Guideline for Water Recycling and Reuse in Red Meat Processing

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1.0 INTRODUCTION

Meat processing facilities consume significant amounts of water to process meat into edible product for human consumption. The requirement to operate under stringent food safety regulations coupled with the potentially catastrophic impact of a food poisoning incident dictates that much of this water is consumed for cleaning and sanitation purposes. Water must be of a potable standard when used in direct contact with meat or indirect contact via surfaces and machines in contact with meat product.

Water availability in Australia is far from guaranteed. Australia has one of the most variable climates of any continent and during times of drought there is strong pressure from the community for industry to demonstrate best practice water consumption. One aspect of this is water reuse and recycling. Unfortunately for meat processors this creates a challenging situation of balancing community concerns for food safety and environmental stewardship.

The capacity for low cost water reuse and recycling in meat processing plants is very limited. This is due in part to legal restrictions from some export markets (e.g. USA) which prohibits reuse or recycling in meat processing operations where there is contact between the water and product or product surfaces. This limits reuse to about 30% of total potable water consumption or less – mainly for use in animal yard washing or external uses.

In jurisdictions where reuse or recycling is permitted when there may be food or food surface contact, the requirement is for the recycled water to be potable quality. Due to the high nutrient, organic and microbial loads of raw meat processing wastewater, the cost of treatment to a potable standard is substantial although technically feasible. During the millennial drought in SE Queensland (approximately 2002 – 2007), this issue was studied by the industry, but with no uptake of options involving direct or indirect contact with meat product. In the face of increasing competition for natural resources and climate change, however, there is a need for the industry to be prepared to reconsider the issue.

The use of a risk-management approach is a well demonstrated systematic method to protect the health of the public and environment. The risk based Hazard Analysis Critical Control Point (HACCP) approach has been used for decades in the food industry and later in water treatment. This document is a guideline for developing a HACCP based plan for water recycling and reuse at red meat processing sites. It has been developed in line with requirements of AQIS Meat Notice No: 2008/06 – The Efficient Use of Water in Export Establishments (DAFF, 2008) and the Australian Water Recycling Guidelines (NRMMC, 2006). The *Recycled Water Management Plan and Validation Guidelines* and *Guide for Preparing a Water Management Plan* (DEWS, 2008) were used as reference documents in developing these meat processing specific guidelines.

These guidelines provide explanatory and supporting information for plant's developing a site level Recycled Water Management Plan for Red Meat Processors (RWMP). The RWMP document is a template and has been adapted from the *Guide for Preparing a Water Management Plan* (DEWS, 2008).

1.1 Scope

In line with (DAFF, 2008), this document is intended primarily to cover on-site water that is being considered for:

- recycling for potable use on site by the occupier; and
- reclamation from a process on site and reuse in the same process, or another on site process for which it is fit for purpose.

The document is also helpful for assessing water that is being considered for:

- supply as recycled water for potable use on-site from a local water authority;
- supply as recycled water for non-potable use from a local water authority, or on site by the occupier;

1.2 Regulatory Background

Relevant regulations and guidelines for the recycle and reuse of water in meat processing sites are:

1. AQIS Meat Notice, 2008 (DAFF, 2008).
2. Export Control (Meat and Meat Products) Orders 2005 (AusGovt, 2005).
3. Australian Standards for Hygienic Production and Transportation of Meat and Meat Products for Human Consumption AS 4696:2007 Part 7 Premises, equipment and essential services.
4. Manual of Importing Country Requirements (DAWR, 2017).
5. Australian Drinking Water Guidelines (Referred to as ADWG) (NHRMC, 2011).
6. Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1) (Referred to as AGWR) (NRMMC, 2006).
7. Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2). Augmentation of Drinking Water Supplies (Referred to as ADWS) (NRMMC, 2008).
8. Other state based guidelines need to be considered.

Meat processors wishing to treat their waste water so that it can be utilised for any potable processing purpose at their plant must meet the following requirements (DAFF, 2008):

- exclude human effluent from the waste water stream to be treated;
- have no physical connection between the potable and any other non-potable supply;
- follow HACCP principles for the management of the recycled water;
- use a multiple barrier approach (See Section 2.1);
- ensure that there is access to the potable local authority supply or acceptable alternative supply in case of system failure;
- meet the Australian Drinking Water Guidelines for potable quality water; and
- must not use the water as a direct ingredient in meat products or use it for drinking water at the establishment.

Further to this, only potable water can be used for the production of meat and meat products unless the water is only 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; or
- in other circumstances where there is no risk of the water coming into contact with or contaminating meat and meat products.

All water recycle or reuse activities must be authorised under an Approved Arrangement with the Department of Agriculture, Fisheries and Forestry Australia (DAFF, 2008).

1.3 Definitions

Term	Definition or abbreviation
ADWG	Australian Drinking Water Guidelines
AQIS	Australian Quarantine and Inspection Service
AWTP	Advanced Water Treatment Plant
DAWR	Department of Agriculture and Water Resources
Direct potable recycled water or direct potable reuse (DPR)	Water produced by an establishment using a controlled process where processing waste water is fully regenerated to make it of potable standard as defined in the regulations and is used solely within that establishment.
HACCP	Hazard analysis critical control point
HSCW	Hot Standard Carcass Weight - the standard definition of the weight of a carcase with hide, feet, tail, head and innards removed, taken within two hours of slaughter
Indirect potable recycled water or indirect potable reuse (IPR)	Water produced by a local water authority using a controlled process where general waste water is fully recycled to make it of potable standard as defined in the regulations. The recycled water is then introduced back into the raw supply which in turn is subject to all the normal treatment procedures that this supply is subject to, to make it potable.
Microfiltration (MF)	Membrane process typically used as pre-treatment for Reverse Osmosis.
Non-potable recycled water	Recycled non-potable water provided for restricted purposes such as irrigation, watering gardens, flushing toilets, washing down external areas which it is fit for the purpose.
Potable water	Water from any source that meets national standards for human consumption.
Raw water	Water intake to a site from external sources (town, bore or other) and which excludes the addition of internally produced recycled water
RWMP	Recycled Water Management Plan
Recycled water	Water that has been used previously for whatever purpose and that has subsequently undergone treatment to potable quality as defined in the regulations.
Reused water	Water that is reclaimed and used again, with or without further treatment, for the same or other purposes that it is fit for the purpose. Reused water is different to potable in that it is not for general use within an establishment and its use must be controlled using HACCP principles.
Reverse Osmosis (RO)	High pressure membrane process used to generate potable quality water.
Scheme	Systematic plan or process for recycle/reuse of treated water
TSS	Total Suspended Solids
Ultrafiltration (UF)	Membrane process intermediate between MF and RO. Removes most microorganisms and large molecular weight molecules but not salts.
WWTP	Wastewater Treatment Plant

2.0 DEVELOPING A WATER RECYCLE AND REUSE PLAN

2.1 Multiple barrier approach

A general preventative principle in water recycling systems is to have a multiple barrier approach (NRMMC, 2008). This caters for the fact that no single barrier or treatment method can be completely effective at eliminating all types of hazards or can be fully effective 100% of the time. If one barrier fails or is not fully functional, hazards are still managed by the other barriers. These guidelines also describe a treatment process which produces potable quality water in batches that are not released for use until the full range of quality checks are completed and the water meets the required standards.

2.2 HACCP Approach

An overview of the HACCP structure is shown in Figure 1 below and these steps are intrinsic to the development of a plan. This document provides background information and discusses requirements of a Water Recycle and Reuse Plan that follows this basic structure.

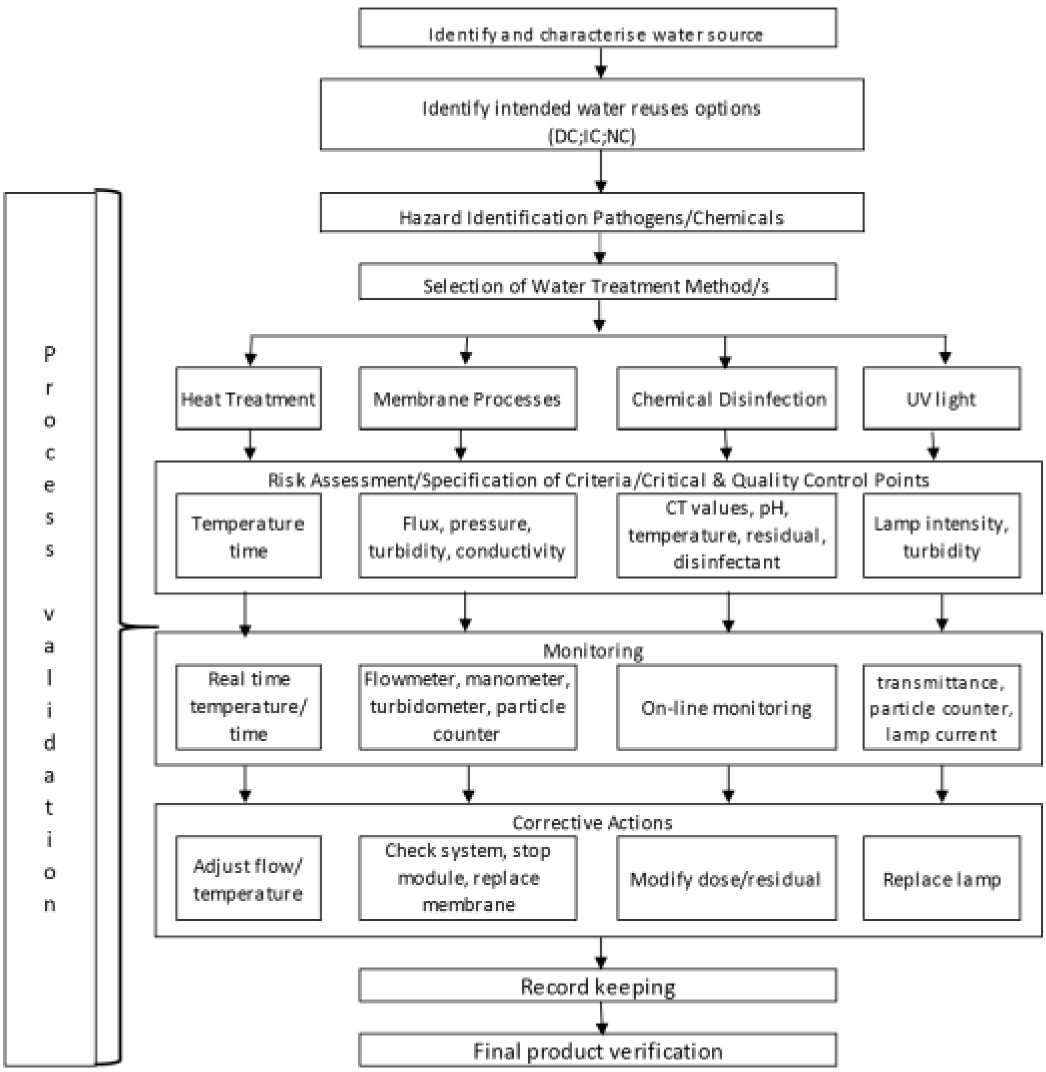


Figure 1: HACCP flow chart (adapted from Casani & Knøchel, 2002)

2.3 Contents of a plan

A template for developing a plan is provided in the Recycled Water Management Plan (RWMP) for Red Meat Processors. This document has been adapted from a template prepared for the Queensland Government (DEWS, 2008) which in turn was adapted from the Australian Guidelines for Water Recycling (NRMMC, 2006).

The plan should describe the context of the RWMP and include relevant background information including:

- its purpose(s), why and by whom the RWMP has been prepared;
- the relevant regulatory and management framework including the applicable legislation, standards, codes or guidelines;
- the company's commitment to the scheme via a suitable policy statement; and
- roles and responsibilities of persons directly involved in the scheme.

The overall RWMP is a comprehensive package of assessment, operating and recording procedures. These are discussed further throughout these guidelines. **TABLE 1** indicates the various aspects of developing a HACCP plan and where it is addressed in this Guideline and the RWMP template.

Table 1: HACCP approach and where it is addressed in Guideline and RWMP

	Guideline Section	RWMP Section
Regulatory Background	1	1
Management commitment/policy	2	2
Team formation and function	2	3.1
Characterise water source	3/4	3.2
Hazard identification	4	3.3
Water Quality Objective	5	3.2
Treatment Methods	6	3.2
Cost Benefit Analysis	6	-
Risk assessment/Specification of criteria/ Critical & Quality Control Points	7	3.3/3.4
Operational control & monitoring	8/9/11	5/6
Scheme validation	10	4
Final product verification	12	6.1
Corrective Action	13	6.1/7
Incident management	13	7
Record Keeping	14	8
Supporting programs	15	9

The Efficient Use of Water in Export Meat Establishments (DAFF, 2008) also stipulates some preliminary work of Stakeholder Analysis and Assessing Current Water Use as described in the following sections.

2.4 Stakeholder analysis

Prior to preparing a recycled or reuse water proposal meat businesses should identify their key stakeholders. Depending upon the nature of the businesses activities, the meat business will have one or more government and a number of private stakeholders. Stakeholders will include:

- Relevant meat authority;
- State departments responsible for:
  - Public Health
  - Water and wastewater provision and infrastructure
  - Environment
  - Work, Health and Safety
  - Fire and Rescue; and
- Key customers or industry groups.

For export meat plants, overseas jurisdictions will need engagement. A starting point when determining a meat business' government stakeholders, is to identify all of the licences, approvals and accreditations held by the business that relate to meat production, water usage or discharge of wastes.

The most critical stakeholders are customers and employees. The use of recycled water for drinking water supplies in communities (direct/indirect potable reuse) remains extremely controversial in Australia and many other countries. Direct potable reuse in meat plants is likely to draw similar community reaction, especially if it is implemented without careful planning and engagement. This warrants high level engagement with customers. For employees, health and safety concerns must be allayed e.g. drinking water source, aerosols, sprays and continual contact with water during processing and sanitation.

2.5 HACCP team

The development of a HACCP plan requires significant managerial and technical expertise and is best addressed through the contribution of a team. This is particularly important in the preliminary stakeholder consultation stage, which will require the input of senior managers and later during the risk assessment stage which will require a greater level of technical/operational input and knowledge. The risk assessment team is primarily responsible for undertaking the hazard identification and risk assessment process, and is also likely to be involved in the development and implementation of various other elements of the RWMP, including ongoing regular reviews. Members should include an expert/consultant; personnel from operations, quality control, laboratory, maintenance, management; and also external regulators i.e. DAFF. At least one member should have formal risk assessment training or equivalent experience or skills.

2.6 Current water use

The Efficient Use of Water in Export Meat Establishments (DAFF, 2008) also stipulates undertaking a water audit.

It is important to map where and how water is used in the process so that possible capture points for water reuse can be identified. Consideration will need to be given to what types of changes to the production or manufacturing processes are required to accommodate or enable the use of recycled water. The meat business also needs to identify the end use of the water that it intends to capture and use. The following points should be considered:

- // What is the current and likely future regional water supply situation? Consider regional water security issues, State and Local Government water plans, planned water infrastructure, likely growth in regional demand and any other factors that could affect future water availability and price. This will help determine the return on investment in water recycling.
- // What are the current water requirements of the business and what are possible future requirements? Consider future expansion plans, changes in product line or anything else that could change water requirements.
- // Current water uses, volumes, infrastructure and treatment.
- // Identification of potential water re-use or capture options. This may require flow metering at various points in the production process and implementation of a water efficiency program.
- // Proposed end use of recycled water including consideration of environmental risk and work, health and safety issues. Before considering treatment options, reuse without treatment should be considered. For example, it may be appropriate for final rinse water to be reused with no or little additional treatment.

When mapping water usage it is important that the business develops a schematic diagram of the production processes.

3.0 WATER RECYCLE/REUSE OPPORTUNITIES IN MEAT PROCESSING

The combined wastewater output from an abattoir has high levels of organic matter (COD, BOD), suspended solids, fats, and nitrogen and phosphorus; moderate conductivity; contains a wide variety of micro-organisms including potential pathogens; has low concentrations of cleaning and disinfection chemicals; is pH neutral; has a temperature ranging from cool to hot; and contains negligible amounts of toxic compounds and heavy metals (MLA, 2008). There are several opportunities to reuse water within meat processing plants where the water quality is fit for the intended purpose. Along with potential health and reputational risks, considerations for the reuse of water include:

- // the cost of treatment compared with the cost of potable sources, and where applicable the effect of reduced trade waste costs if less water is disposed of;
- // the impact of reduced recycling of water to local irrigation where these circumstances exist; and
- // potential increase in energy costs related to treatment.

Recycle/reuse categories are defined as follows:

Direct Contact - Contact of reused water directly with meat product or surfaces that come into contact with the product being processed and includes:

- final rinsing of edible product that is not further processed;
- any preparation surfaces including hooks, tables, conveyors etc, that would have direct contact with meat products or meat packaging materials that may offer a means of cross-contamination of the product;
- final water rinse of clean-in-place (CIP) systems or manual cleaning systems; and
- direct addition of water as an ingredient in a manufactured meat product (currently not allowable (DAFF, 2008)).

Indirect Contact - Reuse of water inside a meat processing environment that is not intended for direct contact with the product or product contact surfaces, including;

- stock washing in cattleyards prior to processing – one of the most common forms of treated effluent reuse in modern plants;
- water reuse for environmental sanitation of non-meat product contact surfaces inside the processing environment and consideration of risk of contamination of unprotected meat product contact surfaces with aerosols or transfer of water from the non-product contact surfaces, dependent on the locality of application of the reused water; and
- use of make-up water for cleaning and sanitation chemicals used in CIP systems or manual sanitation, excluding the final CIP water rinse.

Non-Contact - The lowest risk application of water for reuse, outside of the meat processing environment including:

- boilers and cooling towers, with consideration given, on an individual site basis, to the use and maintenance of this infrastructure and the potential risk of aerosols and transfer of water from these sources into meat processing environments; and
- washing of transport vehicles, taking into account that appropriate water treatment will still be required considering the role of meat product transport vehicles and transport containers for meat product that could offer the potential for cross-contamination to product packaging and then to product.

It is important that all intended water recycle uses are captured in a HACCP plan regardless of whether it is direct, indirect or not in contact with meat product. Table 2 lists various sources of non-potable wastewater in a meat processing plant which are currently undertaken or have the potential for reuse after appropriate treatment. Along with the potential recycle/reuse opportunities shown in this table, these guidelines describe risks involving specific cases of direct potable reuse and reuse in boilers and condensers/cooling towers.

Table 2. Current/potential areas of non-potable water reuse

Water Sources	Potential area for reuse	Category	Known to be undertaken
Stock wash			
Treated wastewater	Initial stock wash	IC	**Y**
Slaughter, evisceration			
Viscera table final wash	Viscera table initial wash	DC	**Y**
Head wash/gut wash/carcass wash	Gut wash/carcass wash (closed loop)	DC	**Y**
Hand wash	Boot and Apron wash	IC	
Knife and equipment steriliser water	Initial stock wash and stockyard washdown, odour scrubber sprays, waste water treatment and rendering plant cleaning	NC	**Y**
Machine cooling water	Initial stock wash and stockyard washdown, odour scrubber sprays, waste water treatment and rendering plant cleaning, boilers/cooling towers	NC	**Y**
Pump cooling/sealing water	Boilers/cooling towers	NC or IC	
General Processing			
Distribution wash down	Landscape watering	NC	**Y**
Truck wash down	Landscape watering	NC	**Y**
Auxiliaries			
Freezer defrost	Wash down water/cooling tower feed	NC	**Y**
Boiler blowdown	Reuse flash steam and recover heat Manual cleaning, amenities (toilet flushing), cooling boiler ash	NC	**Y**
Cooling tower water bleed	**Manual cleaning, amenities (toilet flushing), cooling boiler ash**	**NC**	**Y**

DC - Direct contact; IC - Indirect contact; NC – Non - contact

4.0 HAZARDS IN MEAT PROCESSING WASTEWATER

For high end recycled water uses such as those proposed in this Guideline – direct potable reuse and reuse in boilers and condensers/cooling towers - the list of potential hazards is potentially very large given the highly-contaminated nature of meat processing waste streams, the physical size of most meat facilities and the wide array of microbial and chemical hazards possible. Lists of hazards relevant in sewage systems can be found in Tables 2.2 – 2.4 of NRMMC (2006). Fortunately, unlike direct potable reuse of treated human sewage for which most reuse guidelines are developed, the list of potential hazards and severity of impact may be significantly reduced through existing hazard control mechanisms. These are discussed below in more detail. Nevertheless, the list of potential hazards remains sizeable.

Table 3 provides an example list of hazards that were considered of negligible threat to a proposed reuse scheme based on a risk assessment performed at an Australian red meat processing plant. Note that these hazards may not be negligible in all reuse or recycled water schemes and that the concentrations listed may be very different in other facilities and should not be used as default values. Table 4 provides a list of hazards likely to be of significance in the recycling of red meat process effluent for high quality uses. Again, the hazards and concentrations given are for example only and should not be taken as default values or as capturing all hazards.

Table 3. Hazards likely to be of low threat in meat processing plants.

Hazard Class	Hazard	Typical Effluent concentration[1]
General	TSS	30 - 60 mg/l
	Scums	-
	Foaming	-
	Turbidity	NA
	Colour	green tinge
Chemical	pH	neutral
	DO	2 mg/l
	Alkalinity	500 - 600 mg/l
Nutrients	Nitrite	< 2 mg/l
Inorganics	Magnesium	80 mg/l
	Sulphate	500 mg/l
	Potassium	17.2 mg/l[2]
	Boron	0.1 mg/l[2]
Organics	BOD5	10 mg/l
	Surfactants	NA
Disinfection by-products	NDMA	NA
Metals	Arsenic	0.03 mg/l max[2]
	Cadmium	<0.01 mg/l[2]
	Chromium total	0.7 mg/l

	Copper	0.15 mg/l max[2]
	Lead	<0.05 mg/l max[2]
	Mercury	<0.0001 mg/l[2]
	Nickel	0.2 mg/l max
	Zinc	0.5 ave; 1 mg/l max[2]
	Vanadium	0.6 mg/l
	Iron	NA
	Manganese	0.66 mg/l[2]
	Aluminium	0.4 mg/l
Specialist organics	Antibiotics	NA
	Phthalates	NA
	Phenol	NA
Pesticides	Aldrin, Atrazine	BLOR[2]
	Chlorpyrifos, DDE/DDD	BLOR[2]
	BHC, Heptachlor	BLOR[2]
	Lindane, Dieldrin, Endrin	BLOR[2]

Notes: 1. Levels in WWTP-treated effluent feed to AWTP, NA – not available.
2.Levels in raw wastewater prior to WWTP. BLOR – below limit of reporting.

Table 4. Hazards of significance to recycling of meat processing effluents

Hazard Class	Hazard	Typical Effluent concentration[1]
Flora	plant seeds	
Microbial	bacteria	< 10/100 mL
	Johnes disease	NA
	Q Fever	< 1 /100 mL
	viruses	NA
	helminths	NA
	protozoa	NA
General	oil & grease	< 5 mg/l
	odour	-
Chemical	EC	3 - 4,000 uS/cm
Nutrients	ammonia	<5 mg/l
	nitrate	<30 mg/l
	phosphate	20 mg/l
	Total Nitrogen	40 mg/l
	Total Phosphorus	20 mg/l
Inorganics	sodium	520 mg/l
	chloride	250 mg/l
Organics	biocides	NA

Disinfection by-products	Chlorine disinfection residuals	NA
Specialist	HGPs	NA

Notes: 1 – typical final effluent quality from WWTP unless stated otherwise.
NA – not available; BLOR – below limit of reporting

4.1 Biological hazards

Infectious agents (pathogens) associated with wastewater may be classified within four broad groups: bacteria, viruses, protozoa and helminths or parasitic worms. These infectious agents derive principally from infected persons and other warm-blooded animals, and the diseases associated with these agents are primarily transmitted through human and animal excreta (Casani, 2002). Typical levels in raw meat processing wastewater (Table 5) tend to be similar to those of human sewage.

Table 5. Typical microbial contamination in post-primary treated meat processing effluent

Pathogen	Units	Post-primary
Thermotolerant coliforms	CFU/100ml	>5 x 10^7
Faecal streptococci	CFU/100ml	>5 x 10^7
Cryptosporidium	Oocysts/L	0 - 400
Giardia	Oocysts/L	0 – 1,300

Source: (Johns Environmental pers. comm.)

As an initial barrier in treatment of meat processing waste, human effluent should be excluded from the waste water stream to be treated (DAFF, 2008). This is a critical barrier since the exclusion of human sewage eliminates significant hazards especially human virus loads and personal & pharmaceutical care products from the feed water.

4.1.1 Bacterial hazards

Bacterial hazards are present in the raw wastewater from meat processing plants due to its contamination from yard manure and the opening of ruminant stomachs. Typically, these waste streams comprise 20 – 25% of the total wastewater volume. Bacterial levels are usually similar to sewage.

The animals held in the holding yards for subsequent processing are typically adult animals. These shed disproportionately lower numbers of bacterial pathogens compared to young animals (< 6 weeks old) due to their developed immune systems (Olson et al., 2004). Therefore, pathogen titres in meat processing wastewater are likely to be significantly lower than those reported for animal manure from intensive livestock facilities where young animals are routinely present.

Numerous potential human pathogenic bacterial may be present in the raw wastewater from meat processing plants. Unfortunately, there is little, if any, data concerning these populations. Consequently, it is usual to consider bacterial indicators of faecal contamination such as thermotolerant coliforms and faecal streptococci per Table 5.

Theoretical quantitative risk assessment (QRA) modelling was conducted for meat processing microbial risks by Jain et al (MLA, 2003). They investigated risks posed by numerous microbial pathogens and concluded that for water-borne hazards the major bacterial pathogen of concern was *Campylobacter jejuni*. The risks posed from others were considered several orders of magnitude less. This is useful since *C. jejuni* is identified as the preferred bacterial reference organism for risk assessments in reuse schemes in the National Recycling Guidelines (NRMMC, 2006).

The zoonotic bacteria *Coxiella burnetii* causes the disease Q Fever in humans and can be found Australia wide. It is most commonly spread through inhalation of aerosols or contaminated dust from infected animals in or near abattoirs or animal by-products establishments (MLA, 2003). *C. burnetii* is unlikely to cause human illness through ingestion of contaminated water (MLA, 2003) and therefore, it is not considered as a hazard with respect to a waterborne pathway of infection i.e. via ingestion. There is potential risk from aerosols during the wastewater treatment process, but this is mitigated in Australia by the vaccination of all meat process workers against Q fever and the requirement for all contractors and visitors to take precautions on meat industry sites. This is a useful and effective barrier to the risks posed by this hazard.

4.1.2 Viral hazards

Viral hazards are an extremely concerning issue in high quality recycling of human sewage due to their tiny size and high load in the sewage and infectivity. Fortunately, viruses are host specific and provided human sewage and amenities wastewater is excluded from the meat processing wastewater, the viral load is derived from the ruminants being processed. These pose negligible risk to humans (Anderson, 2007). Nevertheless, it is usual to ensure that the WWTP and AWTP achieve effective reduction in viral loads even though the threat is low.

4.1.3 Protozoan hazards

Protozoan pathogens, principally *Cryptosporidium* and *Giardia* spp, are known to be present in raw meat processing wastewater although there is evidence that some bovine serotypes of protozoans, especially *Cryptosporidium*, are not significantly infective to humans (Olson et al., 2004). Protozoa tend to be more resistant to disinfection processes than viruses and bacteria (Toze, 2004) but are readily removed through meat processing WWTP and membrane processes common in AWTP. The human pathogen, *C. parvum* is identified as the preferred protozoan reference organism for risk assessments in reuse schemes in the National Recycling Guidelines (NRMMC, 2006) and was considered a significant hazard by Jain et al (MLA, 2003) in their QRA study of meat processing effluent microbial hazards.

4.1.4 Helminth hazards

Helminth pathogens tend to be less prevalent in Australia relative to most other parts of the world (Toze, 2004). Parasitic helminth eggs tend to be sizeable (10 – 60 µm) compared to the other pathogens above. In clean water, the eggs settle reasonably rapidly (0.2 – 0.5 m/h). In wastewater, however, they are readily entrapped by particulate flocs in the wastewater and settle out at the settling velocity of the particulates (Sengupta et al, 2011).

Both pond and activated sludge-based WWTP common in Australian meat processing facilities should achieve reasonable removal of helminth eggs from the wastewater and AWTP used for the production of high quality recycled water should eliminate the hazard entirely.

4.2 Chemical hazards

Potential chemical hazards are numerous in meat processing wastewater (see Table 3 and Table 4). Table 4.4 of the NRMMC (2008) Water Recycling Guidelines lists a huge number of chemicals detected in secondary treated human sewage.

Some chemicals are hazardous to human health if ingested, while others may have aesthetic effects on the quality of the product in which they come into contact. Others may have operational implications for processing units in which the water will be used, such as boilers and condensers for example through enhanced corrosion, scaling or the promotion (in cooling towers) of microbial slimes. Data for the chemicals present in meat processing wastewater is far sparser. Chemicals can potentially enter the wastewater via a number of major pathways including the following:

- The animals being processed:
    - BOD/COD, oil & grease, salinity, nutrients (N and P).
    - Animal health care products (antibiotics, growth promoters).
- Cleaning processes in the facility:
    - Surfactants, sanitisers, endocrine disruptors (e.g. in handwash solutions), nano-materials (in eroded coatings and personal care products).
- Chemicals used or generated in the wastewater treatment processes:
    - Aluminium and chlorine based compounds for precipitation of solids, polymer solutions, acids and bases for pH correction, conversion of ammonia to nitrite and nitrate.
- Human-derived chemicals where human amenities effluent and sewage is not segregated:
    - Pharmaceutical and personal care products, drug metabolites.

Hazardous chemicals, particularly heavy metals and persistent or bio-accumulating compounds, are generally absent from the wastewater of meat processing plants since they are not used in the food production process and levels in raw wastewater are usually below limits for drinking water before any degree of treatment (see Table 3). Following problems with meat contamination in the 1990s, stringent national vendor declaration (NVD) protocols were imposed on animals processed through export meat plants to ensure that hazardous chemicals – especially pesticides and veterinary medicines – were eliminated from the food chain. Chemicals used in meat plants need AQIS approval before being brought to site. These source control mechanisms are a very effective barrier to the contamination of recycled water by chemicals.

The Australian Drinking Water Guidelines (NHRMC, 2011) and the Australian Guide to Water Recycling (NHRMC, 2008) list a number of chemicals and the respective desirable limit in drinking water on either a health or an aesthetic basis. AS 3873 (2001) also has some information regarding boiler water treatment which outlines the operational considerations of using recycled water in boilers.

These values are presented in Section 5.2 along with chemical parameters for the efficient operation of cooling towers. Potential for corrosion and scaling are a concern for boilers and cooling towers.

4.3 Physical hazards

Physical hazards relating to the recycling of water in meat processing facilities are common to those experienced at sewage AWTP. Typically, they include:

- High turbidity;
- Colour – usually derived from grass-fed animals and often resistant to biological degradation;
- pH variation due to wastewater treatment;
- Suspended solids from treatment processes; and
- Scums and foams from microbial responses to elevated oil & grease levels in wastewater.

These hazards tend to be readily mitigated by appropriate treatment steps and operating protocols in the WWTP and AWTP.

4.4 Unusual Events

It is important during hazard identification and assessments to consider the impact of non-normal events on the hazards in the wastewater being recycled. The might include:

- Uncontrolled chemical use by contractors;
- Climatic & seasonal events (heavy rainfalls, droughts leading to unusual soil loads in cattle stomachs);
- Spillages, especially of blood or tallow;
- Firefighting chemicals; and
- Accidental cross-connections e.g. human amenities into process effluent.

Various management systems are important in ensuring that the frequency and severity of these events is mitigated.

5.0 WATER QUALITY OBJECTIVE

This section outlines documentation setting standards for water quality for the three recycling uses considered in this Guideline.

5.1 Direct Potable Reuse

Setting water quality objectives for recycled water in DPR schemes is challenging since in some international jurisdictions, such as the USA, the recycling of treated water ("reconditioned" in US parlance) is prohibited for direct contact in food production regardless of quality. In other jurisdictions, such as EU, DPR is acceptable provided it is of potable quality. Therefore, the first step is to ensure that the export markets to which meat and meat products are exported permits DPR at all.

5.1.1 Physical & chemical

In Australia, the primary national guideline for the quality of potable drinking water are the Australian Drinking Water Guidelines (NHMRC, 2016). These outline the required health and aesthetic guideline concentration values for many components, primarily the chemical and physical properties and selected values are listed in Table 6. Further detail on physical and chemical hazard guideline values is available in Table 4.4 and the associated text of the NRMMC (2008) *Water Recycling Guidelines for the Augmentation of Drinking Water Supplies*, which specifically addresses the recycling of effluent for drinking water purposes. As noted above, many of these chemicals are unlikely to be present in meat processing wastewater especially where human amenities effluent is segregated.

It is likely that conformance of the product water from an AWTP supplying a meat processing plant will need to meet these guidelines, especially for direct potable reuse.

Table 6. Water quality characteristics - physical and chemical (NHMRC, 2016)

Water Quality Characteristic Units	Direct Contact (potable quality) ADWG Upper limit (unless stated otherwise) *mg/L*
pH	6.5 – 8.5
Total Dissolved Solids	600
Ammonia	0.5
Nitrite	3
Nitrate	50
Hydrogen Sulphide	0.05
Dissolved Oxygen	> 85% saturation for aesthetics.
Chloride	250
Chlorine	5
Hardness (as CaCO3)	60 - 200
Sodium	180
Sulphate	250
Turbidity	<0.2 NTU is the target for effective filtration of Cryptosporidium and Giardia <1 NTU is the target for effective disinfection >5 NTU is noticeable
Taste/odour	Inoffensive to consumers
Colour (aesthetics)	15 HU
Temperature	n/a

For Australian meat processing plants that export, intake water quality is controlled by the Export Control (Meat and Meat Products) Orders 2005 (Aust Govt 2005). The orders follow the requirements of the Australian Drinking Water Guidelines (NHRMC, 2011) and define potable water as being:

a) acceptable for human consumption;
b) clear, colourless and well aerated; and
c) free from suspended matter, harmful substances and pathogenic organisms.

5.1.2 Microbial

Microbial targets used in DPR schemes are developed around the concept of achieving specified and measureable log reductions of microbial hazards. This requires that reference pathogens for the various groups of microbial hazards are selected, otherwise the routine testing required to validate that the product water is acceptable becomes unaffordable. The NRMMC (2008) *Water Recycling Guidelines for the Augmentation of Drinking Water Supplies* recommends the following reference organisms:

// *Cryptosporidium parvum* for protozoa and helminths;

// A rotavirus and adenovirus combination for enteric viruses; and

// *Campylobacter jejuni* for bacteria.

Note that *C. parvum* was considered a significant hazard by Jain et al (MLA, 2003) and is also considered by Warnecke et al (MLA, 2008) to be a relevant reference organism for protozoa. Wackerneke et al suggest that Salmonella would be a more relevant bacterial reference pathogen to the red meat processing industry and Ascaris or Taenia could be more applicable helminth reference pathogen for some recycled water uses.

A quantitative risk assessment has been applied to microbial hazards for sewage, based on the approach described in Chapter 3 and Appendix 2 of Phase 1 of the *Water Recycling Guidelines* (NRMMC, 2006). This assessment suggests that the minimum log reductions required for production of drinking water from human sewage are:

// *8 log Cryptosporidium;*

// *9.5 log enteric viruses; and*

// *8.1 log Campylobacter.*

This provides a conservative basis on which to design and validate DPR schemes in meat processing plants for the variety of microbial hazards likely to be present. This is discussed further in Section 5.5.1.

These target log reductions translate to water quality objectives. For bacteria they are generally measured in colony forming units (e.g. cfu/100 ml). Water quality standards for potable quality water are defined as follows (Qld Health Regulation:

// E.coli - nil cfu/100 ml; and

// Any viral, bacterial or protozoan pathogens - nil detected

5.2 Boiler Feedwater & Cooling Towers

The water quality objective for indirect and non-contact uses must be 'fit for purpose' and will be case specific. Two areas of interest for recycling of treated wastewater are for feed water for cooling towers and boilers. While it may not be necessary to treat water to strictly potable standard for reuse in a boiler or cooling tower, consideration must be given to the operation and maintenance of this infrastructure and the potential risk of aerosols and transfer of water from these sources into meat processing environments. Water quality requirements for boiler make-up water depend on the pressure at which the boiler is operated; in general, higher pressures require higher-quality water (USEPA, 2012). The primary concern is scale buildup and corrosion and factors to consider are water hardness, control of insoluble scales (calcium and magnesium), silica and alumina and alkalinity.

Similarly, with cooling towers, factors to consider are scale build up and biological growth which can plug nozzles and sprays and reduce overall efficiency. The potential for microbial growth is a particularly important consideration, namely the presence of *Legionella* bacteria (AS/NZS3666.3, 2011). The addition of a biocide and regular maintenance of the chemical balance of the water helps prevent biofilm formation and limit the existence of pathogens. With respect to water quality objectives, legionella is considered as not detected if less than 10 cfu/ml. The standard describes testing and control strategies for levels in excess of this figure. Normal operation of a cooling tower would see heterotrophic microorganisms (most bacteria) detected at levels less than 100,000 cfu/ml. The standard also describes testing and control strategies for levels in excess of this figure.

Table 7 outlines various guideline values for hazards when the recycled water is used for boiler or cooling tower feed. Boiler limits are sourced from AS 3873 (2001) and the cooling tower limits are based on AS/NZS3666 (2011) and various other sources. Limits for potable water are listed for comparison purposes only. Indicative values are provided for both boilers and cooling towers. It is important that service providers are consulted regarding feed water quality to avoid equipment damage.

Further information can be found in *Guidance for the use of recycled water by industry* (ISI, 2008) and *Guidelines for Water Reuse* (USEPA, 2012).

Table 7. Water quality characteristics for boiler or cooling tower feed

Water Quality Characteristic	Direct Contact (potable quality) Meets ADWG[1] Upper limit (unless stated otherwise)	Non-Contact	
		Boilers[5]	Cooling towers[2]
Units	***mg/L***	***mg/L***	***mg/L***
Microbiological (other than legionella)	See section 5.2.1	HPC < 100,000 CFU/mL[2]	
Legionella	n/a	n/a	< 10 cfu/ml[2]
pH	6.5 – 8.5	7.5 – 9.5	6-8.5 depending on construction material[3]
Total Dissolved Solids	600	<2000	300-2500[3] and up to 8000[4]
Oil & Grease	-	Not detectable	Not detectable
Ammonia	0.5	Refer supplier	Refer supplier
Nitrite	3	Refer supplier	Refer supplier
Nitrate	50	Refer supplier	Refer supplier
Hydrogen Sulphide	0.05	Refer supplier	Refer supplier
Dissolved Oxygen	> 85% saturation for aesthetics. No guideline for health consideration	<0.05	n/a
Chloride	250	n/a	Up to 1000 ppm depending on construction material [4]
Hardness (as $CaCO_3$) max	60 - 200	5-10	800-1000[4]
Turbidity	<0.2 NTU is the target for effective filtration of Cryptosporidium and Giardia <1 NTU is the target for effective disinfection >5 NTU is noticeable	n/a	n/a
Taste/odour	Inoffensive to consumers	n/a	n/a
Colour (aesthetics)	15 HU	n/a	n/a
Temperature	n/a	n/a	Refer supplier

[1] (NHRMC, 2011)
[2] AS/NZS3666.3, 2011
[3] Hydrochem, 2016. [4] Mesan, no date.
[5] AS 3873 (2001). Range for 2 MPa fire tube and water tube boilers

6.0 RECYCLING TECHNOLOGY AND COST ASSESSMENT FOR POTABLE RECYCLED WATER

This section evaluates the technological issues associated with upgrading treated meat processing effluent to potable quality for direct potable recycled water reuse for three options:

- Substitution of all possible town potable water within a facility;
- Substitution of town water feed to boilers; and
- Substitution of town water feed to condensers or cooling towers.

It explores the degree of wastewater treatment recommended to provide treated effluent suitable as feed to an Advanced Water Treatment Plant (AWTP). The components and performance of a best practice AWTP are reviewed and commentary provided on alternate technologies. Finally, a concise cost benefit analysis for AWTPs processing typical Australian meat processing effluent flows are presented to examine the economics of DPR.

6.1 Pre-Treatment Prior to Reuse Plant

Australian meat processing plants have a variety of wastewater treatment plants (WWTP). These typically fall into one of three categories:

1. **Traditional pond systems**. Many small to medium sized plants operate traditional pond based systems with subsequent disposal to land irrigation. These systems comprise some primary treatment (screens, screw press, saveall, perhaps DAF) followed by anaerobic and aerobic (facultative) ponds. This system typically reduces organic contamination to low levels (BOD_5 ~ 10 – 50 mg/L), but the final treated effluent contains high nutrient (nitrogen, phosphorus) concentrations, elevated levels of TSS often due to algal growth and significant microbial load.
2. **Urban confined systems**. Meat plants located in urban settings or industrial parks with little or no land available for effluent irrigation typically adopt more rigorous primary treatment in which a chemically dosed dissolved air flotation (DAF) unit is used after equalisation, screening and/or screw press treatment to reduce contaminant levels to achieve compliance with sewer discharge standards. The discharged effluent is usually still strong with high BOD (~ 300 – 600 mg/L), nitrogen (TN ~ 100 mg/L), TSS, oil; & grease concentrations and significant microbial load. In a few circumstances, and where land is available, some degree of biological treatment may occur.
3. **Advanced Nutrient Removal Systems / Biological Nutrient Removal**. An increasing number of Australian meat processing plants have installed sophisticated WWTP which include rigorous primary treatment followed by anaerobic treatment usually in Covered Anaerobic Lagoons (CAL), and subsequent activated sludge treatment including biological nitrogen removal and phosphorus reduction through chemical dosing. Disinfection is rare. These systems produce a high quality treated effluent with reduced nitrogen and phosphorus levels, negligible organic (BOD_5 < 10 mg/L), TSS and oil & grease levels. For most, the microbial load remains significant but less than the above systems. The effluent is disposed of by the full variety of choices including land irrigation, sewer or surface water discharge.

Only meat processing plants with the latter type of WWTP can realistically consider direct potable reuse since the levels of nutrients and other contaminants in the treated effluent from traditional pond or urban confined systems are too high for AWTP processing except in the relatively few instances where urban confined systems have subsequent nutrient removal processes. This in no manner precludes these systems from non-potable reuse of treated effluent in their operations, but this is usually limited to a few external uses.

6.2 Description of an AWTP

Many AWTP have been installed both overseas and within Australia to provide potable or near potable (e.g. Class A+ salinity reduced) quality recycled water for industrial facilities or communities. SE Queensland installed several AWTPs during the millennial drought, although some have been mothballed.

The dominant technology for AWTP is membrane processing using a combination of ultrafiltration (UF) or microfiltration (MF) as a first membrane step followed by reverse osmosis (RO). AWTP of this type are cost effective, proven and validated on both municipal and industrial scale. This treatment methodology is shown in **FIGURE 2**. Slight variations on this treatment train do exist at facilities where the source water vastly differs from standard BNR effluent, or if the treated water is being used in specialised equipment. As mentioned in Section 6.1, the minimum pre-treatment consists of advanced biological treatment – usually activated sludge based in Australia – incorporating nutrient removal.

6.2.1 Coarse Filtration

The first step usually consists of a fine filtration process (FT-01) to remove suspended solids from the wastewater, such as bacterial floc that may have carried over from the secondary treatment. The filter is periodically backflushed with the filter permeate water; this backflush is sent back to the head of the secondary treatment system. The coarse filtration process is important to limit the requirement for frequent backflushing and cleaning of the downstream membrane processes.

Municipal plants typically use dual media filtration (DMF) as the preferred option in view of its economies of scale at the large flows typical of these plants. Industrial AWTPs utilise a variety of options including DMF, dissolved air flotation filtration (DAFF) or cloth filter disk (CDF) systems – the latter due to their cost effectiveness at lower flows typical of industrial facilities.

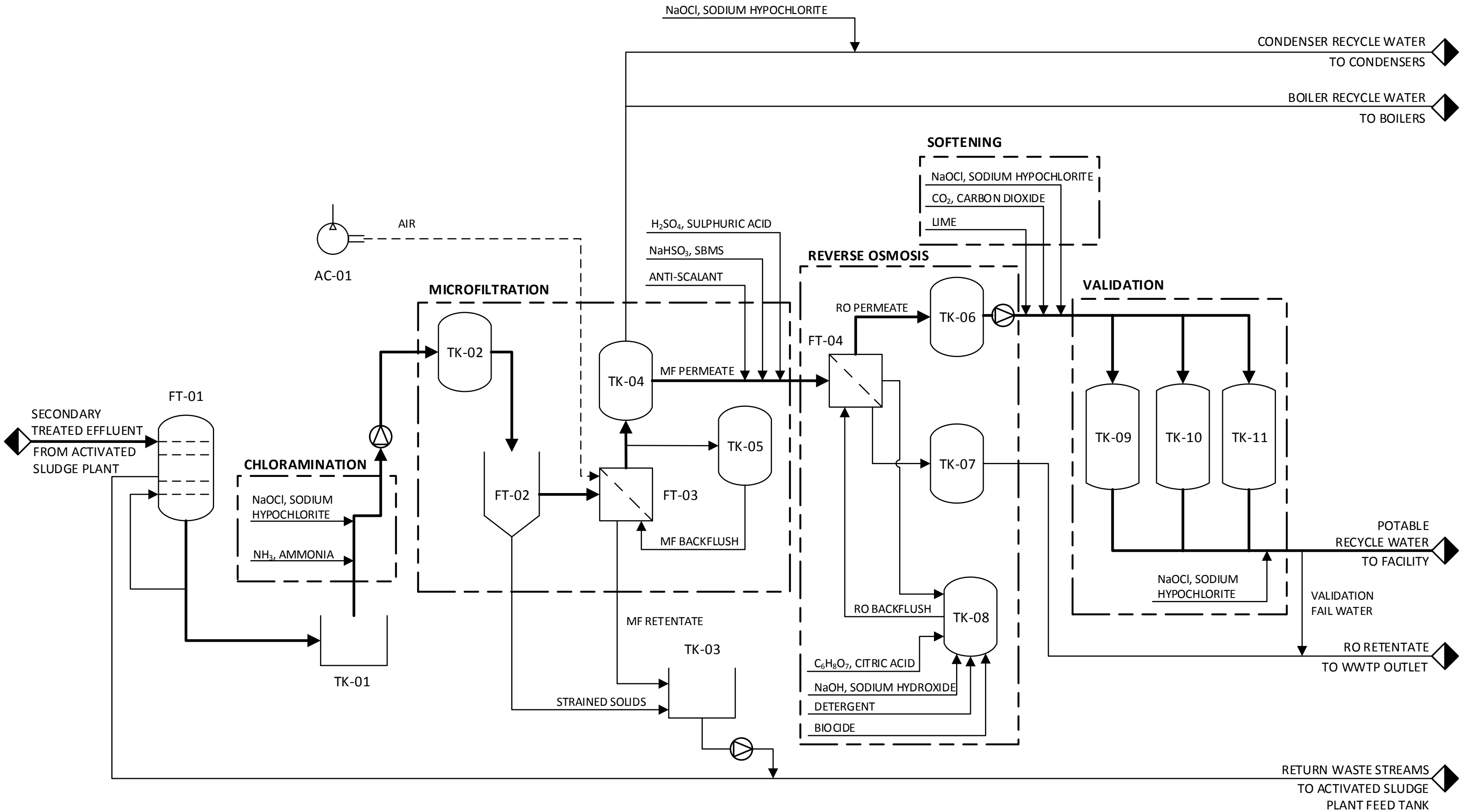


Figure 2: A Typical AWTP process diagram

6.2.2 Chloramination

Following coarse filtration, the water enters a pit (TK-01) before being pumped to the microfiltration section. The water is dosed in-line with aqueous ammonia (NH_3) and sodium hypochlorite (NaOCl) as the reagents for the chloramination process. The sodium hypochlorite reacts with the water to form hypochlorous acid (HOCl), which reacts in turn with ammonia to form either monochloramine (NH_2Cl), dichloramine ($NHCl_2$) or nitrogen trichloride (NCl_3). These chloramines are slow-reacting disinfectants, which are useful for preventing membrane bio-fouling in downstream filtration units, which is a key operating issue for AWTP. The other advantages of chloramines include excellent persistence and they do not damage membranes unlike other more aggressive disinfectants.

6.2.3 Microfiltration

Following chloramination, the water is pumped into the microfiltration (MF) feed tank (TK-02). From the MF feed tank, the water is fed via a strainer (FT-02) to the microfiltration unit (FT-03). The microfiltration unit acts as a protective barrier for the much more selective RO membrane downstream with a pore size of about 0.03 – 10 µm. It captures and retains algae, protozoa such as *Cryptosporidium* and *Giardia* cysts, large bacteria and any remaining suspended or colloidal material. Its performance is aided by the accumulation of a layer on the membrane which acts to filter smaller material.

Typically, the MF rack feeds effluent in parallel to numerous membrane modules operated in a dead end mode (i.e. retained material is retained by the membrane until backflushed, but there is continuous flow of liquid through the semi-permeable MF membrane (termed “permeate”).

Photo 1. MF rack processing treated effluent at Yatala brewery

Use of the microfiltration unit prevents rapid fouling on the RO membrane, resulting in less frequent cleaning and maintenance intervals.

Permeate water from the MF membrane enters the MF permeate tank (TK-04) and the MF backflush tank (TK-05). Once the pressure drop across the microfiltration membrane increases beyond a threshold level, it is backflushed with permeate water from the MF backflush tank to clean it. Compressed air (AC-01) is also used periodically to assist with cleaning. Retentate from the microfiltration combines with strained solids in a pit, from which they are pumped back to the feed tank for the activated sludge plant.

The microfiltration permeate water then enters either the reverse osmosis unit for further treatment, or it can be sent at this stage to boilers or condensers for immediate non-potable uses (providing that the water quality objectives for the respective uses outlined earlier have been met). Further disinfection may be required on the stream being used in condensers to ensure that there is a residual chlorine level, which inhibits growth of *Legionella* and other bacteria that may contaminate condensers. The water intended for boiler usage will need to pass through the boiler pre-treatment system for softening to ensure that there is minimal corrosion or scaling of boiler internals.

6.2.4 Reverse Osmosis

In the reverse osmosis system, sulphuric acid and/or sodium metabisulphite is added for pH correction and dechlorination, respectively. Anti-scalant may also be added to prevent scaling of the RO system if deemed necessary. Immediately prior to the reverse osmosis membranes, cartridge filters can be used as a final protection of the membranes, in the event that there is a breakdown of the MF membrane.

The RO membrane (FT-04) acts in a similar manner to the microfiltration membrane, but with a much smaller pore size, making it much more effective at removing dissolved low molecular weight compounds. The RO unit removes virtually all microorganisms, including bacteria, viruses and helminths. Large compounds, salts and most ions are also retained. Water and other small compounds will pass preferentially through to the permeate side. The retentate or concentrate is sent to a tank (TK-07) before being discharged to the WWTP outlet as a waste stream with no further treatment. This stream will typically be saline since it contains the retained salts. Certain compounds – such as ammonia or *N*-Nitroso-dimethylamine (NDMA) – can pass through with the permeate to a degree.

RO units are generally modular and stacked into membrane racks. Feed is applied in a crossflow mode in which feed is continually passed across the membrane surface at high velocity to minimise the build-up of a fouling layer.

The majority of the RO permeate stream is sent to the RO permeate tank (TK-06). A smaller fraction is sent to the RO CIP tank (TK-08), where it is dosed with a number of chemicals to assist with cleaning the RO membrane. These chemicals can include citric acid to break down inorganic fouling, sodium hydroxide for pH correction, as well as a surfactant and biocide. The main permeate stream is then softened prior to entering the validation section.

6.2.5 Softening

The RO permeate product water is typically highly aggressive since it lacks alkalinity and is acidic (typically pH 5-6). This makes it corrosive to metal piping and pipe fittings.

Consequently, it is usual to soften it for example with the dosing of carbon dioxide (CO_2) and lime $Ca(OH)_2$ into the water as it is pumped from the RO permeate tank into the validation tanks. This is done to correct the pH from slightly acidic conditions to neutrality and to re-mineralise the water. Post softening, chlorine (in this example, in the form of sodium hypochlorite) is added to provide a free chlorine residual. This ensures that microbial regrowth through the validation tanks and pipe system is controlled. It is also able to be monitored.

6.2.6 Verification

For the production of potable recycled water for direct reuse such as in this instance, it is necessary to ensure that the water complies with quality specifications and is safe to use. Usually this dictates a "batch lot" system which can be sampled, tested and verified as fit for use. This might consist of a number of storage tanks (TK-09, TK-10, TK-11) that cycle through the 3 stages of batch verification:

- Filling
- Verification
- In-use

In a typical system, the first tank may be in the 'filling' stage. This means that it is continuously being fed water from the AWTP. The second tank would be in the 'verification' stage, in which water samples are collected and awaiting verification from a laboratory that the product water meets the relevant specifications. The third tank would be in the 'in-use' stage, meaning that the water in this tank has been found acceptable for use and is currently being supplied to the facility after disinfection for its end use.

The tanks sequence through each stage. Once the results from laboratory reveal that the 'verification' tank has passed the relevant specifications, it can replace the emptied 'in-use' stage, which then becomes the 'filling' tank. The previous "filling" tank is now full and becomes the 'verification' tank and so on.

If the results from the laboratory for a particular batch of water have detectable microbial levels or chemical levels above acceptable thresholds, that particularly batch of water will be dumped and not used in the facility as potable water.

6.3 Alternate Technologies for AWTP

There are few if any alternate technologies for producing potable recycled water other than that shown in Section 6.2. Membrane processes dominate due to their robustness, low cost, proven performance and extensive validation over several decades. Nevertheless, there are optional elements that may suit particular applications. These are summarised in **Table 8**.

Table 8: Summary of alternate technology options

Type	Principal pollutants removed	Comments
Combined Secondary/Tertiary		
Membrane Bioreactors	BOD, TSS, microorganisms, nutrients	Combines activated sludge and membrane separation variation of MBR
Tertiary Treatment		
Membrane Distillation	BOD, TSS, salt – Na, Ca, Mg	Alternative to RO treatment
Electrodialysis	BOD, TSS, salt – Na, Ca, Mg	
Advanced oxidation technologies: H_2O_2/UV & Ozone/ H_2O_2	Barrier against NDMA, pharmaceuticals and endocrine disrupters	UV Oxidation used in the Bundamba Advanced Water Treatment Plant
UV photolysis	NDMA, BOD	
Treatment of cooling tower feed		
Hydrocavitation	bacteria, control of scaling and corrosion in cooling towers, condensers	Hydrocavitation system currently in use on cooling towers at Golden Circle, Queensland

Membrane bioreactors have not been trialed in Australian red meat processing plants but are in widespread use in the smaller sewage treatment systems. Their use of ultrafiltration membranes to replace traditional settling and clarifier systems in activated sludge treatment potentially offers a first stage membrane process to replace MF in **FIGURE 2**. Potentially, the treated effluent from the MBR could be processed through a RO system to provide potable quality recycled water.

Advanced oxidation process (AOP) technologies are increasingly used post RO to eliminate organic compounds passing through RO membranes (Photo 2). The usual test compound is the carcinogenic NDMA with a molecular weight of 74 g/mol, which may be formed at low levels via chloramination of nitrogen-containing effluents or as a byproduct of industrial processes including food manufacture. Approximately 50% of NDMA may pass through RO membranes. AOP processes are useful since the highly oxidising environment effectively destroys the residual organic contaminants remaining in the RO product water.

Photo 2. TiO2/UV advanced oxidation process treating reverse osmosis product water

6.4 AWTP Treatment Performance

6.4.1 Microbial Hazard Reduction

Current risk assessment protocols recommended for the evaluation of the required treatment performance of WWTP and AWTP systems tend to identify a design minimum logarithmic (log) reduction in the population of a given microbial hazard. As noted in Section 5.1.2, these design log reductions are determined from a knowledge of the microbial hazard load in the raw wastewater and the performance of treatment technologies.

For a non-potable recycled water use such as boiler feed water or condenser makeup, the reuse equivalent in the NRMMC (2006) guideline might be "Municipal use – open spaces…unrestricted access & application" (Table 3.8). The guideline recommends the following log reduction targets for this use:

Virus: 6.0 log reduction;
Protozoa: 4.5 log reduction; and
Bacteria: 5.0 log reduction.

For direct potable recycled water, more stringent design target is required. The values developed in Section 5.1.2 are:

Virus: 9.5 log reduction;
Protozoa: 8.0 log reduction; and
Bacteria: 8.1 log reduction.

The NRMMC approach is predicated on processing raw human sewage for recycled water uses. Provided human amenities sewage is not entering the process WWTP at the meat processing plant, the virus target above probably merits reduction since viruses are host specific and bovine viruses pose negligible threat to human health.

Table 10 shows the indicative log removals of enteric pathogens and indicator organisms achieved by treatment processes used in the WWTP and AWTP (NRMMC & EPHC, 2006 Table 3.4). By the combined use of multiple barriers and different treatment technologies in sequence, it is possible to achieve the target log reductions required for the various microbial health hazards. The use of MF and RO in sequence is critical to this. Microbial performance specifications have been reported as shown in **Table 9**, however, removal rates vary dramatically depending on the installation and maintenance of the membranes (USEPA, 2012).

Table 9: Microbiological removal Performance of membranes (USEPA, 2004)

	Pore size	Performance
Microfiltration	0.05 µm	3-6 log reduction of bacteria
Ultrafiltration	0.002-0.05 µm	complete removal of protozoan cysts and bacteria and 4-6 log reduction for viruses
Nanofiltration and reverse osmosis	<0.002µm	higher pressure required, complete removal of all microorganisms and also some dissolved organic and inorganic compounds.

Table 10: Indicative log removals of enteric pathogens & indicator organisms (NRMMC, 2006**)**

Type of Microorganism	Indicative log reduction[a]							
	Escherichia coli	Bacterial pathogens (including Campylobacter)	Viruses (including adenoviruses, rotaviruses and enteroviruses)	Phage	Giardia	Cryptosporidium	Clostridium perfringens	Helminths
Bacteria	X	X					X	
Protozoa and Helminths					X	X		X
Viruses			X	X				
Treatment								
Primary treatment	0-0.5	0-0.5	0-0.1	N/A	0.5-1.0	0- 0.5	0- 0.5	0-0.2
Secondary treatment	1.0-3.0	1.0-3.0	0.5-2.0	0.5-2.5	0.5-1.5	0.5-1.0	0.5-1.0	0-2.0
Dual media filtration with coagulation	0-1.0	0-1.0	0.5-3.0	1.0-4.0	1.0-3.0	1.5-2.5	0-1.0	2.0-3.0
Membrane filtration	3.5->6.0	3.5->6.0	2.5->6.0	3->6.0	>6.0	>6.0	>6.0	>6.0
Reverse osmosis	>6.0	>6.0	>6.0	>6.0	>6.0	>6.0	>6.0	>6.0
Lagoon storage	1.0-5.0	1.0-5.0	1.0-4.0	1.0-4.0	3.0-4.0	1.0-3.5	N/A	1.5-3.0
Chlorination	2.0-6.0	2.0-6.0	1.0-3.0	0-2.5	0.5-1.5	0-0.5	1.0-2.0	0-1.0
Ozonation	2.0-6.0	2.0-6.0	3.0-6.0	2.0-6.0	N/A	N/A	0-0.5	N/A
UV Light	2.0->4.0	2.0->4.0	>1.0 adenovirus >3.0 enterovirus, hepatitis A	3.0->6.0	>3.0	>3.0	N/A	N/A

N/A = Not available; UV= Ultraviolet

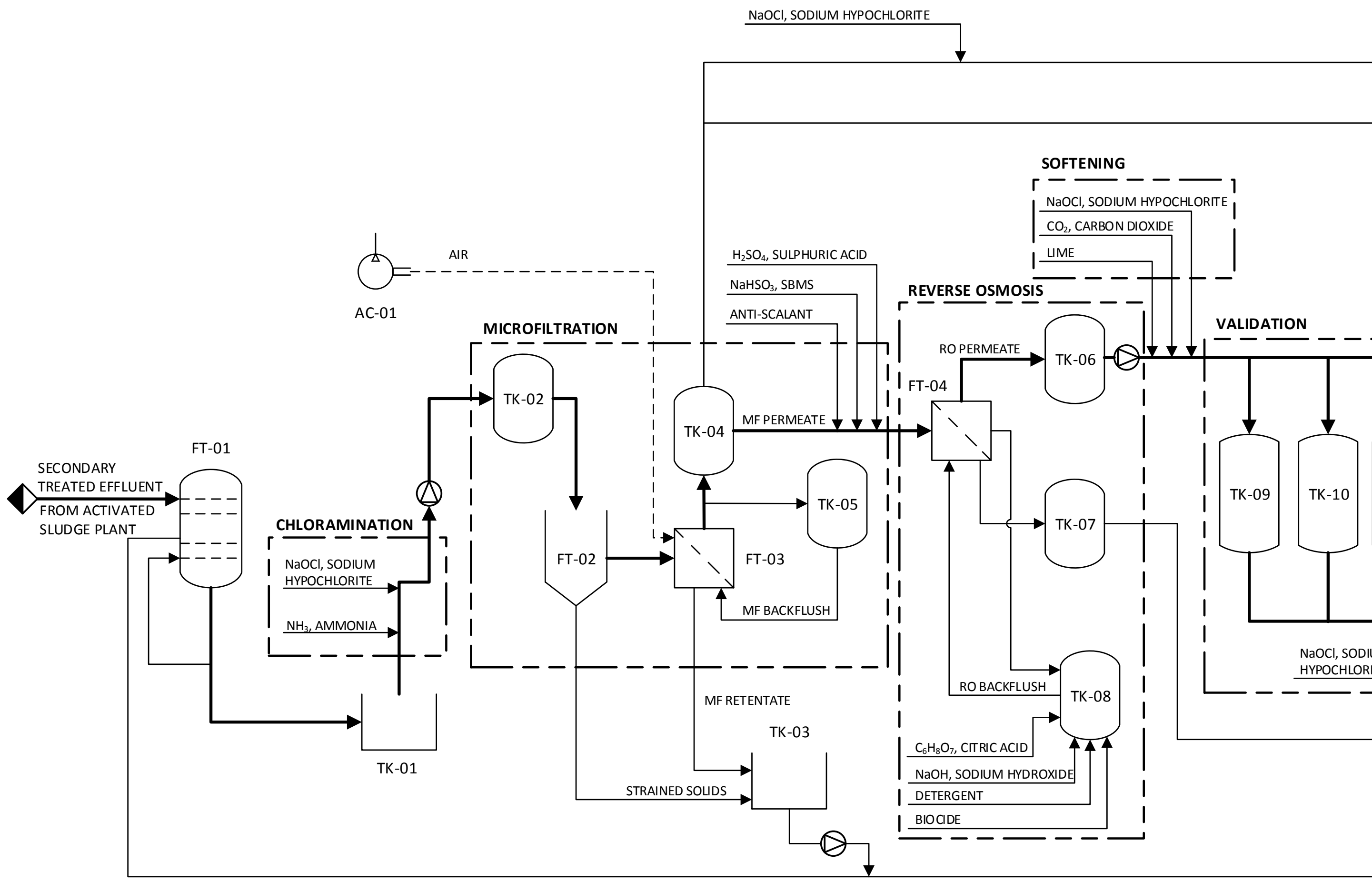
[a] Reduction depends on specific features of the process, including times, pore size, filter depths, disinfectant

Sources= WHO (1989), Rose *et. al.*(1996,2001), NRC (1998); Bitton (1999), USEPA (1999, 2003, 2004). Mara and Horan (2003).

6.4.2 Chemical Hazard Reduction

The advanced nature of the upstream WWTP is important in eliminating chemical contaminants from the feedwater (treated effluent) to the AWTP. As noted in Section 4.0, meat processing wastewater contains relatively limited chemical hazards due to the controls that exist to protect the integrity of the meat products manufactured at the facility. Consequently, it is rare to find significant levels of metals or organic contaminants such as pesticides or PCBs in the wastewater. A study of a variety of solid waste streams from four Australian meat processing plants in 2002 found negligible quantities of these components (MLA, 2001).

The target reductions will depend on the intended recycled water use. For boilers and condensers, it is possible that water treated up to and including microfiltration may suffice for the purpose, although the additional reduction in TDS by RO treatment certainly assists improved cycles of concentration in condensers. For potable recycling, it is crucial to ensure that chemical residues after the AWTP meet drinking water guidelines. In this instance, the use of RO provides significant benefit. Typical levels of BOD_5 and TSS are less than 1 mg/L and TN, ammonia-N and phosphate-P less than 0.1 mg/L after treatment by advanced WWTP incorporating nutrient removal and the AWTP shown in **FIGURE 2**



(NRMMC, 2006, Table A3.2).

6.5 Technology cost/benefit analysis

In addition to ensuring the technical viability of a proposed AWTP, the economic feasibility should be explored to ensure that the project represents a sound investment of capital funds. Different meat processing facilities face different economic conditions which impact upon the viability of the project in their region. To this end, a number of scenarios have been investigated in this CBA analysis. They aim to cover the gamut of possible economic conditions.

6.5.1 CBA Methodology

All scenarios were prepared using standard cost benefit methodology with annual time-steps out to 20 years of operation – the assumed plant life. Capital expenditure (CAPEX) for each scenario was spent over two years (the construction phase), before operation of the AWTP commences, resulting in positive savings in the form of reduced potable water intake and potentially reduced trade waste charges. Operational expenditure (OPEX) includes electrical power, cleaning and dosing chemicals, membrane replacement, operating labour and equipment maintenance. The savings and OPEX combine to form the Earnings Before Interest, Tax, Depreciation and Amortisation (EBITDA). Taxation, interest, depreciation and amortisation were not considered in this CBA. Strictly speaking, there are no actual 'earnings' associated with this project, but rather savings due to reduced expenditure. Nevertheless, the term 'EBITDA' will be used in this CBA.

The scenarios investigated are summarised in **TABLE 11**. They explore the impact of three major variables on the investment return on the AWTP. These are:

- Meat processing facility size as determined by daily wastewater generation. Three flows are used – 1, 3 and 5 ML/day. Many plants in Australia producing between 3 to 5 ML/day have the type of WWTP required.
- Purchase price for potable town supply water. The values of $3.50/kL and $2.00/kL represent values typically paid in Queensland and southern states respectively. Water prices are higher in Queensland, and this provides a greater incentive for meat processors there to invest in this technology.
- Whether trade waste charges (on volume only) exist on existing final effluent. Scenarios without trade waste charges assume the cost of disposal of the wastewater is negligible.

Table 11: CBA Scenarios

Number	Scenario
1	1 ML/day plant, paying $2.00/kL for potable water, no trade waste charges.
2	1 ML/day plant, paying $3.50/kL for potable water, no trade waste charges.
3	3 ML/day plant, paying $2.00/kL for potable water, no trade waste charges.
4	3 ML/day plant, paying $3.50/kL for potable water, no trade waste charges.
5	5 ML/day plant, paying $2.00/kL for potable water, no trade waste charges.
6	5 ML/day plant, paying $3.50/kL for potable water, no trade waste charges.

7	3 ML/day plant, paying $3.50/kL for potable water, plus $1.00/kL trade waste charges.

All scenarios assumed that the price of water increased at a rate of approximately 2% per year. A discount rate of 7% was applied to account for the time value of money. It was assumed that all plants operate for 240 days/year (48 weeks/year at 5 days/week) and that they already have an advanced WWTP capable of achieving the AWTP feedwater quality required. All scenarios include a water recovery rate of 70% (70% of the water fed through the AWTP can be recovered and recycled, 30% must be purged to the WWTP outfall). It is also assumed that 15% of the total water that is fed through the AWTP plant is recovered from the MF permeate (before RO treatment) and used for the boilers and condensers. This reduces the OPEX component for this fraction.

6.5.2 Overall CBA Outcomes

TABLE 12 outlines the results of the CBA in the form of capital costs, savings and OPEX (on a $/kL basis), payback period, annual net benefit and net present value (after 20 years of operation). The capital costs for each scenario were calculated based upon cost data kindly supplied by Prof. G Leslie (UNSW) which was scaled from the costs for the Kranji NEWater Plant (Singapore). Note that these capital costs do not include engineering, legal and administration costs or project contingencies (typically 20 – 40% of direct equipment cost). Operating costs were sourced from typical values for plants that are currently in operation.

Table 12: Capital Costs per Scenario

Scenario	CAPEX	Savings	OPEX	Payback period	Annual net benefit (initial)	Net Present Value (NPV)
	$	***$/kL***	***$/kL***	***years***	***$/year***	***$***
1	$4,300,000	$1.40	$0.93	N/A	$114,000	-$2,590,000
2	$4,300,000	$2.45	$0.93	18	$366,000	$290,000
3	$9,100,000	$1.40	$0.93	N/A	$342,000	-$4,320,000
4	$9,100,000	$2.45	$0.93	11	$1,098,000	$4,310,000
5	$12,900,000	$1.40	$0.93	N/A	$570,000	-$5,150,000
6	$12,900,000	$2.45	$0.93	9	$1,830,000	$9,240,000

7	$9,100,000	$3.15	$0.93	7	$1,602,000	$10,070,000

Note: The payback period refers to the number of years of operation only, and does not consider the time taken to construct the AWTP.

6.5.3 Impact of Facility Scale

Figure 3 shows the present value of Scenarios 2, 4 and 6. All 3 scenarios are for plants paying $3.50/kL for potable water with no trade waste charges. The difference is the size of the plants (1, 3 and 5 ML/day wastewater respectively). It is clear that the larger plants benefit from economies of scale relative to the smaller plant, despite the modularity of membrane processes forming the major part of the AWTP. Whilst savings are linearly proportional with plant throughput, the unit cost of equipment reduces as the plant increases in size. This indicates that an AWTP is best suited for larger meat processing plants. Even for the largest facilities (5 ML/day) at high input water cost, the payback is of the order of 9 years.

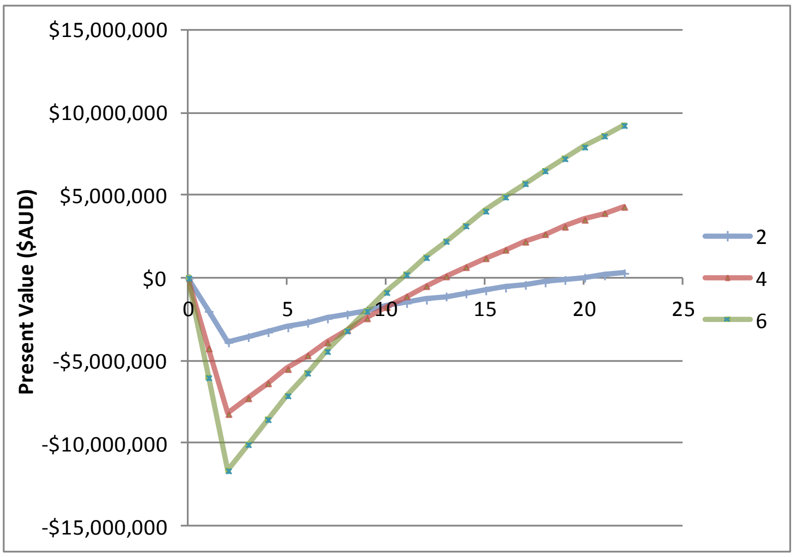


Figure 3: Impact of scale

6.5.4 Impact of Potable Water Intake Price

Figure 4 compares the net present value of Scenarios 3 and 4. These are for processing plants paying $2.00/kL and $3.50/kL for potable water, respectively. The difference in net present value over 20 years is striking and makes it clear that only plants that are paying high town water supply charges (i.e. more than $3.00/kL) are likely to find direct potable reuse economically attractive.

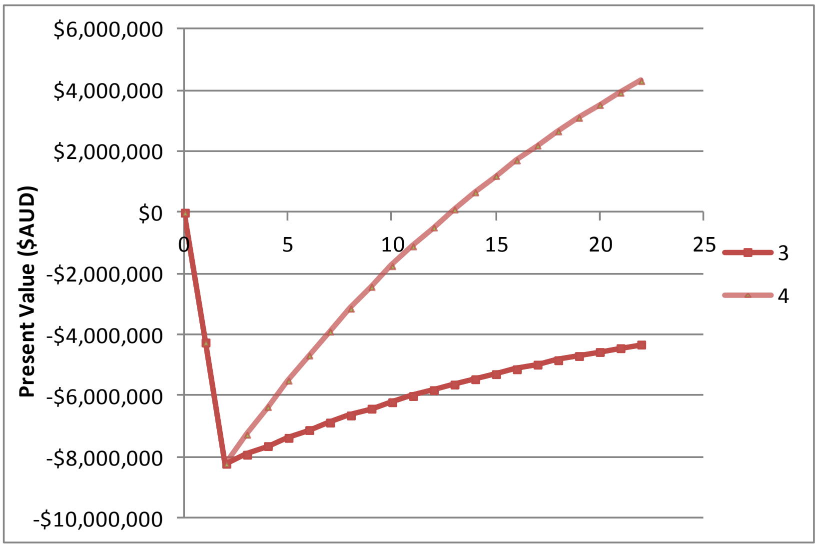


Figure 4: Impact of potable water intake price

6.5.5 Impact of Discharge Costs

Figure 5 contrasts the NPV for Scenarios 4 and 7. Scenario 4 represents a meat processing facility of 3 ML/day with no volumetric discharge costs for the wastewater (i.e. disposal to land or similar) whereas the Scenario 7 facility (also 3 ML/day) is charged $1.00/kL for disposal (ie. trade waste charges or similar). Both pay $3.50/kL for town supply intake. Again, there is a large difference in NPV over the project lifetime, with Scenario 7 having more than double the value of Scenario 4. This demonstrates the added benefit of an AWTP where discharge charges are high.

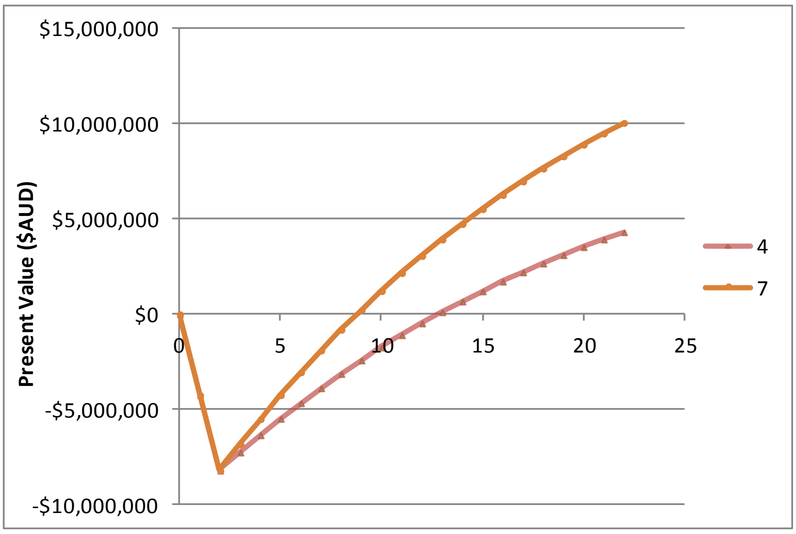


Figure 5: Impact of discharge costs

7.0 HAZARD IDENTIFICATION AND RISK ASSESSMENT

The success of a risk mitigation plan is dependent on careful and accurate definition of the hazards likely to be present in the feed water to both the wastewater treatment plant (WWTP) and the recycled water treatment plant and the initial concentration and variability in concentration of each hazard. This needs to take into account mitigation barriers earlier in the system (e.g. source control, etc). Hazards and risk are defined in the following terms (NRMMC, 2008):

- a hazard is a biological, chemical, physical or radiological agent that has the potential to cause harm;
- a hazardous event is an incident or situation that can lead to the presence of hazard (what can happen and how); and
- risk is the likelihood that identified hazards will cause harm in exposed populations. In the case of meat processors, this is meat processing staff and consumers of meat product.

A risk assessment needs to consider and document:

- The likelihood and impact of each identified hazard in order to calculate the risk for that hazard;
- The cut-off threshold for significant risks; and
- any existing management systems e.g. existing HACCP certifications held by meat processors.

Specific considerations for hazard and risk assessment are described in the following sections.

Note: Much of the detail in undertaking a risk assessment is provided in The Recycled Water Management Plan for Red Meat Processors. This document provides a suggested hazard identification and risk assessment process which can be adapted for use by specific sites.

7.1 Methodology

Risk management focuses primarily on preventing hazardous events from occurring rather than mitigating the impacts once they have occurred. AS/NZS31000, 2009 presents the generic principles, framework and process to be applied to risk management for any undertaking or organisation. The principles and framework relate to the values and internal arrangements that embed risk management within an organisation, while the process sets out the basic steps for a logical and consistent methodology which can be adapted to most situations (DEWS, 2008).

Any risk management methodology can be used as long as it is consistently applied. A suggested methodology for meat processors is provided in the RWMP. The agreed risk management methodology should be clearly documented. While the specific methodology may vary, the main elements of hazard identification and risk assessment should be addressed, as outlined in the following sections.

Risk assessments of industrial facilities are expensive, especially since a highly skilled and experienced risk team needs to be engaged. Where reuse of treated water back to the facility for high level uses is planned, it is likely that external experts with excellent credentials will be essential to convince customers, unions and Government regulators that the hazard identification and risk mitigation assessments have been performed to an appropriate level. These experts typically need to have process engineering (especially wastewater and advanced water treatment), risk assessment and specific hazard knowledge skills coupled with experience in the industry. The external experts can then work with internal risk team members to conduct hazard identification (See Section 4.0).

Often a two-step hazard assessment is useful in controlling the cost of the process and minimising the danger of the team becoming bogged down in minor detail (NRMMC 2006):

- Step 1 scans the full list of potential hazards identified coupled with the best data concerning levels and variability in the proposed wastewater feed to the reuse process (WWTP & AWTP). A rapid initial assessment by the risk team can then eliminate hazards considered to pose low or negligible risk (or those that would be mitigated by controls for other more significant hazards).
- Step 2 then focusses a more detailed risk assessment on the remaining hazards considered to pose the higher threat to safe reuse.

The risk assessment team is responsible for completing the identification of potential hazards and the risk assessment, and may also be further involved in the development and implementation of the RWMP. Members should include personnel from operations, quality control, laboratory, maintenance, management, and DAFF (e.g. meat inspectors) where applicable. At least one member of the risk assessment team should have formal risk assessment training or equivalent experience or skills, and this should be documented (DEWS, 2008). The remaining members of the team should receive an introduction to the risk assessment process, prior to commencing the risk assessment.

7.2 Hazard identification

Hazards are identified and documented beginning with source water characterisation and then at each step of the treatment, storage and use of recycled water. All potential hazards must be identified at their introduction to the process. They may relate to human or environmental health or financial impacts. The most significant human health hazards will be microorganisms capable of causing illnesses, however biological, chemical and physical factors should be considered. Secondary to this is the identification of hazards which pose a risk for non-contact uses. A discussion of likely and potential hazards relevant to meat processing is included in Section 4.0 of this document. Consideration should also be given to variability of potential hazards to ensure seasonal and intermittent hazards are captured.

7.3 Hazardous events

Hazardous events are those that may result from or lead to the presence of a hazard. These can vary from process failure to human error or unauthorised use of recycled water. The hazardous events identified and their sources or where they may occur in the process are documented.

7.4 Unmitigated risks

Here, a record is made of the level of unmitigated risk, also known as maximum risk, estimated for the identified hazards and hazardous events in the absence of any preventive measures. An initial screening-level risk assessment may be used to screen out very low risk hazards, allowing more detailed qualitative or quantitative risk assessment processes to focus on hazards of most relevance to the scheme.

7.5 Significant risks

Once all hazards and hazardous events have been assessed in terms of unmitigated risk, the analysis team should agree to and document the cut off for significant risk. The cut off distinguishes between what is and is not considered an acceptable level of risk. Significant risks will determine management priorities and generally be the focus of the critical control points.

7.6 Uncertainty levels

Some level of uncertainty is inherent in the estimation of risk. The degree of uncertainty will depend on the variability of the hazard itself within the system, and the comprehensiveness and reliability of available knowledge and data. Understanding the uncertainty associated with hazards may assist in identifying measures that may be implemented to moderate hazard variability, or targeted research to address knowledge deficiencies. Here, documentation is undertaken for the main sources of uncertainty for each hazard and hazardous event to contextualise future risk assessments and inform research and development programs.

7.7 Control measures and residual risk

In this step, the existing control measures and multiple barriers that prevent significant hazards from being present in the recycled water and hazardous events from occurring are identified. Subsequent residual risk rankings are assigned to each significant risk.

Where the existing measures identified do not sufficiently mitigate significant hazards, alternative and additional control measures should be identified that ensure residual risks are reduced to acceptable levels. Detail should be provided regarding specific preventive measures and strategies addressing each significant risk. Relevant procedures should be attached or referred to if required. For dual reticulation schemes, detail of measures to prevent and control cross connections, such as audit programs, should be included.

8.0 OPERATIONAL CONTROL

Note: A detailed example of the identification of critical control points, critical limits and alert levels is provided in the accompanying RWMP.

8.1 Critical control points

Critical control points (CCPs) are control measures that are essential in removing significant hazards or reducing them to an acceptable level, and for which performance efficacy can be monitored and controlled. Failure of a CCP is likely to require the scheme to be shut down or cease supply until corrective action can be taken.

Quality control points (QCPs) are also important in controlling significant hazards, but are not key mechanisms for assuring effective hazard removal, either because the hazard will be sufficiently mitigated at a subsequent process step, or because performance is not able to be adequately monitored and controlled to enable a timely response to any failures.

A decision tree which has been adapted from the AGWR (DEWS, 2008) is used to identify Critical Control Points (CCPs) and Quality Control Points (QCPs). Each process step within the system is assessed with respect to significant hazards (those with an unmitigated risk of moderate to very high) using this decision tree (**Figure 6**). **Table 13** shows examples of potential critical control points and monitoring parameters in meat processing.

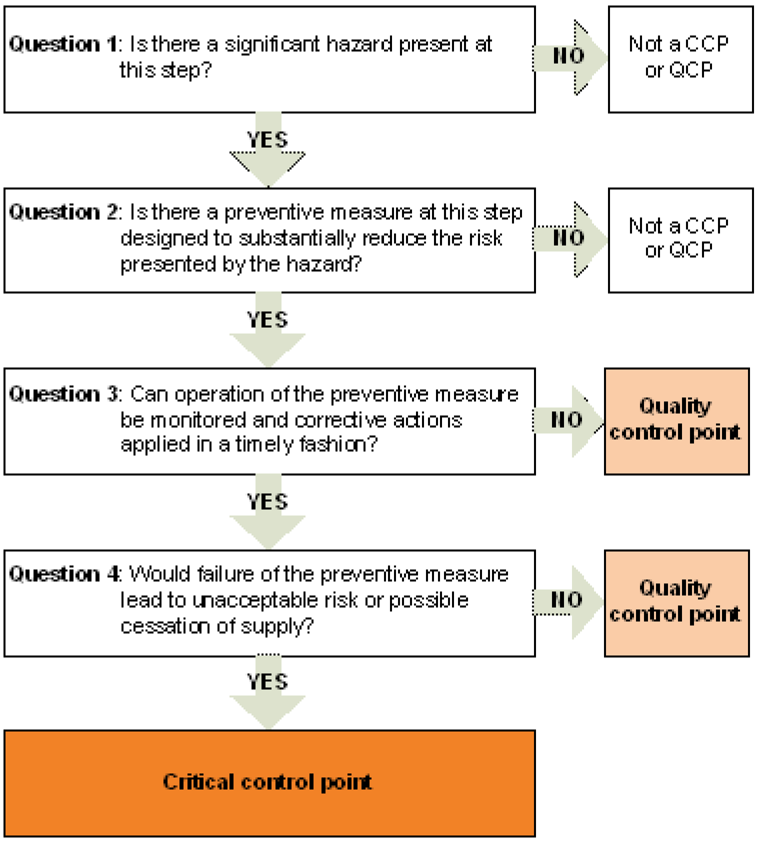


Figure 6: Decision Tree for identifying critical and quality control points

Table 13: Examples of potential critical control points and monitoring parameters (adapted from NRMMC, 2008)

Potential critical control point	Hazards	Potential critical limit parameters

Membrane filtration	Pathogens	• Transmembrane pressure • Pressure-based tests • Total organic carbon • Turbidity or particle counts • Flux
Reverse osmosis	Chemical Pathogens	• Transmembrane pressure • Total organic carbon • Flow meters on permeate and brine • Conductivity on permeate and brine
Advanced oxidation	Organic chemicals Pathogens	• UV light dose & transmissivity • Hydrogen peroxide dose rates • Oxidation reduction potential • Turbidity • Flow rate
Disinfection and storage	Pathogens	• Disinfection residual or dose • Time/concentration (Ct) • Temperature • pH

8.2 Critical limits

Critical limits define the operational tolerance levels for monitoring the performance of critical processes. Operation within critical limits indicates the process is functioning effectively to remove the relevant hazards and produce water of acceptable quality. Critical limits should be exact values, not a range. Here, record is kept of the operational monitoring parameters and critical limits identified for each critical control point and the corrective actions required when these limits are deviated from.

8.3 Alert levels

Target criteria, alert levels, or early warning systems for the scheme should also be identified, along with details of corrective actions that will be undertaken in response to deviations from the target criteria to prevent exceedance of critical limits. See the RWMP for a detailed example with alert levels.

9.0 MONITORING

Establishing a risk-based recycled water management scheme requires varying stages and levels of monitoring. Baseline monitoring is undertaken before establishing a recycled water system, whereas validation, operational and verification monitoring are undertaken in establishing and running such a system. Types of monitoring are as follows with examples shown in **Table 14** (NRMMC, 2008):

- // Baseline - gather information that will underpin the risk assessment process, and provide a basis for assessing potential impacts of the use of recycled water. This includes source water characterisation and hazard identification as per Section 7 of this document.
- // Validation - obtain evidence that the elements of the recycled water quality management plan will achieve performance requirements. Refer to Section 10 of this document for further details.
- // Operational - conduct a planned sequence of observations or measurements of control parameters to assess whether a preventive measure is operating within design specifications

and is under control. Refer to Section 9 of this document.

- Verification – apply final methods, procedures or tests to determine compliance with water quality standards prior to release for end use. Refer to Section 6.2.6 and 12.0 of this document.

Table 14: Indicative monitoring requirements (NRMMC, 2008)

Type of monitoring	Location	Parameters	Frequency
Baseline	Treated wastewater	Pathogens or reference pathogens Chemicals	Source waters to be frequently monitored e.g. weekly for pathogens or indicators and on a monthly basis for chemicals, for several months, to establish the range of hazards
Validation	Pre-commissioning & commissioning trials (sampled after process being validated)	Target parameters i.e. pathogens, chemicals, other. Operational monitoring indicators and surrogates (see below)	Sufficient frequency to prove effectiveness of the process against target compounds, in a statistically valid manner
Operational	On-site	Process specific monitoring of activity, surrogates and indicators	Mix of continuous and manual monitoring as required
Verification	At point of supply of potable water	Microbial indicators: Chemicals: Disinfection byproducts Biological monitoring	e.g. Microbial indicators Tested 3 times/week Chemicals: monthly Disinfection byproducts: monthly Biological monitoring: Monthly

With respect to laboratory analysis, preference is for a laboratory that is National Association of Testing Authorities (NATA) accredited. Where a NATA accredited analysis is not used the processor should supply documentation of the methodology including the quality assurance (QA)/quality control (QC) procedures used to perform this analysis.

10.0 SCHEME VALIDATION

The following section on validation is as described in DEWS (2008). Validation is the process of proving that the recycled water system will be capable of consistently achieving the performance objectives and meeting the minimum water quality criteria identified for the scheme. Three phases of validation need to be addressed:

- pre-commissioning validation – generally undertaken during the planning and design stage to determine the combination of treatment components that will be required to meet the required water quality;
- commissioning validation – confirms that selected components perform as expected when operating as part of the treatment system; and
- commissioning verification – testing of final product water to show that the system as a whole produces the expected water quality.

Revalidation may need to occur at later stages in response to significant changes to the scheme or operating conditions (refer to 10.2 below).

10.1 Validation methodologies

Within each of the validation phases, there are numerous methodologies that may be used to demonstrate system performance. Appropriate methodologies depend on the type and complexity of scheme, the chosen technologies and hazards being addressed. These methodologies are briefly described below. A crucial point is that any one of these methodologies should not be solely relied on and it is suggested to use a points system to determine which of these methodologies might be used (discussed below). For further information, see DEWS (2008).

10.1.1 Pre-commissioning validation

- *Historical Data* - evidence should be provided that historical data is directly applicable to the treatment process and operating conditions for the scheme. A report should be prepared compiling all historical data including information on data source, summary of results, rationale and relevance for inclusion of the data.
- *Scientific Literature* – include a reference list and evidence that the scientific literature is directly applicable to the treatment process and operating conditions for the scheme. For meat processing plants it will be initially challenging to find information directly relating to industry effluent reuse, but the ample literature developed for reuse of sewage treatment plant treated effluent, much of it Australian, should be suitable.
- *Manufacturers Specifications* – these should be critically reviewed including provision of references, details of manufacturers testing methodology, information on pilot tests and evidence that the manufacturers specifications are applicable to the treatment process and operational conditions.

10.1.2 Commissioning validation

- *Pilot plant* – provide evidence that the pilot plant is comparable to a full-scale plant for example, comparison or volumes, pressure, size of treatment component and types of treatment components. Note that the use of standard technologies for AWTP (MF, RO, etc) should permit full-scale plant design and construction with minimal need for pilot scale work.

However, pilot studies may be needed if alternate technologies are being considered.

- *Specific challenge testing* – this involves inoculating influent to a treatment process with a known quantity of micro–organisms or a known concentration of a chemical and then testing the treated water to determine how much is removed by the treatment step. Testing should be done by a third-party. For meat processing AWTP, careful scoping of this testing is recommended since most independent third party validation teams will have lots of sewage effluent experience but little if any experience with meat processing. Consequently, the scope for viral challenge testing could be scaled back in view of the low risk from host specific viral loads. In contrast, higher emphasis might be placed on bacterial challenge testing.
- *On-site tracer studies* – e.g. use of dyes or microspheres (tracers) to determine detention time and effectiveness of treatment processes with respect to possible hot/cold spots, leaks, short circuits and other. These studies could be considered part of the vendor supply contract to prove compliance with design values.
- *Direct integrity testing* – testing the integrity of membranes by use of physical tests such as pressure-based and marker-based tests. Again these should be performed under a performance contract with key equipment vendors.
- *Continuous indirect integrity testing* - monitoring of some aspect of filtrate water quality as a surrogate measure of membrane integrity e.g. turbidity, particle counts or conductivity. This is typically built in through in-line monitoring equipment.

10.1.3 Commissioning verification

This involves monitoring of final water quality. An intensive monitoring campaign will be required once the AWTP begins to operate to ensure that the facility is achieving the required final water quality. During this time, the water is usually dumped, or used for non-potable uses. The campaign is typically a combination of in-line monitoring using the sensors installed in the AWTP and off-line monitoring of identified hazard levels in the final product water. A thorough final report should be prepared that describes the full list of microbial and chemical hazards monitored and information on the commissioning verification test methodology and results. Evidence should be supplied that demonstrates that the treatment system is reliable and robust and the scheme is able to consistently provide the required water quality prior to supply to the user. See DEWS (2008) for further information.

10.1.4 Points system for designation of validation technologies

DEWS (2008) details the main types of validation and suggests a ‘points system’ as a guide to selecting suitable combinations of validation methods for different scheme types. This is shown in **Table 15**. As a suggestion, for validation of a system that produces potable quality water, a total score of 14 could be sought, while for non-contact uses a total score of 11 could be sought. Allocated points are indicative only.

Table 15: Validation methodologies and point allocation

Validation stage	Method	Point allocation	Direct contact supply	Non contact supply
Pre-commissioning validation	Historical data	1	1	1
	Scientific literature	1	1	1
	Manufacturers specifications	1	1	1
Commissioning validation	Pilot plant	3		
	Challenge testing	3	3	
	Tracer studies	3		
	Direct integrity testing	3		
	Continuous indirect integrity testing	3	3	3
Commissioning verification	Monitoring of final water quality	5	5	5
Total			14	11

10.2 Validation program

The validation program documents how the performance of the recycled water scheme will be assessed. It contains information about the methodology to be used to validate each component, as well as the system as a whole. Outcomes from the validation program should be incorporated into the detail of the RWMP for all schemes.

10.2.1 Validation of treatment processes

The process for validating the individual treatment processes that contribute to the required water quality objectives should be documented. Although the methodology may vary, for each process the following should be addressed:

- identify target pathogens;
- specify log reduction requirement;
- identify the methodology to be used to demonstrate log reduction; and
- provide analysis of data or evidence to show that the required log reduction can be achieved.

AMPC

10.2.2 Verification of final water quality

As well as individually validating process units, results of final water quality monitoring should be assessed to confirm that overall system performance is adequate to meet the water quality criteria (commissioning verification).

10.2.3 Validation of critical limits, operational limits and corrective actions

In conjunction with validation of treatment processes and final water quality, critical limits and associated corrective responses should be validated to demonstrate that:

- the system is capable of consistently operating within the set limits;
- the limits effectively indicate the corresponding control measure is performing at a level to achieve the required hazard removal; and
- operating within critical limits ensures recycled water quality criteria are met at the verification step.

This stage needs to demonstrate that the critical limits, operational limits and corrective actions can be consistently achieved, and are set at a level appropriate to ensure the required treatment performance.

10.2.4 Validation report

The validation program should be documented in a report that details the following for each item being validated; this may be in a separate report appended to the RWMP:

- the aim of the validation;
- the methodology used;
- the results of the validation undertaken;
- the conclusion of the validation, that is, whether the aim of the validation was met; and
- a summary of outcomes from the validation program.

10.2.5 Revalidation

Throughout the life of the scheme, significant changes to operating conditions or processes may occur that necessitate revalidation of individual processes and the system as a whole to ensure that water quality objectives can still be consistently achieved under the altered conditions.

Document scenarios that may occur that will trigger revalidation of systems or processes. Types of changes to the scheme that may be considered include:

- wastewater quality, e.g. new or increased concentrations of hazards detected; or a new process development that impacts on wastewater quality;
- upgrades or changes to infrastructure or processes (both within the meat processing plant, or the wastewater treatment plant), such as treatment components, chemicals, critical limits or operating parameters; plant capacity. Particular significant process changes that may seriously

affect high end AWTPs in a meat processing plant might include:

- / installation of salted hide shed (elevated brine, EC levels);
- / any major change to the render facility (increased organic, fat and nutrient loads on the WWTP).

// audits or reviews indicating ongoing compliance issues;

// new intended end uses requiring more stringent water quality standards; and

// changes to legislation, water quality criteria or industry standards (especially in overseas customer jurisdictions).

11.0 OPERATIONAL PROCEDURES AND PROCESS CONTROL

Documented procedures and control measures are required for ensuring system processes and activities occur effectively and correctly to produce recycled water of acceptable quality. This information may be formalised in the organisation's operating procedures which should be described and referenced in the RWMP where applicable. **TABLE 16** lists examples of operating and process control procedures that may be included in the system. These are broadly described below:

// Operational procedures - should describe process control programs for the scheme. This should include positions responsible for the activities and how staff are trained in the procedures.

// Source water monitoring - characterisation of the treated effluent quality from the upstream WWTP must be ongoing to account for changes over time, and assist identification of new or emerging hazards. Parameters and monitoring frequencies should be risk based.

// Operational monitoring - a plan should show details of operational monitoring protocols, including:

- / responsible personnel
- / operational monitoring parameters
- / criteria or performance targets
- / monitoring frequency
- / analysis of results to determine operational efficacy.

An example of operational monitoring parameters is shown in **TABLE 17**.

// Non-conformance and corrective actions - include procedures for corrective actions which establish process control, immediately when critical limits or target criteria are exceeded. These may be included as part of the operational procedures for the scheme or as separate corrective procedures. Include the responsibilities for actions in procedures, and how reviews will occur after corrective actions are taken.

// Communication systems - document the communication systems to be implemented when process control is lost, including the responsibilities for executing communication protocols.

// Monitoring equipment - equipment used for operational monitoring needs to be capable and suitable for the monitoring task. Consequently, maintenance of the monitoring equipment is critical in the provision of consistent and reliable results and performance. Provide details of the maintenance requirements for the equipment and infrastructure used in the scheme. Detail the responsibility for scheme and process maintenance. This information may be available in the manufacturer's specification and summarised in an organisation's maintenance schedule.

Table 16: Examples of operating and maintenance procedures. Adapted from (DEWS, 2010)

Category	**Activity**
Maintenance	Calibrating water quality monitoring and testing equipment
Maintenance	Commissioning of new assets to minimise water quality risk
Maintenance	Maintenance of water treatment equipment and distribution system
Maintenance	Maintenance of filter media
Operational	Critical control point – monitoring, routine and corrective action
Operational	Water quality sampling and analysis
Operational	Operation of water treatment units
Operational	Management of disinfection process
Management	Incident response
Management	Water quality verification plan
Management	Document control
Management	Operator training

Table 17: Examples of operational monitoring parameters. Adapted from (NRMMC, 2008)

Treatment process	Hazard	Activity and function	Surrogate/indicator parameter
Membrane filtration	Pathogens	Trans-membrane pressure. Pressure based tests	COD, turbidity, particle counts
Reverse osmosis	Pathogens, chemicals	Trans-membrane pressure, flow & conductivity on brine and permeate.	COD, conductivity
Advanced oxidation	Pathogens, chemicals	UV light dose, hydrogen peroxide dose, oxidation reduction potential	Plate count
Chlorination	Pathogens	Concentration, contact time, pH	Plate count

12.0 VERIFICATION OF RECYCLED WATER QUALITY AND OPERATIONAL PERFORMANCE

Verification monitoring is an assessment of the performance of the scheme. As opposed to operational monitoring, it does not occur in 'real time', and should be independent of operational monitoring. It is used to confirm product quality, compliance with water quality criteria and identify weaknesses in the existing control measures (DEWS, 2008). Verification includes regular sampling and testing to assess whether recycled water quality is meeting guideline values and regulatory requirements. It is generally carried out at the final water quality monitoring points prior to delivery for use. There must be a documented verification monitoring plan. Verification will typically include a broad range of parameters during commissioning and in the initial months of operation. Once sufficient data has been collected to confirm that water of the desired quality is being reliably produced, the list of parameters and monitoring frequencies can be reviewed and refined. Successful verification provides (NRMMC, 2008):

- confidence for all recycled water stakeholders, including regulators, in the quality of the water supplied and the functioning of the system as a whole; and
- an indication of problems and a trigger for corrective actions or incidents.

Refer to Section 6 of the RWMP template for further details.

13.0 MANAGEMENT OF INCIDENTS

Potential hazards and events that could lead to unintended production of non-potable water and contamination of meat product include:

- equipment failure leading to non-conformance with critical limits, guideline values and other requirements;
- consequence of extended power failure;
- accidental spill of chemical leading to waste water treatment system; and
- accidental cross connections of supply water.

Most modern AWTP are fully automated and have very thorough in-line monitoring to identify detrimental changes in feedwater quality and/or equipment malfunction. In these circumstances, the plant either shuts down, or directs product water to a contingency storage until the issue is resolved. In some respects, the operation of AWTPs is easier than the front end of the meat processing WWTP since the treated effluent fed to the AWTP is of much superior quality than raw wastewater with its challenging combination of high levels of gross and suspended solids, fats and irregular flow.

For meat processing plants producing potable quality product water from treated effluent, verification of final quality is best performed on a batch lot system (for example as described in Section 6.2.6), despite the fact that the AWTP operates continuously. Each batch is not released for use until final quality checks are obtained. Where treated water did not meet Australian Drinking Water Guidelines (or the agreed final water specification), the batch would be dumped, or reprocessed and corrective action taken. An overall incident management plan describing responsibilities, corrective actions and communication lines should be documented. This should include internal reporting as well as any required regulatory and external reporting.

14.0 DOCUMENTATION MANAGEMENT AND REPORTING

A document management and reporting system is required as follows (DEWS, 2008):

- There should be a procedure for document control, to ensure that all copies of documents referenced in the RWMP are current and controlled;
- There should be a procedure for record keeping and document retention;
- Records should be maintained for all operations of the recycled water scheme. Document retention times should be based on any relevant regulatory requirements and to satisfy auditing needs;
- Where practicable, monitoring information should be recorded on template forms. Records from CCPs should be appropriately checked and counter–signed by a manager or supervisor;
- There should be a procedure outlining how internal reporting and reviews will be conducted, specifying the timeframes within which information should be passed on;
- There should be a procedure for ensuring that monitoring and audit results are communicated to all relevant staff; and

- Where electronic systems are used, summarise their attributes and functionalities that ensure adequate document management and record keeping.

15.0 SUPPORTING PROGRAMS

15.1 Operator and contractor training

Include an awareness and training program for operators, contractors and end users. This may be in the form of procedures attached to the RWMP as reference documents. In particular,

- Describe the training requirements for operators and contractors for the different aspects of the scheme;
- Document the skills and experience required by operators and contractors; and
- Document communication procedures which increase awareness and participation in water quality management.

15.2 Evaluation and audit

Provide a process for internal and external audits, including frequencies, roles and responsibilities and the process for documenting and reporting results. Additionally, outline any triggers that may result from audit results e.g. changes to the scheme or the RWMP. Document the process for long-term data collection and how it will be used to assess performance and identify problems.

15.3 Review and continuous improvement

Document the review and continuous improvement mechanisms that will be undertaken for the plan. This should include roles and responsibilities, the documentation and communication of results, the involvement of senior management and any revised or new processes that may be triggered by reviews.

16.0 REFERENCES

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