrane process should be systematically validated to determine the LRV for each system

7.2.5. Microfiltration

Microfiltration is effective in removing protozoa (due to their larger size) and is effective against some types of viruses and bacteria which are large enough to be caught in the filtration medium (EPA Victoria, 2002). LRVs reported for microfiltration through a ceramic medium used for municipal wastewater are 1-4 for viruses, 1-4 for bacteria and 4 for protozoa (Gray et al. 2015).

7.2.6. Ozonation

This is a process whereby the wastewater is dosed with ozone, a very strong oxidising agent. The ozone works to deactivate pathogens present in the wastewater through oxidation via free radicals formed, though the exact mechanisms are still being researched (WHO, 2004). Ozone is effective for deactivating bacteria and viruses, achieving log reduction values (LRV) from 2-4 (Gray et al. 2015) in municipal wastewater. Protozoa are less vulnerable to ozonation and although WHO (2004) reports that a 99% deactivation can be achieved for some species, Gray et al. (2015) has recorded the log reduction values as ‘0’. Wu and Doan (2005) also reported COD and BOD removal of up to 10.7% and 23.6% respectively. Although ozonation is considered to be more effective at reducing bacteria and viruses from wastewater than chlorination, the lack of residuals limits the lasting effects of ozonation (EPA Victoria, 2002).

8. HACCP Planning

The Australian Standard *AS ISO 22000 Food Safety Management Systems – requirements for any organization in the food chain* (ISO 22000) species the requirements for a food safety management system that combines the following generally recognized key elements to ensure food safety along the food chain, up to the point of final consumption:

- interactive communication
- system management
- prerequisite programs
- Hazard Analysis and Critical Control Point (HACCP) principles.

ISO 22000 combines HACCP Plan with pre-requisite programs (PRPs) and operational PRPs (OPRPs) to provide a framework for managing risks and ensuring the safety of food products. ISO 22000 and HACCP principles are also considered an effective method for managing water quality, for both drinking and recycled water.

This section of the report will outline the general process for using the results of the risk assessment to establish prerequisite programs and critical control points (CCPs) for managing reuse of process water. CCPs are a step at which control can be applied and is essential to prevent or eliminate a food safety hazard or reduce it to an acceptable level. CCPs are the points in the process where performance can be monitored in a timely fashion, such as continuously, and where performance has gone out of established control limits (critical limits), a corrective action can be implemented to reduce or stop the hazard from affecting the final product.

In the context of producing recycled water, critical controls points are generally established at the treatment steps that are essential in achieving the LRVs required to make the water fit for the use.

ISO 22000 identifies PRPs as the basic conditions and activities necessary to maintain hygienic environment throughout the food chain suitable for the production, handling and provision of safe end production and safe food for human consumption. These are the programs and activities that are essential for ensuring food safety, but often cannot be monitored in real time and have an associated corrective action that can be immediately applied to reduce or remove a hazard.

8.1. Hazard assessment

Relevant hazards have been identified in sections 2 and 5 of this report. The risk to public health associated with those hazards has been assessed using QMRA techniques. The level of treatment (LRVs) required to meet produce recycled water that is fit for the use has also been identified. Options for treatment technologies and an overview of the process for validating LRVs are presented in section 6.

A general hazardous event assessment is presented in Table 20 to determine the preventive measures and understand the PRPs and the OPRPs that will need to be established for managing risk. This provides a guide only. Each site should undertake a comprehensive site risk assessment that includes assessment of risk (likelihood and consequences) and assessment of the effectiveness of the preventive measures.

Table 20 General Hazardous Event Assessment

Process step	Hazardous event	Preventive Measures

Stock receipt	Increased pathogen load in stock being processed	• Animal welfare standards
		  ○ veterinarian practices
		  ○ animal husbandry
		• QA/QC processes
		• Supplier approval processes

Recycled water treatment	Insufficient treatment resulting in recycled water that is not fit for the use	• Establishment of critical control points at each treatment step (HACCP Plan) • Validation of treatment processes and commissioning testing • Operational monitoring of indictors of treatment performance • Verification monitoring and non-conformance procedures
Recycled water treatment	Failure of a water treatment process resulting in poor quality recycled water e.g. poor disinfection or inadequate filtration	• Validation of treatment processes and commissioning testing • Operational monitoring of indictors of treatment performance • Verification monitoring and non-conformance procedures • Maintenance and calibration programs • Staff training and awareness
Recycled water treatment	Contamination of treated recycled water	• Procurement procedures (use of materials approved for use in water treatment) • Operational maintenance of equipment and infrastructure • System design (total separation of on-site sewerage systems and recycled water systems)
Recycled water use	Accidental or unplanned exposure of food products to recycled water	• Establishment of critical control points at each treatment step (HACCP Plan) • Validation of treatment processes and commissioning testing • Operational monitoring of indictors of treatment performance • Verification monitoring and non-conformance procedures
Recycled water use	Accidental or unplanned exposure of staff to recycled water	• Establishment of critical control points at each treatment step (HACCP Plan) • Validation of treatment processes and commissioning testing • Operational monitoring of indictors of treatment performance • Verification monitoring and non-conformance procedures • Staff training and awareness • Personal Protective Equipment (PPE)
Recycled water use	Accidental or unplanned exposure of the public (neighbouring sites) to recycled water	• Establishment of critical control points at each treatment step (HACCP Plan) • Validation of treatment processes and commissioning testing • Operational monitoring of indictors of treatment performance • Verification monitoring and non-conformance procedures

8.2. Prerequisite programs

The World Health Organization defines PRPs as “practices and conditions needed prior to and during the implementation of HACCP and which are essential for food safety”. Prerequisite programs provide a foundation for an effective HACCP system. A CCP is designed to control a food safety hazard that has been determined to be reasonably likely to occur. A prerequisite program may prevent a food safety hazard from occurring. They are often facility-wide programs rather than process or product specific. They reduce the likelihood of certain hazards.

All of the preventive measures identified in a risk assessment that are not CCPs should be documented in a PRP. Examples include:

- maintenance and calibration programs
- staff training and awareness
- procurement procedures (use of materials approved for use in water treatment)
- operational maintenance of equipment and infrastructure
- system design (total separation of on-site sewerage systems and recycled water systems)
- animal welfare standards
    - veterinarian practices
    - animal husbandry
- QA/QC processes
- supplier approval processes.

PRPs should include the following information for each program:

- the food safety hazard(s) to be controlled by the programme
- control measures(s)
- monitoring procedures that demonstrate that the PRP is implemented
- corrections and corrective actions to be taken if monitoring shows that the PRP is not controlled
- responsibilities and authorities
- records of monitoring.

8.3. HACCP Plan

HACCP Plans must be established for each CCP and include the following information for each critical control point:

a) food safety hazard(s) to be controlled at the CCP
b) control measures
c) critical limits
d) monitoring procedures
e) corrections and corrective actions to be taken if critical limits are exceeded
f) responsibilities and authorities
g) records of monitoring.

Generally as a minimum, each process step that is being relied upon to achieve LRVs will be a CCP. The performance of the treatment steps must be monitoring in real time, continuously and online.

The system should have the ability to detect an exceedance of a defined critical limit and a corrective action must be able to be applied, such as shutting down the system or increasing the dose of a disinfectant.

During validation, the operating range for a treatment component will have been defined and validated, this operating range informs the establishment of CCPs, indicators of performance and critical limits. Refer to the following example.

Chlorine disinfection – the validation of the LRV will be demonstrated through calculating the C.t. C.t. is the concentration of the disinfectant in the water and the time that the disinfectant will be in contact with the water. The LRV achieved is documented in a number of guidelines (C.t. tables) published by organisations such as the US Environmental Protection Agency (US EPA). The tables take into consideration other influencing factors such as temperature, pH and turbidity. The HACCP Plan for chlorine disinfection should include critical limits to ensure that if the C.t. is not achieved, a corrective action, such as increasing chlorine dose or stopping supply, is triggered. Critical limits should include free chlorine residual, flow, pH, temperature and turbidity.

8.4. Monitoring programs

8.4.1. Operational monitoring

Operational monitoring is the monitoring of the CCPs. Monitoring programs should be established for each CCP and should ensure that the monitoring methods and frequency is capable of determining when critical limits have been exceeded, in time for the product to be isolated before it is used or consumed. It is expected that the monitoring of CCP performance consists of online and continuous monitoring of the surrogates and indicators identified during the validation process with programmed alarms and automatic shutdowns. Operational monitoring programs should include:

a) parameters as identified in the validation investigation
b) critical limits that identify when the system has deviated from acceptable operation
c) frequencies and locations suitable to detect the deviation from acceptable operation
d) actions to be undertaken when a critical limit is exceeded
e) monitoring devices used
f) calibration methods
g) responsibilities and authorities
h) records of monitoring.

8.4.2. Verification monitoring

Verification monitoring is the final check to ensure that the HACCP Plans and PRPs are being implemented and are effective. In the context of water recycling, verification is testing the final water produced to ensure that it meets the required standard.

A verification monitoring program should be developed to document the monitoring of the recycled water that is produced by the scheme. Any deviation from the required water quality standard, should trigger a corrective response.

9. Conclusions

The risk associated with the reuse of abattoir wastewater is not well established, limiting the options for reuse of process water and implementing water saving initiatives.

Stage 1 of the project included making estimations of risk for a range of pathogens known to be relevant to cattle and beef production. Stage 2 included a site-specific assessment, with a targeted monitoring program, aimed at providing more information on expected pathogen concentrations in wastewater from a range of abattoir production processes.

The results of the Stage 1 risk screening and estimation identify the disease burden and LRVs required for the reuse of a range of source waters for a range of uses. These results can be used to inform preliminary investigations about implementing a process water reuse program in abattoirs. Once a decision has been made on the most ideal source water and uses, as well as confirming that the system can be configured appropriately, additional testing will be required to validate the proposed treatment system.

The specific uses investigated for this project were based on those with high consumption of potable water and then grouped according to volume and type of exposure and comprised of:

- potable uses for any use that could result in recycled water contacting with the products
- outdoor uses, such as irrigation of pasture and other open spaces
- truck wash, this is a current use at the site
- cleaning – cleaning is a significant user of potable water and there is potential to use recycled water for the first wash down of surfaces around the site.

Due to interest in reusing process water for cooling tower systems, the reuse of abattoir process water in cooling towers was investigated, however a QMRA was not undertaken. Literature review indicates that aerosols generated by cooling towers have the potential to travel for up to 10 km from the source, therefore risk mitigation should include reducing aerosols and managing potential hazardous pathogens. A worked example for cooling towers is presented below, identifying potential risk mitigation activities.

The Stage 2 site-specific assessment indicated that the *E. coli* counts in a range of process water sources was highly variable and will require a high level of treatment, however, specific testing for pathogenic strains of *E. coli* (STEC) within the source waters may reveal that the treatment required may be lower than reported in this document. This investigation did not reveal current sources of process water that would be considered suitable for reuse without further treatment.

Cryptosporidium analysis was limited to the untreated combined wastewater due to the cost of analysis. This was to give an indication of the worst case scenario for *cryptosporidium.* It should be noted also, that the analysis only included count and did not include infectivity, which would provide a more accurate input into the QMRA. The analysis showed that the *cryptosporidium* concentration did not vary significantly across the sample period with less than 50 organisms/100 mL recorded for each sample.

C. burnetii, the causative agent of Q fever is an important consideration for abattoirs, and there is very little information regarding *C. burnetii* risk in relation to reuse of abattoir process water. This project included sampling for *C. .burnetii* in a range of process water sources. The results indicated that during the sampling program, only 2 out of 25 samples were positive for C. burnetii, with low concentrations on the cusp of detection. There were no detections of *C. burnetii* in any process waters sourced after evisceration. A QMRA for *C. burnetii* was not undertaken due to the absence of reliable data on removal or reduction of *C. burnetii* from wastewater through treatment processes. *C. burnetii* is well managed through workplace vaccination programs for abattoir workers.

There are several options for treatment technologies, however all treatment systems must be validated to prove that they can achieve the level of treatment required to make the recycled water fit for the use (achieving LRVs) and to determine the operating range to inform the establishments of CCPs.

Any water recycling project will require all risks to be managed, establishing a HACCP Plan and PRPs within a food safety management system. This report provides guidance on the establishment of CCPs and HACCP Plans, PRPs and monitoring programs.

9.1.1. Example: Reuse of treated wastewater for cleaning

The results of the QRMA indicate that to use treated wastewater for cleaning (no contact with meat or meat products, or meat production surfaces), further treatment is required to meet the DALYs for exposure to 0.02 L of cleaning water 240 times per year (7 LRV Bacteria, 5 LRV *Cryptosporidium).* According to the LRV estimates reported in the AGWR (Table 19), a combination of membrane filtration and chlorine disinfection may be appropriate to meet the LRV, depending on the treatment efficacy that can be validated for the membrane, and achieving adequate C.t.

The HACCP Plan for a treatment train of this type would include the following critical control points and potential critical parameters:

- Membrane filtration – pressure decay, turbidity, flow
- Disinfection – C.t. (flow, chlorine residual), temperature, turbidity and pH.

9.1.2. Example: Reuse of process water in cooling tower processes

The results of the sampling program indicated that whilst there were low concentrations of *C. burnetii* in the combined process waters, process water sourced after evisceration or from 'clean' areas did not contain *C. burnetii*. Whilst the sampling program was limited to 5 samples at each site, and pathogen loads could be dependent on disease burden in the cattle being processed, process water sourced from 'clean' areas represents the best opportunity for process water reuse for cooling towers. Alternatively, a more detailed sampling program for *C. burnetii* could be undertaken to better characterise occurrence in process water.

The requirements to mitigate *Legionella* risk from cooling towers are well established and covered in relevant guidelines by state health regulators. Risk management activities include:

- preventing stagnation of water and nutrient growth
- ensuring suitable quality water is used

- ensuring the cooling tower system is in good working order
- ensuring the location of the tower is suitable and public access to the cooling tower is restricted.

These techniques should all form part of a risk management plan for any cooling tower. In addition to these requirements, abattoir facilities proposing to reuse process water for cooling towers, should also understand the *C. burnetii* risk and implement appropriate preventive measures. Preventive measures for managing additional risk of *C. burnetii* include:

- selectively sourcing process water from 'clean' areas that are unlikely to contain *C. burnetii*
- implementation of additional testing programs to characterise *C. burnetii* in process water
- installing an effective drift eliminator to comply with AS/NZ 3666.1

The Victorian HHS (2015) recommends that people within a radius of 500 m should be considered as being potentially exposed to droplets from a cooling tower.

A drift eliminator constructed and fitted to comply with AS/NZS 3666.1 can significantly reduce the aerosols leaving a tower. Drift eliminators are designed to capture large water droplets caught in the cooling tower air stream by causing the droplets to change direction and lose velocity at impact on the blade walls and fall back into the tower. Manufacturers estimate that and efficient drift eliminators will keep drift losses to less than .001% of the re-circulating water flow rate.

This project did not include any assessment of suitability of physical properties of process water suitability for reuse.

9.1.3. Limitations

This project is a preliminary investigation into the potential opportunities for reuse. The results are estimates that can be used to make high level planning decisions about reuse. The monitoring program was limited only three parameters, *E. coli*, an indicator of faecal contamination, *Cryptosporidium* and *C. burnetii*. The risk level associated with Shiga toxin producing *E. coli* (STEC) can be better understood through specific testing for STEC. *Cryptosporidium* was tested for presence and count, therefore the risk would better characterised through testing of infectivity. Additionally, the calculation of bacterial risk may also benefit from QMRA on *Campylobacter*.

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Glossary

Word	Description
ADWG	Australian Drinking Water Guidelines
AGWR	Australian Guidelines for Water Recycling
AQIS	Australian Quarantine and Inspection Service
AWRCE	Australian Water Recycling Centre of Excellence
BNR	Biological Nitrogen Removal
CAMRA	Center for Advancing Microbial Risk Assessment
CCPs	Critical Control Points
DAFF	Department of Agriculture, Forestry and fisheries
DALYs	Disability Adjusted Life Years
DAWR	Department of Agriculture and Water Resources
EMIAC	Export Meat Industry Advisory Committee
EPA	NSW Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
HACCP	Hazard Analysis and Critical Control Point
LRV	Log Removal Value
NHMRC	National Health and Medical Research Council
NRMMC	National Resource Management Ministerial Council
STEC	Shiga Toxin producing *E. coli*
UV	Ultraviolet
WHO	World Health Organisation

Appendix A Standards and Guidelines

AQIS Meat Notice 2008/06 Efficient Use of Water in Export Meat Establishments

Australian Federal Government Department of Agriculture, Fisheries and Forestry (DAFF) (now known as Federal Department of Agriculture and Water Resources (DAWR)) prepared the AQIS Meat Notice 2008/06 Efficient Use of Water in Export Meat Establishments (the Meat Notice) dated 13 October 2008 to advise export registered processors relating to the use of recycled and reused water in meat establishments. The Notice covers recycled water for potable use on site and water reclaimed from a process on site and reused in the same process or another process that is fit for the purpose.

The Meat Notice has the following definitions:

- **Recycled water** - water that has been used previously for whatever propose and that has subsequently undergone a manmade process to make it of potable standard as defined in the regulations.
- **Potable water** – water from any source that is acceptable for human consumption.

The Meat Notice references AS 4696 and identifies the following requirements for occupiers of establishments wishing to treat their wastewater so that it can be utilised for any potable processing purpose on the establishment without leaving the establishment:

- exclude human effluent from the wastewater stream to be treated, have no physical connection between the potable and any other non-potable supply
- follow the analysis and management process outlined in the Attachment to the Meat Notice (i.e. HACCP principles)
- use a multiple barrier approach (i.e. use more than one treatment process to ensure if one step fails at least one other treatment step will address the potential hazards)
- ensure that there is access to the potable local authority supply or acceptable alternative supply in case of system failure
- the treated water must meet the ADWG for potable water
- must not use the water as a direct ingredient in meat products or use it for drinking water at the establishment.

The Meat Notice states that establishments wishing to use direct planned recycled potable water as part of their production process must provide full details of the system, to the responsible DAWR Area Technical Manager (ATM) who will consult with Central Office for initial in principle approval prior to construction of the facility, and then final approval once validated, prior to using this recycled water in production. DAWR will inform the relevant state food safety authority of the proposal to ensure any concerns of the local authority is identified and addressed.

Full details of the approved program must then be incorporated in the establishment's Approved Arrangement through its HACCP program and water standard operating procedure.

The Meat Notice summarised the process of obtaining approval to undertake the on-site recovery of water. The process has been broken down into five stages. These stages being:

- Stage 1: Self assessment prior to preliminary meeting with regulators
- Stage 2: Risk assessment through to formal submission to the principal regulator (DAWR)
- Stage 3: Approval process undertaken by the principal regulator (DAWR)
- Stage 4: Commissioning, validation and verification
- Stage 5: Approval to use water in production processes.

The self assessment stage will require a detailed investigation to determine the level of treatment required to treat wastewater to a potable standard. This will include:

- characterisation of the wastewater to determine the pathogen concentration
- calculation of the level of pathogen reduction required
- design of a multiple barrier treatment train that is capable of achieving the identified pathogen reduction
- development of a validation plan to prove that the treatment train can achieve the pathogen reduction

The process identified above is detailed in the ADWG and AGWR which are detailed below. The information gathered in the self assessment stage should inform the risk assessment process.

Once the regulator has granted approval to commence, the construction and commissioning stage will include:

- validation testing to confirm that the treatment train is effectively treating the wastewater to the required standard
- verification testing to confirm the final product water is of a potable standard
- development of a HACCP plan.

AS4696:2007 Hygienic Production and Transportation of Meat and Meat Products for Human Consumption

AS 4696:2007 Hygienic Production and Transportation of Meat and Meat Products for Human Consumption (AS 4696) sets that standard to ensure that meat and meat products for human consumption comply with food safety requirements. AS 4696 is also referred to as the Australian Meat Standard.

AS 4696 recognises that food safety risks extend through the entire food preparation chain and are not confined to the preparation, handling and storage of end products. It consolidates the rules for the construction of premises and transportation of meat and meat products and is broad enough to apply to retailers who store or prepare meat and meat products and to their transportation from the retailer to the consumer. Processors are responsible for the hygienic operations of their facilities. Their ability to operate hygienically is verified though assessment against department performance standards with the results being recorded in a national database.

Potable water must be used in the production of meat and meat products unless the approved arrangement expressly provides for the use of the non-potable water and the circumstances in which it is used. Non-potable water may also be used for steam production (other than steam used or to be used in direct or indirect contact with meat and meat products), fire control, the cleaning of yards, the washing of animals (other than the final wash) and other similar purposes not connected with meat and meat products.

AS 4696 also defines relevant terms, as follows:

- **Ingredient** means any substance (including a food additive) that is used in the preparation, manufacture or handling of meat and meat products
- **Potable** when used in relation to water**,** means water that is acceptable for human consumption.

Additionally, AS 4696 requires that potable water is supplied in lines that:

- are used only for potable water; and
- are physically separate from the supply of non-potable water; and
- are identified for use for potable water if any non-potable water is used at the business.

The reuse of wastewater for potable purposes is permitted under the standard as long as the water doesn't make contact either directly or indirectly with meat and meat products

Ice must be made from potable water and is protected from contamination during its making, storage and handling. Steam used or to be used in direct or indirect contact with meat and meat products must be produced from potable water and must not contain substances that may create a food safety hazard or jeopardise the wholesomeness of meat and meat products. Only potable running water that is not recycled is to be used for immersion thawing or cooling. Untreated waste from toilets is to be treated separately from other waste at the plant and does not discharge into the plant's waste system. Water used to clean the meat carrying compartment is to be potable.

Australian Drinking Water Guidelines

The *Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy* 2011 (ADWG) prepared by the National Health and Medical Research Council (NHMRC) and the National Resource Management Ministerial Council (NRMMC) is Australia's authoritative document on drinking water quality. The ADWG water quality standards are not mandatory; however, they provide a basis for determining the quality of water to be supplied to consumers in all parts of Australia.

Drinking water is defined as water intended primarily for human consumption, either directly, as supplied from the tap, or indirectly, in beverages, ice or foods prepared with water. The ADWG recommends a multiple barrier approach from catchment to tap, supported by a risk management framework.

The ADWG contains standards for the acceptable concentrations of microbiological, chemical and physical hazards and their indicators.

The microbial standards seek to ensure that drinking water is free of microorganisms that can cause disease. The ADWG identify indicators that can be monitored to provide an indication of the safety of water. The following microbiological indicators should not be detected in drinking water:

- Bacteriods
- Coliphages
- *Clostridium perfringens*
- *E. coli*

- Intestinal enterococci
- Thermotolerant coliforms.

Heterotrophic plate counts (HPC) and total coliforms are indicators that if used as an indicator, guideline numbers should be established on a system-specific basis.

Microbiological guidelines have been set for microbiological pathogens, that are not recommended as indicators that should be routinely monitored, but should be investigated to ensure that they are managed in the drinking water. Pathogens relevant to humans and cattle that should not be detected drinking water can include:

- *Campylobacter*
- *E. coli*
- *Mycbacterium*
- *Salmonella*
- *Yersinia*
- *Blastocystis*
- *Cryptopsoridium*
- *Lysteria*
- *Coxiella burnettii.*

Guidelines for chemical and physical hazards have also been identified in ADWG and should be considered in a risk based approach.

Australian Guidelines for Water Recycling

Managing Health and Environmental Risks (Phase 1)

The *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1)* (AGWR) outline a risk management framework for the control of risks to public health and the environment posed by the use of recycled water. The AGWR focuses on recycled water sourced from human sewage however the risk based approach and methods outlined in the AGWR are relevant to recycled water from a range of sources.

The AGWR recommends:

- removing hazards using treatment processes – these are managed by the recycled water provider and controlled via the user agreement, which specifies the water quality requirements for the identified uses
- reducing exposure through preventative measures at the site of use – these are managed onsite by the recycled water user.

The AGWR include:

- a specific definition of safety, particularly for microbiological quality, based on the use of DALYs
- health-based performance targets, including required reductions of microbiological and chemical hazards
- use of reference pathogens.

DALYs are the metric used in these guidelines to define tolerable microbial risk. The advantage of DALYs is that they include a measurement of the severity of impacts on human health arising out of infection and illness. They differentiate between relatively mild impacts, such as diarrhoea, and severe impacts, such as haemolytic uremic syndrome and even death. In terms of waterborne disease, the most commonly recognised illness is gastroenteritis (involving symptoms such as diarrhoea and vomiting) caused by ingestion of enteric pathogens. However, a number of waterborne pathogens can cause more severe and long-lasting symptoms in a small percentage of infected people. Determining DALYs for individual hazards includes considering acute impacts (eg diarrhoeal disease or even death) and chronic impacts (eg reactive arthritis and haemolytic syndrome). Calculation of DALYs includes consideration of each of the symptoms caused by a particular pathogen and the relative frequency of occurrence.

The tolerable risk adopted in the AGWR is 10^{-6} DALYs per person per year, which is consistent with the WHO *Guidelines for Drinking-Water Quality* (WHO 2006a). This is approximately equivalent to an annual diarrhoeal risk of illness of 10^{-3} (i.e. 1 illness per 1000 people). In comparison, the reported rate of diarrhoeal illness in Australia is 0.8–0.92 cases per person per year (NHMRC & NRMMC 2006)

Managing Health and Environmental Risks (Phase 2) Augmentation of Drinking Water Supplies

Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2) Augmentation of Drinking Water Supplies (AGWR Phase 2). Guideline values for individual parameters and the principles for calculating guideline values from health and toxicological information described by the ADWG are applied in the AGWR Phase 2.

The AGWR Phase 2 describe the point of application as the point where the verification of recycled water quality must be applied at the point of entry to the receiving water, e.g. drinking water supply system.

Wastewater used as a source for the production of high-quality recycled water for potable uses can contain a wide range of agents that pose potential risks to human health, including chemicals and pathogenic (disease-causing) microorganisms.

Appendix B Literature Review

The European Food Safety Authority (EFSA) reviewed carcass decontamination with reheated recycled water, which is practiced in Denmark and Canada (EFSA 2010). It was found through investigation of abiotic and microbiological risks that the effectiveness of using reheated recycled water did not differ significantly from decontamination using potable water (EFSA 2010). Risks for heated recycled water were heat-resistant microorganisms including *C. botulinum, C. perfringens, C. difficile* and *B. cereus* and also the accumulation of chemical contaminants, including veterinary drugs (EFSA 2010). Though the chemical risks were not addressed, the microbiological risks can be controlled using reheating and ensuring the frequency of renewal of the recycled water (EFSA 2010).

Meat and Livestock Australia (MLA) funded an investigated the single reuse of water from the beef viscera table to clean and wash paunch, conducted by Richard Ford and Associates (2013). Specifically, the potable hot and cold water used to sterilise and then cool the moving-top viscera tables to clean the paunch emptying tank, the area surrounding the paunch opening room and beef runners (Ford & Associates 2013). Water analysis suggested high levels of generic *E. coli* and coliforms (in the $\log_{10}$106? range), therefore the water was not at acceptable quality to come in contact with the meat product (Ford & Associates 2013).

MLA and Teys Brothers conducted an investigation into the reuse of steriliser water from the "clean" end of the viscera table for spraying the table, which is filtered for solids then pumped from a holding tank to the holding yard to wash away manure (Teys Bros Pty Ltd 2011). During the trial, an estimated 1,000 kL per week was recycled (Teys Bros Pty Ltd, 2011). Water quality monitoring revealed that the *E. coli* levels in the captured water was too high for reuse, as it posed unacceptable risk for workers who would be exposed to the water when it was used in the stockyards (Teys Bros Pty Ltd 2011).

Steriliser water used in the Boning Room step of a lamb processing plant was reused for the Contra-shears and hosing down the outside of the rendering plant at the Tatiara Meat Company, a large exporter and processor of lamb (Phillips 2011). Reportedly the project successfully saved up to 100 kL of potable water consumption a day (Phillips 2011). Steriliser water was captured and transferred to a holding tank after filtering for solids (Phillips 2011). Water quality tests of the steriliser water indicated some microorganisms were in the water, however, since the holding tank was heated via steam injection, this was deemed to be controlled (Phillips 2011).

MLA published a report prepared by JBS Australia Pty Ltd (JBS Australia), which investigated the reuse of tripe wash water. Tripe undergoes two stages of washing in centrifuges, the first to scald and blanch it to remove the inner linings, and the second is being refined by hot water to degrease and polish (JBS Australia 2014). The proposed reuse was to capture the wastewater from the second wash, and use it for the primary wash. Although the system was trialled, changes to water volumes in the tripe process negatively affected the recycling stream, meaning that there was insufficient water for the recycling (JBS Australia 2014). The water volume was inadequate to wash the tripe, effecting the quality of the product. This halted the trial, and ultimately made it unviable because of the cost of the equipment and the unavailability of high flow tripe wash systems in other beef processing plants (JBS Australia). Water quality testing of the recycled water indicated that the load

of microorganisms was very low, because of the temperature that the process was run at and that total suspended solids were also low (JBS Australia).

A feasibility study on the use of microfiltration membranes for water reuse in meat processing plants was conducted by the UNESCO centre of Membrane Science and Technology and published by MLA in 2006. The study focused on white water (water from handwashing, steriliser pots and viscera table sterilisation) and using membrane filtration to reduce the total organic carbon, turbidity and chemical oxygen demand (COD).

A study was published by MLA in 2011, investigating the use of patented technology developed by Distech Company, Vapour Compression Vacuum Distillation (VCVD), to treat wastewater to meet potable water standards and therefore to be appropriate for reuse (Sentance 2011). A pilot plant was established and it was found that the Distech D50 pilot plant was able to deactivate *Cryptosporidium*, viruses, coliforms and *E. coli* in a test solution, however, some *Enterococci* survived and the system was not able to deactivate *Clostridium perfringens* (Sentance 2011). Although the findings in the study indicated that the water treated met the Australian Drinking Water Guidelines (ADWG), it was concluded that further water quality analysis would be required to establish that this technology could reliably treat water to potable water standards (Sentance 2011). Furthermore, it was concluded that the economic viability of the technology would vary greatly for each plant, as it is dependent on the wastewater produced (Sentance 2011).

Northern Co-Operative Meat Company undertook research into reusing 'white wastewater' effluent from their abattoir through installation of drainage systems which allowed for the white wastewater to be captured (Northern Cooperative Meat Company Ltd 2004). Specifically, they collected water used for boot washing at the viscera table, hot water used to wash viscera table, cold water used to second wash the viscera table, handwashing and the steriliser from the hide-on process step (Northern Cooperative Meat Company Ltd 2004). The tannery adjacent was able to utilise this water without treating to potable water quality and without incurring significant risks (confirmed by the CSIRO) (Northern Cooperative Meat Company Ltd 2014). The CSIRO identified that there were some issues with microbial risk and temperatures, and consequently a model was established, used to predict the volume of water, the contamination load and temperature of each wastewater source (Northern Cooperative Meat Company Ltd). Using the model, an appropriate stream of effluent was developed using a combination of wastewater sources.

'White wastewater' was also collected at Oakey Abattoir Pty Ltd (Oakey Abattoir), detailed in their investigation of water use, reuse and effluent management on their site (Oakey Abattoir Pty Ltd 2007). Through collecting water used for sterilisation on the slaughter floor and reusing it in the stock yards for cattle wash down, they were able to save 500 kL of water per week (Oakey Abattoir Pty Ltd 2007). It was noted that the reused water was warmer, meaning that it removed manure and dirt more efficiently (Oakey Abattoir Pty Ltd 2007).

A study conducted by Northcutt et al. (2008) investigated the recycling of water from the chiller in a poultry processing plant. Recycled water and potable water were blended together, and water quality samples were taken (Northcutt et al. 2008). The carcasses were tested for *E. coli*, coliforms and *Campylobacter* before and after being chilled. The water from the chiller and carcasses were also tested for *Salmonella*. The tests indicated that *E. Coli*, coliforms and *Campylobacter* levels were reduced from 2.6, 2.9, 2.6 log cfu/mL (pre-chill) to 1.5, 1.5 and 2.0 log cfu/mL (post-chill)

respectively, meaning that the reused water blended with potable water was successfully used to reduce bacteria (Northcutt et al. 2008). Similarly, the prevalence of *Salmonella* went from 25% of carcasses (pre-chill) to 22% of carcasses (post-chill) (Northcutt et al. 2008). It must be noted that criteria for acceptable bacteria counts were not mentioned in this paper and no comparison was made of log reductions achieved through using only potable water.

In 2006 the Churchill Abattoir published a report via MLA outlining their plans and development of a wastewater recycling system at their abattoir. The strategy involved using an aerobic treatment lagoon and an updated slow sand filter in order to produce water fit for non-potable uses (Spence 2006). Although there were project difficulties caused by changes in effluent water quality and other factors, through this project they were able to save up to 11 ML per year between June 2006 and June 2007. This project was ongoing in the report by Spence (2006).