AUSTRALIAN MEAT PROCESSOR CORPORATION

Strategic evaluation of RD&E opportunities for water reuse and recycling at Australian abattoirs

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Executive Summary

This is the final report for project 2016/1021 “Strategic evaluation of RD&E opportunities for water reuse and recycling at Australian abattoirs”. The objective of the project was to identify the needs and opportunities to achieve water efficiency gains at Australian meat processers through reuse/recycling, while adhering to the highest food safety and product quality standards.

Currently, large abattoirs use approximately 7 kL of water per tonne of hot standard carcass weight produced (tHSCW) (AMPC wastewater report, 2012) at an average cost of $2.2/kL. Four strategies have been highlighted to reduce fresh water consumption and costs associated with water:

1) Water conservation: this is a strategy suitable to abattoirs at all sizes to save up to 10% of town water consumption. The payback period ranges from immediate to up to 3 years. Simple actions can include staff education/awareness, fixing water leaks and the adoption of dry cleaning methods.

2) Water reuse: this strategy allows the reuse of one process waste stream to the same or another process with or without pre-treatment, which can save 15% of town water consumption with a payback of less than 5 years. Abattoirs at all sizes can adopt this strategy. However, small abattoirs (< 100 kL/d) might be limited to waste streams requiring no treatment or simple treatment (such as screening before reusing). Before starting any reuse project, sites should contact AQIS to assure its feasibility. AQIS has already approved some reuse options such as (AQIS, 2008): (i) the reuse of steriliser and hand-wash water collected and used to wash cattle yards; and (ii) the reuse of steriliser water collected from clean end on the viscera table and used for the initial viscera table wash.

3) Non-potable water recycling: more than 40% of town water consumption can be saved by using non-potable water. This recycled water cannot be used in direct or indirect contact with meat and meat products. Different water qualities can be produced depending on the end-use purposes. For example, some abattoirs are already using non-potable recycled water for irrigation. This strategy can be adopted by medium to large sites due to the higher investment cost and payback time (6-10 years) than the two previous strategies.

4) Potable water recycling: more than 70% of town water consumption could potentially be saved by introducing direct potable recycle schemes in facilities. However, international regulations and public acceptance limit its implementation by prohibiting the use of recycled water in contact with meat or meat products. However, these might change in the future due to the reduction of conventional sources of potable water and public awareness. Domestic abattoirs could use potable recycled water, which will however be limited to large sites due to high investment cost and payback time (around 10 years).

Water conservation, water reuse and non-potable water recycling are three ways to replace or minimise external supplies by 65%, thereby reducing costs and improving the sustainability of the operation. However, when considering water recycling/reuse, food safety and national and

international product quality expectations and regulations need to remain the top priority. For this reason, the use of potable recycled water produced on-site is a challenge for international abattoirs. The main benefits of using these three strategies are:

- Save water intake and disposal costs
- Produce sustainable products meeting customer demand
- Reduced energy demand (e.g. through hot water recycling)
- Improve operational performance (e.g. less chemical use for cleaning, boilers and cooling towers)
- Preserve product value
- Recover nutrients from the wastewater with market value

Based on these findings, it is recommended that AMPC consider research aiming to reduce water consumption by at least 60% through reusing or recycling water within abattoirs. Using reused/recycled water can require an initial investment (payback around 5 years), but can potentially save $240/day in water supply costs for a plant processing 625 head per day with additional savings in trade waste or discharge possible (estimated from: 1 ML/day water consumption, 40% recycled water, town water cost: $2.2/kL, recycled water cost: $1.6/kL).

Contents

Abbreviations

AWTP	Advanced Water Treatment Plant
AnMBR	Anaerobic Membrane Bioreactor
BOD	Biochemical Oxygen Demand
CAL	Covered Anaerobic Lagoon
CBA	Cost Benefit Analysis
COD	Chemical Oxygen Demand
DAF	Dissolved Air Flotation
EC	Conductivity
FO	Forward Osmosis
FOG	Fats, Oils and Grease
FRP	Ortho-phosphate Phosphorus
HSCW	Hot Standard Carcass Weight
MBR	Membrane Bioreactor
MD	Membrane Distillation
MF	Microfiltration
NF	Nanofiltration
O&G	Oil and Grease
RO	Reverse Osmosis
SBR	Sequencing Batch Reactor
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solids
UF	Ultrafiltration
UV	Ultraviolet

1 Background and Objectives

During the past decade, AMPC financed multiple research projects aiming to decrease water consumption and to improve water efficiencies at Australian abattoirs. AMPC now requires a clear framework for further R&D and research translation to maximise industry benefit from these activities.

Project A.PIA.0086 “Review of abattoir water usage reduction, recycling and reuse” is a very good working base to build the proposed framework. Within a good overview of the process wastewater quality and quantity, the cost-benefit analysis (CBA) of recycled and reuse water and the risk assessment of recycling and reuse activities are described among others. Nevertheless, an update of this document is essential due to:

- There have been substantial advances in technologies for wastewater treatment and production of recycled water in the past 10 years, including the development of sophisticated online control and monitoring processes that ensure water quality.
- There have been strong advances in the use of recycled water in Australia in municipal wastewater treatment and in industrial applications (including food industries). The successful uptake of water recycling technologies (particularly in related industries), may provide valuable case studies for the red meat industry to reference in development on a water conservation, reuse and recycling plan.
- There have been continuing developments in the use of recycled water in the international meat processing community. It is critical for the Australian industry to consider potential changes in “Global Best Practice” when developing a water conservation, reuse and recycling policy. Consideration of international activities will ensure Australian meat processors remain internationally competitive.
- Australian meat processors currently utilise a range of different wastewater treatment technologies, and this is often dependent on the location of the plant and the method of effluent discharge. The final effluent will vary substantially depending on this up-stream treatment, but there is currently little data available to determine how the wastewater quality would impact the selection and cost of additional treatment to enable water recycling.

An understanding of water consumption and quality is needed while the understanding of wastewater production and quality is essential to elaborate strategies for the implementation of water conservation, reuse and recycling at Australian abattoirs. This report supplies:

- A description of the water usage and wastewater production;
- An overview of the national and international regulations regarding water reuse/recycling;

- Four strategies to decrease town water consumption, including value proposition and benefits, research/implementation, and key risks.

2 Introduction to Water Usage at Red Meat Processing Plants

2.1 Descriptions of Water Use

Water usage represents a large financial cost for the Australian red meat industry due to the water purchase and disposal costs and the large amount of water needed for meat processing. Firstly, the average purchase price of potable town water is $2.2/kL and can reach up to $3.5/kL (AMPC, 2012[1]). In addition, treatment and disposal costs range from essentially nothing to greater than $2/kL volume, plus potential penalties for organic and nutrient contaminants. Considering water usage by large Australian red meat processors is around 7 kL per tHSCW (AMPC, 2012), a plant processing 625 head per day (*ca.* 150 tHSCW/day) would consume 1 ML/d water, costing in the range of $2,000 to over $5,000 per day for supply, treatment and discharge.

Currently, many Australian abattoirs use municipal potable water supplies, water at this quality may be used in all production activities, including production areas where it contacts meat and meat surfaces. Table 1 presents the breakdown of general water consumption in an abattoir (AMPC wastewater report, 2012).

Potable water is primarily used in the following areas: slaughter, evisceration (mostly wash-down inedible and edible offal processing), and casing processing. The consumption of potable water has been significantly reduced since 2003.

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[1] AMPC Factsheet - Recycled Water Opportunities in Sustainable Food Production & Manufacture

Table 1. Water consumption in an abattoir.

Major Areas of Water Consumption	Percent of Total Fresh Water Consumption	Water quality
Stockyard (mostly wash-down)	7-24%	Non-potable (except last cattle wash)
Slaughter, evisceration	44-60%	Potable
Boning room	5-10%	Potable
Inedible & edible offal processing	7-38%	Potable[a]
Casings processing	9-20%	Potable[b]
Rendering	2-8%	Non-Potable
Chillers	2%	Non-Potable
Boiler losses	1-4%	Non-Potable
Amenities	2-5%	Non-Potable

From (AMPC wastewater report, 2012).

[a] Reused water can be used except for final wash.

[b] If casings are to be washed for rendering only, reused water could be used.

2.2 Descriptions of Wastewater Production

There are five main areas in Australian slaughterhouse that generate wastewater: stockyard, slaughter / evisceration (kill floor), boning room, inedible and edible offal processing, and rendering (AMPC wastewater report, 2012). Small facilities may not operate a rendering plant. Slaughter / evisceration is the area producing the highest volume of wastewater and may represent 50% of the total wastewater production (P.PIP.0172). Boning room produces low contaminated wastewater. Thus, this waste stream can be directly reused reducing the final volume of wastewater production (P.PIP.0172). Figure 1~~Figure 1~~ presents the water usage and wastewater production of a typical abattoir. Wastewater is generally grouped into 2 main categories (AMPC wastewater report, 2012):

- Red waste: includes all wastewater from the rendering plant, slaughter floor and offal processing. This effluent is contaminated with blood (main source of nitrogen) and fats.
- Green waste: wastewater generated from manure and paunch wastes (stockyard washing, animal stomach emptying and other internal organs processing). It contains high level of phosphorus and sodium, and it is generally screened to remove coarse solids before mixing with red stream.

The technologies used to treat wastewater are site dependent. Appendix A presents the production of wastewater and the current wastewater treatment practices at red meat processing facilities. In this project, four Australian abattoir sites have been further studied to describe the current waste stream quality, wastewater treatment processes used and the form of discharge. The sites investigated are discussed in Appendix B.

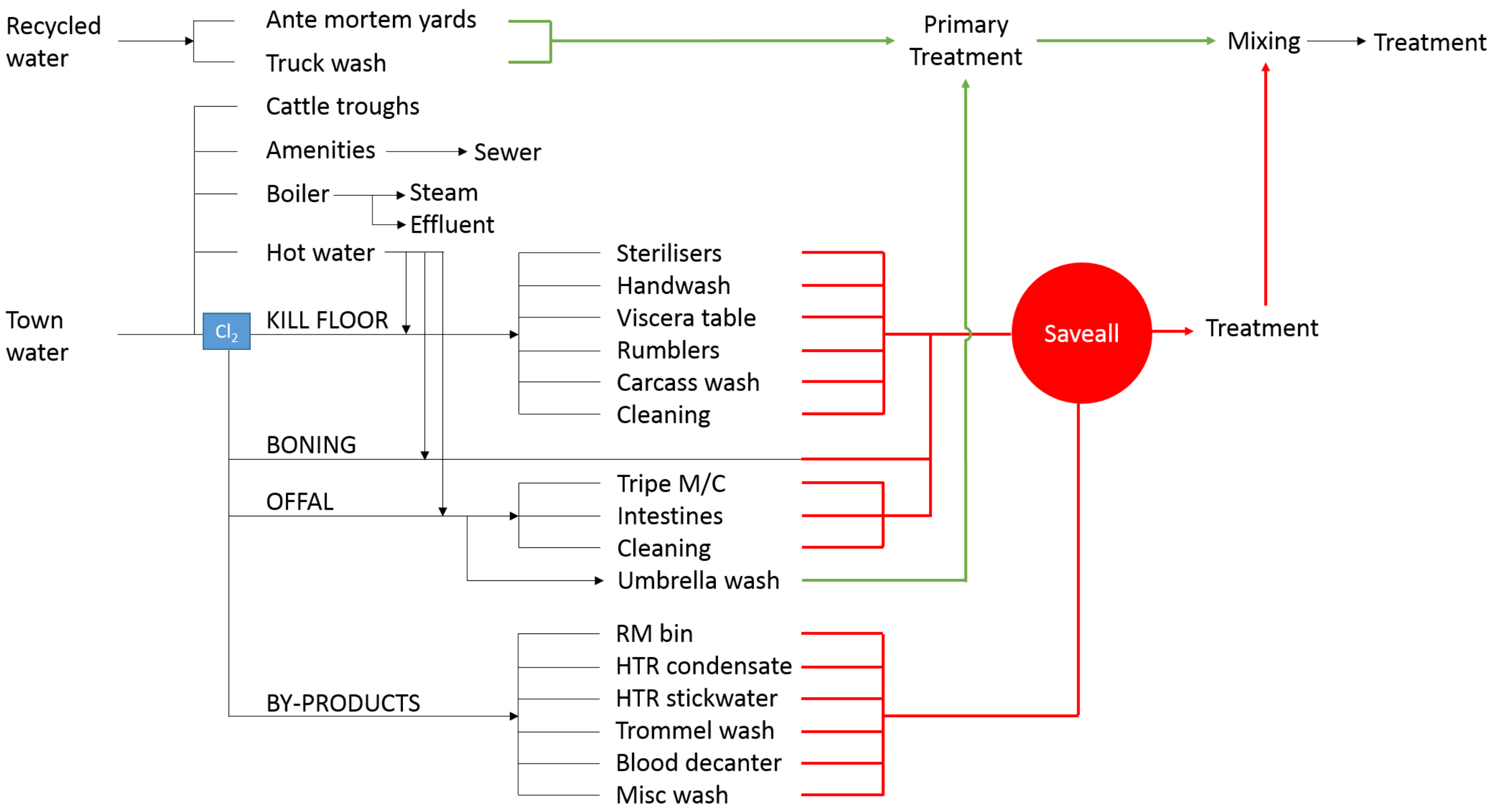

Figure 1. Process schematic of common water usage and wastewater productions in abattoirs. Adapted from (P.PIP.0172). Green line = green stream; red line = red stream.

2.3 Wastewater Treatment and Discharge

Abattoir wastewaters are rich in both organic contaminants and nutrients, which require removal/recovery prior to discharge or re-use. In some cases, these contaminants can be recovered and used in value-add processes. A summary of key contaminants is:

- Fats, Oil and Grease (FOG)
- Organics Compounds
- Solids and/or Particulates
- Phosphorous
- Nitrogen
- Trace metals
- Odour
- Biosecurity and Pathogens

During the development of a water recycling scheme, these contaminants need to be removed (or ideally recovered) from the wastewater stream. Depending on the waste stream quality and the desired end-use (which impacts product quality requirements), different wastewater treatment processed can be used. Figure 2~~Figure 2~~ summarises the different processes able to remove/recover contaminants present in wastewater. More information on wastewater treatment processes can be find in A.PIA.0086 report and Appendix A.

In Australia, treated wastewater is generally discharged in one of three ways (AMPC wastewater, 2012):

- Sewer (local regulation);
- Surface waters such as river, waterway or seaway (state regulation);
- Land irrigation (state regulation).

The quality of treated effluent required for disposal depends on the disposal route, and is dictated by state or local regulatory disposal standards. Table C.1 in Appendix C summarises the water quality needed for sewer, surface water or irrigation discharge according to the Australian and New Zealand guidelines (ANZECC and ARMCANZ, 2000). However, facilities have to follow their respective state/local authority guidelines.

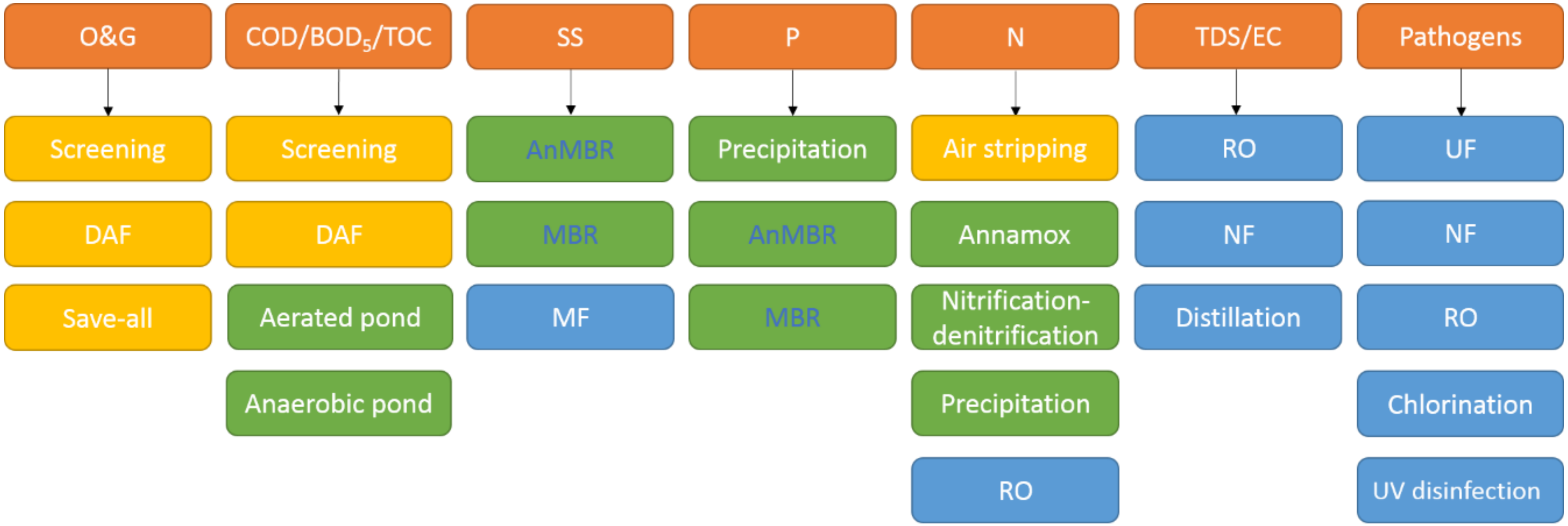

Figure 2. Principal treatment processes to remove contaminants present in wastewater. Orange = contaminants, Yellow = primary treatment, green = biological treatment, blue = advanced treatment. AnMBR = anaerobic membrane bioreactor (mix of biological and advanced treatment), DAF = dissolved air filtration, MBR = membrane bioreactor (mix of biological and advanced treatment), MF = microfiltration, NF = nanofiltration, RO = reverse osmosis, UF = ultrafiltration.

3 Regulations around Water Use and Reuse

The application of water recycling and reuse at abattoirs offers multiple benefits as it can decrease water usage, reduce external supply dependence, provide energy savings and result in lower costs for wastewater treatment and disposal. Water can be reused or recycled from various sources and can be produced at different quality levels depending on its end-use, typically as potable or non-potable water.

Non-potable water is lower quality than potable water and can be produced from rain water or wastewater streams with relatively little treatment and at low cost. However, due to the lower quality, non-potable water must not get into contact with meat or meat surfaces to mitigate the risks of meat contamination. Therefore, this non-potable water can be used for:

- Stockyard wash
- Truck wash
- Amenities
- Irrigation

These uses typically account for 30 to 50% of water use at an Australian slaughterhouse (A.PIA.0086).

Direct reuse of wastewater is also possible where low contaminated wastewater from one process/area can be reused, with or without further treatment, on another process/area within the same slaughterhouse following strict requirements such as (AQIS, 2008):

- Exclude human effluent from the water stream to be reused,
- No physical connection between the potable and reused supply,
- Access to the potable municipal system or other acceptable alternative supply in case of system failure.

Several risks can be associated with the reuse of water or the use of recycled water. One of the main risks is the potential impact on food safety, which requires operators to adhere to strict policies and regulations in order to protect public health. Therefore, key risk parameters must be carefully managed during water reuse and recycling, most importantly the level of biological (including pathogens) and chemical contaminants. Recognizing and managing these risks is critical to the successful implementation of water reuse and recycled water schemes.

Advanced water treatment processes such as membrane filtration, UV/H_2O_2 and ozone are effective treatment processes able to remove pathogens and chemical contaminants to produce very high quality water (Figure 2~~Figure 2~~). These processes need to be integrated in a specific operating framework, which is typically based on a multiple-barrier approach with advanced monitoring and control methods to reduce the potential chemical and biological risks to an acceptable level. A review on the actual technology used to recycle water is presented in Appendix D.

3.1 Australia

The recycling of wastewater after high level treatment is feasible according to the AQIS Meat Notice: 2008/06 "Efficient use of water in export meat establishments" (AQIS, 2008). Slaughterhouses may use recycled water from abattoir wastewater through a direct planned potable end-use scheme if they meet the following requirements:

- Exclude human effluent from the water stream to be reused,
- No physical connection between the potable and any other non-potable supply,
- Follow the Hazard Analysis Critical Control Points (HACCP) principles,
- Use a multiple-barrier approach,
- Access to the potable local authority water system or other acceptable alternative supply in case of system failure,
- Must meet the Australian Drinking Water Guidelines for potable water,
- Must not use the water as a direct ingredient in meat products or use it for drinking water at the establishment.

Australian abattoir's intending to use recycled water must contact AQIS before any construction and for final approval before utilization in meat processing operation.

3.2 Europe

The European Commission Integrated Pollution Prevention and Control (IPPC) edited a "reference document on best available techniques in the slaughterhouses and animal by-products industries" in 2005 (IPPC, 2005). This guide references the different actions a slaughterhouse can adopt to minimise its water consumption. Non-potable water can be used in the industry but should be clearly separated from the drinking water supply and for specific purposes as mentioned in the Australian regulation. The EU listed establishments have to test their potable water according to AQIS Notice Meat: 99/15 (AQIS, 1999). However, the IPPC document clearly specifies that "food and veterinary legislation requires potable water to be used in slaughterhouses, so there are virtually no opportunities for re-use of water”. Since 2005, the position of the European Union (EU) changed and water reuse become a top priority area in the “Strategic Implementation Plan of the European Innovation Partnership on Water”. To-date, there is no water reuse guidelines or regulations at EU level (Alcalde Sanz and Gawlik, 2014). However, there are directives regarding food safety and the use of water reuse. These directives have to be taken into account during the development of guidelines/regulations. Greece, Spain and Italy are the only European countries with current legislation allowing the use of recycled water from wastewater in food industry. However, Italy forbids the use of recycled water in direct contact with meat. Nowadays, there are two major barriers limiting the use of water reuse in the EU: (i) Limited awareness of potential benefits among stakeholders and the general public, and (ii) lack of a supportive and coherent framework for water reuse (Alcalde Sanz and Gawlik, 2014; Mudgal et al., 2015). For Europe, Australia is a good example to follow regarding its success to develop a national waste recycling guidelines (NRMMC et al., 2006, 2008).

3.3 USA

In the USA and under the current legislation, recycled water can be used in food processing or as an ingredient but should be at the same standard as drinking water. In some circumstances non-drinking water (i.e. non-potable) is used by the food industry, but should not be in contact with food (e.g. for fire control, steam production). In these instances, the water should be clearly identified as non-potable water and not connect or mix with the potable water supply used directly in food production. Part 416.2 (g) of the Title 9 Code of Federal Regulations (CFR, 1999) authorises the use of water recycling in contact with meat:

“§416.2 Establishment grounds and facilities

(1) Water supply and water, ice, and solution reuse. (1) A supply of running water that complies with the National Primary Drinking Water regulations (40 CFR part 141), at a suitable temperature and under pressure as needed, must be provided in all areas where required (for processing product, for cleaning rooms and equipment, utensils, and packaging materials, for employee sanitary facilities, etc.). If an establishment uses a municipal water supply, it must make available to FSIS, upon request, a water report, issued under the authority of the State or local health agency, certifying or attesting to the potability of the water supply. If an establishment uses a private well for its water supply, it must make available to FSIS, upon request, documentation certifying the potability of the water supply that has been renewed at least semi-annually.

(2) Water, ice, and solutions (such as brine, liquid smoke, or propylene glycol) used to chill or cook ready-to-eat product may be reused for the same purpose, provided that they are maintained free of pathogenic organisms and fecal coliform organisms and that other physical, chemical, and microbiological contamination have been reduced to prevent adulteration of product.

(3) Water, ice, and solutions used to chill or wash raw product may be reused for the same purpose provided that measures are taken to reduce physical, chemical, and microbiological contamination

so as to prevent contamination or adulteration of product. Reuse that which has come into contact with raw product may not be used on ready-to-eat product.

(4) Reconditioned water that has never contained human waste and that has been treated by an onsite advanced wastewater treatment facility may be used on raw product, except in product formulation, and throughout the facility in edible and inedible production areas, provided that measures are taken to ensure that this water meets the criteria prescribed in paragraph (g)(1) of this section. Product, facilities, equipment, and utensils coming in contact with this water must undergo a separate final rinse with non-reconditioned water that meets the criteria prescribed in paragraph (g)(1) of this section.

(5) Any water that has never contained human waste and that is free of pathogenic organisms may be used in edible and inedible product areas, provided it does not contact edible product. For example, such reuse water may be used to move heavy solids, to flush the bottom of open evisceration troughs, or to wash ante mortem areas, livestock pens, trucks, poultry cages, picker aprons, picking room floors, and similar areas within the establishment.

(6) Water that does not meet the use conditions of paragraphs (g)(1) through (g)(5) of this section may not be used in areas where edible product is handled or prepared or in any manner that would allow it to adulterate edible product or create insanitary conditions.”

3.4 Asia

To date, China does not have any slaughtering standards code. Thus, the use of recycled water meeting the Australia standards should not be an issue for Asian country establishments. However, it can be an issue for Japan.

4 Strategy 1 – Water Conservation/Substitution

4.1 Introduction

Due to water scarcity, Australian authorities put pressure on abattoirs to reduce their water consumption. Alternative methods are already used by some abattoirs to significantly reduce the total water consumption by more than 10%. These alternative methods include:

- Dry cleaning using scrapping methods
- High pressure trigger
- Use automated water start/stop controls
- Reduce the hose nozzle size
- Avoid running water and replace system with shower heads operated by pedals or sensor

- Avoid water leak
- Staff awareness/education on water consumption

A proof of feasible application of alternative waterless cleaning for carcass chillers is presented in A.ENV.0138 project. This new protocol using a mechanical floor scrubber reduces 74% of water consumption used for cleaning (*ca.* 1% in total abattoir), saves around 94% of chemical, around 0.25% of energy by decreasing the water temperature from 82ºC to 30ºC, and 60% in labour. Microbial tests were performed and showed that less than 5 CFU/cm^2 were present on doors, wall and wall jamb. This value is the benchmark used by the Department of Agriculture, Fisheries and Forestry (DAFF). This new protocol is ready to be or already applied in Australian abattoir.

However, the water pressure from authorities is only on cold water and not hot water, due to the importance of hot water for decontamination. Thus, there is a problem between environment sustainability and food safety. In 2005, PRMS.076 project validated an alternative procedure for knife cleaning on the slaughter floor. It showed that the use of two knives during processing operation can decrease the water temperature from 82ºC to 60ºC to clean the knives. 82ºC is the actual international regulation to avoid *E. coli* contamination. In this alternative procedure, the knife was washed in hand-wash water and then immersed in water at 60ºC for the time it took the operator to complete the specific operation with the other knife. This protocol does not have an impact on the water consumption. Whereas, this temperature reduction has a positive impact by decreasing the wastewater temperature, increasing the safety of the operators, and the energy consumption whilst maintaining the production of a high quality product. This protocol has not been accepted by AQIS potentially because of the followings:

(i) 82ºC is the international temperature standard and regulators are not keen to change it because of the potential negative impact on the exportation market with Japan, USA and Europe;

(ii) At lower temperature the fat does not dissolved as much as 82ºC limiting its removal;

(iii) A change of temperature might involve the installation of a second boiler;

(iv) A decrease of the knife decontamination temperature might reduce the chance of hot water reuse in the abattoir.

4.2 Value Proposition and Benefits

- Abattoirs are using around 7 kL of water per tHSCW, which can cost up to $3.5/kL.
- Water consumption produces wastewater that cost the industry in treatment and disposal from nothing to $2/kL volume, plus potential penalties for organic and nutrient contaminants.

- Water conservation can save up to 10% of town water consumption which represents a saving of $260 per day or $65,000 per annum for a typical processing plant[2] (after payback period).
- Generally, smaller plants use less water per unit of production than larger plants, due to the absence of further processing operations such as boning of carcass, freezing and chilling of cartons and rendering of by-products (McPhail et al., 2014). Thus, water conservation might save less than 10% of town water consumption for small plant (< 75 tHSCW/day).
- Payback period of water conservation ranges from immediate benefit to 3 years based on a typical plant (Table 2~~Table 2~~).

Table 2. Examples of water conservation measures and payback times.

Measure	Capital cost ($)	Water savings (kL/day)	Payback period[a]
Minimizing receipt of very dirty stocks	NIL	Up to 10	Immediate
Efficient spray nozzles	~ 5,000	~ 55	~ 2 months
Flow control of continuous flow sterilisers	~ 5,000	~ 30	~ 4 months
On/off control of flow	~ 2,000	~ 6	~ 7 months
Automatic controls for hand washing	~ 10,000	~ 12	~ 16 months
High pressure ring main for cleaning	~ 50,000	~ 50	~ 1.5 years
Floor cleaning machines	~ 20,000	< 10	~ 3.2 years

Adapted from (A.PIA.0086) and (Pagan et al., 2002).

[a] Taking into account potential maintenance/repair costs and limiting heating savings (Pagan et al., 2002).

4.3 Research/Implementation Plan

- Limit the evaporation of hot water by covering the tray for example.
- Insulate water pipes to avoid temperature and energy loss.
- Implement existing protocols such as dry cleaning if not done already as mentioned previously.
- Use waterless technology such as high pressure trigger or automatic water start/stop controls if not done already as mentioned previously.

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[2] Typical plant: abattoir processing 150 tHSCW/day, 5 days/week, 250 days/year, 7 kL/day, including boning and rendering plants (Pagan et al., 2002). Water cost: $2.5/kL including purchase, pumping, treatment and disposal.

4.4 Key Risks

- Knowledge and understanding of how a new technology/protocol will impact a specific operation.

5 Strategy 2 – Direct Reuse of Water (With or Without Prior Treatment)

5.1 Introduction

Direct reuse is a viable option to reduce the consumption of town water. Basically, it is the use of “wastewater” from one process to the same or another process with or without pre-treatment. Low contaminated waste streams such as killing floor, boning room and chiller defrost, can be easily reused with or without pre-treatment. For example, waste streams from boning room and defrost collection from chillers can be recycled to the cattle yards (A.ENV.0151). This reuse represents around 5 - 15% of saved water. However, before starting to reuse water from one process to another one, an onsite wastewater characterization needs to be done and AQIS consulted to assure its feasibility.

Several AMPC and MLA projects studied different options to reuse water and are summarised in Table 3~~Table 3~~. Several projects failed to succeed because of:

- Change of water flow during the project causing an impossibility to use the reuse system (e.g. A.ENV.0137). It is highly recommended to well determine the project and take into account future changes having an impact on the studied technology before starting a project.
- High concentration of microbial contaminants in the storage tank (e.g. A.ENV.0078). Chlorination can avoid the growth of bacteria.
- High payback time (e.g. PRENV.040).

As per this table, water reuse has generally a payback period around 5 years. The majority of plants do not have drainage collection system, which is increasing the payback period. With the drainage system already included in the plant, the payback period would be under three years.

Following reuse options have already been approved by AQIS (AQIS, 2008):

- Steriliser and hand-wash water collected and used to wash cattle yards;
- Carcase decontamination wash water collected, coarsely filtered, and reused immediately for the same purpose whilst maintaining a temperature that is lethal to pathogens;
- Steriliser water collected from clean end on the viscera table and used for the initial viscera table wash,

- Steriliser water collected and used to wash moving dry landing area (hide on area).

Table 3. AMPC/MLA Water reuse projects.

Project	Reuse option	Fraction of water saved	Key inputs/outputs	Technology readiness	Payback period (year)[a]
A.ENV.0078	steriliser water to contra-shear + outside rendering plant washing	~ 5%	Stop using hot potable water through contra-shears and hoses outside Rendering and replace with reused steriliser water from the Boning Room.	Solid screen commercially available	5.5 (including extra drainage system)
A.ENV.0081	filtered water from the viscera table to cattle yards washing	Potentially ~ 5 - 6%	- Quantity of water reuse produce greater than needed - Bacterial growth in storage tank if not used daily → Not approved by AQIS Solution to problem: Chlorination	Chlorination is well established and done for rain water tank.	3.5
A.ENV.0137	2nd tripe wash reused for 1st wash	Potentially ~ 6%	Project stop due to implementation of a water conservation plan. An unsuitable water flow used within the designed process caused an aesthetic change of the tripe unfit for commercial sale.		
PRENV.040	steriliser pots + hand-wash basins + viscera tables	~ 10%	Possibility to reuse low contaminated streams by membrane filtration. Loss of water temperature avoiding heat recovery. Might need RO membrane or activated carbon to remove colour.	Membrane technologies commercially available	4 years with UF polymeric membrane 12.4 years with ceramic membrane

[a] Payback period was calculated using purchase water cost of $0.75/kL, treatment cost and pumping around site of $0.05/kL, treating and disposal cost of $0.50/kL for sewage, $0.80/kL for surface water and $0.30/kL for land. However, in some area, the purchase of water supply can cost up to $3.5/kL and the discharge costs around $1-2/kL, which will decrease the payback time (PRENV.030).

5.2 Value Proposition

- Abattoirs are using around 7 kL of water per tHSCW, which can cost up to $3.5/kL.
- Water consumption produces wastewater that cost the industry an estimated $1 – 2/kL volume in treatment and disposal.
- Water reuse can save up to 15% of town water consumption which represents a saving of $390 per day or $97,500 per annum for a typical processing plant[3] (after payback period). Direct reuse without pre-treatment can be implemented to all sites. If pre-treatment before reuse is necessary, a CBA will have to determine the project viability.

5.3 Research Plan

- Fully characterise waste stream (i.e. quality and quantity) to determine the treatment needed before reuse. Run a cost benefit analysis (CBA) to assure viable reuse option.
- Trial ceramic membrane, which are capable of reusing sterilised hot water from the tripe room and slaughter floor (15% of the hot water consumption) by avoiding energy loss: 1 year project with an estimated budget of $70,000 (excluding salaries).
- Use UF and UV to potable reuse low contaminated streams such as steriliser pots and viscera table wastes: 1 year project with an estimated budget of $100,000 (excluding salaries). The payback period might be of more than 10 years depending on the sale price of the reclaimed water in comparison to the potable water price.
- Develop a CBA model to recycle clean streams with different conventional or new advanced treatments such as membrane bioreactor (MBR), ceramic membrane and disinfection (physical or chemical): 6 months project, estimated budget $50,000.

5.4 Technology Readiness

- Ceramic membranes are commercially available and become affordable. They need less cleaning (maintenance) than polymeric membranes and are more robust and poses a much greater lifetime.
- UF membranes are widely used in domestic water reuse area and some industries such as dairy. They are commercially available.
- Disinfection processes such as UV or ozone are commercially available and widely proven

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[3] Typical plant: abattoir processing 150 tHSCW/day, 5 days/week, 250 days/year, 7 kL/day, including boning and rendering plants (Pagan et al., 2002). Water cost: $2.5/kL including purchase, pumping, treatment and disposal.

in drinking water treatment.

5.5 Key Risks

- Knowledge and understanding of how a specific treatment will impact a specific operation.
- Payback period.

5.6 Summary of Benefits

- Save water intake and disposal costs
- Reduce dependence on external supplies by 5 - 15%
- Reduced energy demand (e.g. through hot water recycling)
- Preserve product value

6 Strategy 3 – Recycling at Non-potable Standard

6.1 Introduction

Wastewater can be treated to reach high water quality by using different technologies (Appendix D) depending on the wastewater composition. To date, non-potable recycled water (class A, Table C.3) can be used for:

- Stockyard washing
- Truck washing
- Amenities
- Fire control
- Irrigation
- Cooling systems
- Boiler feed
- Cleaning in place system
- Inedible offal processing
- Steam production (not in contact with meat and meat products)

- Cattle drinking water
- Animal washing (not final)
- Floor washing

By using non-potable recycled water, town water consumption can be reduced by more than 40%, which represent a town water saving of *ca.* \$360 per day or \$90,000 per annum (1 ML/day water consumption, 40% recycled water, town water cost: \$2.5/kL, recycled water cost: \$1.6/kL). Furthermore, water recycling does not limit the recovery of nutrients and fat, and can be an added value to the factory. Generally, the payback of recycling plant including membrane filtration and disinfection system is around 6 - 10 years, which is considered as high risk for industry. However, the cost of town water is continuously increasing every year (Figure 3~~Figure 3~~) meanwhile decreasing cost of the technology subsequently reducing the payback period. In addition to reduce of town water consumption and disposal cost, water recycling options reduce the dependence on external water supplies without compromising food safety.

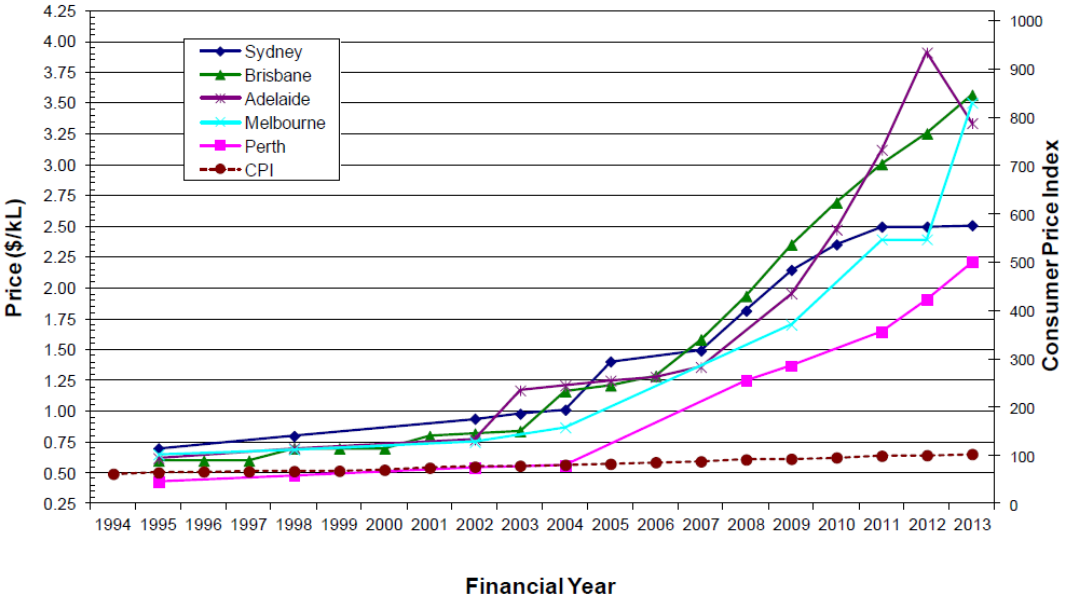

Figure 3. Tap water prices in Australian cities (from (McPhail et al., 2014)).

Depending on the end use, the quality of recycled water can differ. For example, stockyard wash and truck wash do not need to have high quality water (Appendix C Table C.2). Water reuse might be a better option for these end-uses. Boilers and chillers need high quality water (Appendix C Table C.2) as ions corrode the system. In contrary to potable water, the presence of pathogen is tolerated to up to 10^3 colony forming per unit, but Legionella bacteria can be an issue for boiler and should be absent.

Following reuse options have already been approved by AQIS (AQIS, 2008):

- Tertiary treated effluent water used as the initial wash in the ante mortem yards and as an initial wash of stock;
- Chlorinated tertiary treated water used as final wash in ante mortem yards and as final wash of stock.

Since 2010, Radfords abattoir has invested $1.4 million in "Water and Energy Recovery" projects to both secure its water supply and diminished its energy (electricity and gas) consumption (Radfords, 2010). To secure its water supply, an ultrafiltration (UF) membrane has been installed to recycle up to 90% of its processing effluent water to a potable standard. By recycling its used water, Radfords decreased by 40.6% its water consumption. However, little information has been found regarding the water recycling treatment process and if a disinfection process is used in combination to the UF membrane. Also, we are not sure that this recycled water is used in direct contact with meat product. To decrease its energy consumption, Radfords invested in new cooling tower and heat exchange, and a new evaporation system.

In this project, four Australian slaughterhouses were assessed (Appendix B). From the final quality effluent of Sites A, B and C (Appendix B), it is possible to produce high quality non-potable water or class A (Table C.3). To reach this quality, an ultrafiltration (UF) membrane to remove particulates and pathogens is necessary. The payback period for a UF system is less than five years (PRENV.040). Furthermore, a sand filtration pre-treatment might be needed to limit UF fouling and a disinfection system such as UV or chlorination after UF membranes. Alternatively, low contaminated effluent such as boning room and kill floor can be used to produce class A water limiting pre-treatment step. The advantage to produce class A water is the possibility to use it for primary contact recreation, residential non-potable and municipal use with public access. Thus, this water can be used for wash-down, boiler feed and cooling towers for example. However, for some systems such as cooling tower, it might be necessary to add a reverse osmosis (RO) membrane or a distillation process to remove all the inorganics avoiding the system to scale. The advantages of RO to distillation system are that RO uses less space, energy and time demanding to treat water. The operating cost and maintenance of RO membranes are more expensive than UF membranes, increasing the payback period.

Effluent from Site D can also be used to produce class A water. However, due to the absence of treatment, it is possible to use other technologies that the ones previously mentioned. 2013.5024 project demonstrated the feasibility to use MF metal membranes to remove fat from stick water for heat recovery with a payback of less than one year. Stick water is a heavy contaminated wastewater (high COD, high fat, high nitrogen). By using MF metallic membranes, it can be assumed that 80% of the COD and almost all the fat can be removed at very high temperature (2013.5024). The feed permeate of metallic membranes can be combined to the rest of the effluent to be treated by an anaerobic MBR (AnMBR). The technology of a membrane bioreactor (MBR) combines biological treatment with membrane filtration to remove COD and fat. Anaerobic MBR has the advantages to potentially combine energy and nutrient recovery. Aerobic MBR process is not able to remove N. Air stripping, precipitation, NF or RO is needed to remove it. If the TDS/conductivity needs to be reduced, NF and RO are the best options. NF membrane predominately removes divalent ions and is around half of the RO efficiency (*ca.* > 95% for RO). Depending on the end-use water quality needed, NF membrane might be sufficient which will decrease the payback period as this membrane are less energy consuming. Membrane bioreactors (aerobic or anaerobic) are interesting technologies with a potential payback of 5 years, which can be reduced to 3 years if there is nutrient recovery (N and P; A.ENV.0133).

6.2 Value Proposition

- Abattoirs are using around 7 kL of water per tHSCW, which can cost up to $3.5/kL.
- Water consumption produces wastewater that cost the industry an estimated $1 – 2/kL volume in treatment and disposal.
- Waste processing system can be adopted to recover valuable products such as nutrients, grease and energy. Product recovery has the potential to reduce waste production and waste management costs, and create revenue.
- Water recycling at non-potable standard can save more than 40% of town water consumption, which represents a saving of $360 per day or $90,000 per annum for a typical processing plant[4] (after payback period). However, non-potable water recycling is limited to medium to large sites. Sites paying more than $3/kL of water cost are good candidates for non-potable water recycling water.

6.3 Research/Implementation Plan

- Applicability of UF and UV to produce class A recycled water: 18 months project, estimated cost $120,000 (excluding salaries).
- Use of membrane filtration (NF or RO) system at low recovery (50%). Permeate of the membrane filtration system can be used for chillers and boilers, concentrate can be used for irrigation: 18 months project, estimated budget $150,000 (excluding salaries).

6.4 Technology Readiness

- The majority of the advanced technologies are commercially available. More information

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[4] Typical plant: abattoir processing 150 tHSCW/day, 5 days/week, 250 days/year, 7 kL/day, including boning and rendering plants (Pagan et al., 2002). Water cost: $2.5/kL including purchase, pumping, treatment and disposal, recycled water cost: $1.6/kL.

on the different technologies are presented in Appendix D.

6.5 Key Risks

- Knowledge and understanding of how a specific treatment will impact a specific operation.
- Payback period.
- Regulatory restrictions on the use of recycled water.

6.6 Summary of Benefits

- Save town water intake and disposal costs
- Reduce dependence on external supplies by more than 40%
- Reduced energy demand (e.g. through hot water recycling)
- Improve operational performance (e.g. less chemical use for cleaning, boilers and cooling towers)
- Preserve product value
- Recover nutrients from the wastewater with market value

7 Strategy 4 – Recycling Water at Potable Standard

7.1 Introduction

Due to global climate change, urbanisation and population growth, water recycling becomes an alternative source of water supply (Semiat, 2008). Recycled water is already used as: (i) indirect potable reuse (IPR) to recharge aquifers and dams for drinking water use in the USA (California) and Australia (Perth) for example; and (ii) direct potable reuse (DPR) to mix directly with potable water in the USA (Texas) and Namibia. The main differences between potable recycled water (class A+) and class A non-potable recycled water (Table C.3) are the need to validate and monitor the different treatment train and the absence of pathogen (AWRCoE, 2014), which increase the payback period to around 10 years depending on the town water cost. Advanced technologies exist to produce high quality water from wastewater. For example, from sites A to C, recycled water can be produced to potable water standard (class A+, Table C.3) by using UF, RO and UV treatments. UF pre-treatment might be needed in order to remove all big particles and protect RO membranes from fouling. However, the main barriers of this strategy are public perception and regulation. To promote the use of water recycling as drinking water, we have to prove that the risks linked to water reuse such as microbial and chemical, are managed. Therefore, online monitoring and validation system have to be used to assure the good performance of the system and its ability to remove pathogens (Pype et al., 2016).

Water recycling is part of the solution to reach the “Zero discharge waste” that many industries want to reach by 2020.

7.2 Value Proposition

- Abattoirs are using around 7 kL of water per tHSCW, which can cost up to $3.5/kL.
- Water consumption produces wastewater that cost the industry an estimated $1 – 2/kL volume in treatment and disposal.
- Waste processing system can be adopted to recover valuable products such as nutrients, grease and energy. Product recovery has the potential to reduce waste production and waste management costs, and create revenue.
- Water recycling at potable standard can save more than 70% of town water consumption, which represents a saving of $350 per day or $87,500 per annum for a typical processing plant[5] (after payback period). However, potable water recycling is limited to large sites. Sites paying more than $4/kL of water cost are good candidates for potable water recycling water.

7.3 Research/implementation plan

- Use FO coupled to RO to produce high quality water and highly concentrated wastewater for nutrients recovery: 24 months project, $200,000(excluding salaries).
- Use membrane bioreactors (MBR) as an alternative to conventional treatment technologies to produce high quality water: 24 months projects, $200,000 (excluding salaries).
- Use osmotic membrane bioreactors (OMBR) as an alternative to conventional treatment technologies to produce high quality water: 36 months project, $300,000 (excluding salaries).
- Develop a CBA model to recycle treated wastewater with conventional advanced treatment (UF/RO/Disinfection): 6 months project, estimated budget $50,000.
- Consider and discuss new or emerging advanced treatment options and the potential

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[5] Typical plant: abattoir processing 150 tHSCW/day, 5 days/week, 250 days/year, 7 kL/day, including boning and rendering plants (Pagan et al., 2002). Water cost: $4.1/kL including purchase, pumping, treatment and disposal; recycled water cost: $3.6/kL (according to Ingham personal communication).

these have on changing the cost/benefit equation for recycled water. These options may have higher commercial risk as they remain unproven at this time, but have the potential to have a major impact on the future of recycling in the red meat industry.

- Public awareness/education about water recycling: 12 months project, estimated budget $50,000.

7.4 Technology readiness

- The majority of the advanced technologies are commercially available. More information on the different technologies are presented in Appendix D.
- OMBR is a new technology under research.

7.5 Key Risks

- Knowledge and understanding of how a specific treatment will impact a specific operation.
- Payback period.
- Public acceptance of water recycling in contact with meat products – misconception/perceived quality impacts.
- Regulatory restrictions on the use of recycled water.

7.6 Summary of Benefits

- Save town water intake and disposal costs
- Secure water consumption to freely operate
- Reduce dependence on external supplies by more than 70%
- Reach the “zero-discharge” challenge
- Produce sustainable products meeting customers demand
- Reduced energy demand (e.g. through hot water recycling)
- Improve operational performance (e.g. less chemical use for cleaning, boilers and cooling towers)
- Preserve product value

- Recover nutrients from the wastewater with market value

8 Conclusions/ Recommendations

By adopting water conservation, water reuse and/or water recycling, Australian abattoirs would be able to save from 5% to more than 70% of town water.

Water conservation should be the first strategy that abattoirs should implement. This strategy has a very high public acceptance. For example, by reducing the hose nozzle size and avoiding running water by replacing system with automated water start/stop controls, around 10% of potable town water can be reduced. Most of the water conservation measures have a payback of less than 1 year (A.PIA.0086).

Water reuse is another easy way to reduce significantly potable town water consumption and it has a very good public acceptance. The direct reuse of boning room waste and defrost chiller water to the cattle yard can save up to 15% of town potable water and it is already well established in several sites. However, some sites will need to install a drainage system to collect waste streams (estimated cost: $25,000; PRENV.030). The payback period of water reuse system is around 3 to 5 years (depending on the presence or not of drainage system).

Water recycling to non-potable level has a higher payback period (> 5 years), but can save more than 40% of potable town water. The main advantage to produce high quality recycled water, except saving water, is to protect chillers and boilers from corrosion and scaling systems. By doing so, the life time of the system will be extended and the cleaning reduced. This strategy has a very good public acceptance. Non-potable recycled water strategy is viable for medium to large sites.

Water recycling to potable standard does not necessary need more treatment than high quality non-potable water. However, this strategy will need to include monitoring and more testing to assure the water quality. Thus, the payback time will be higher than the non-potable water recycling strategy (around 10 years), but more than 70% of the total water use during the process will be recycled water. One of the major limitation to implement potable recycled water to Australian abattoir is the regulation and public acceptance. Currently, the majority of Europe is against the use of water recycled in contact with meat. Potable water recycling strategy is viable for large plant.

Process waste streams can be recycled at potable and non-potable standards. However, treatment technologies are not the limiting point to adopt water recycling at Australian abattoirs. Actual regulations are very strict and the use of recycled water as drinking water is not well accepted. Abattoirs (excluding EU establishments) which want to adopt water recycling as an alternative source of drinking water (potable standard in contact with meat) should communicate with AQIS and health regulators before starting any project.

Tey Bros. (now Teys Australia) Beenleigh site reduced town water consumption by more than 34% prior 2004 to 2007 (P.PIP.0172) partly by using recycled water for ante mortem yards and truck wash (which do not require water at potable standard). According to the actual regulation and the previous AMPC/MLA project research, future AMPC projects should focus on:

- Reduce by 40% water consumption by using recycled water at non-potable standard for medium to large sites.
- Take into account new technologies and their possible application in water recycling scheme to decrease the payback period, which is one of the barriers to adopt water recycling at abattoir.
- Use of ceramic membrane to reuse hot wastewater streams.

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10 Appendix A (developed in conjunction with 2016/1023)

10.1 Production of wastewater at red meat processing facilities

Australian red meat processing facilities generate large volumes of wastewater rich in organic contaminants and nutrients (Johns, 1995; Liu and Haynes, 2011). The wastewater is relatively concentrated with total organics in the order of 10,000 mg L^{-1} as COD, with high nitrogen and phosphorous levels. While potentially expensive, the removal of these contaminants is necessary in order to comply with water discharge regulations. These contaminants also make red meat processing facilities are strong candidates for advanced treatment processes aimed at removal and/or subsequent recovery of energy, nutrient, and water resources.

Processes such as covered anaerobic lagoons (CAL) and high-rate anaerobic membrane processes (AnMBR) generate revenue on the basis of energy recovery (payback 2-5 years) but leave residual nitrogen (200-400 mgN L^{-1}) and phosphorous (up to 50 mgP L^{-1}). The wastewater can be irrigated, but this generally requires very large land footprints; or discharged to sewer, but this can result in excessive trade waste charges (\$0.95 kL^{-1}, \$0.93 $kgBOD^{-1}$, \$1.80-2.10 kgN^{-1} and \$1.70-4.20 kgP^{-1}; QUU 2014/15 trade waste charges). In general,

- Existing treatment practices such as crusted or covered lagoons remove organics, but do not reduce N or P.
- Emerging nutrient recovery technologies, such as struvite precipitation are effective for P removal, but not suitable as a stand-alone technology for N recovery.
- Emerging processes such as Anammox allow economic removal of N, and are nearer to market, but do not offer the possibility for nitrogen or alternative product recovery.

These existing and developing wastewater technologies target specific contaminants in the wastewater and are not suitable as stand-alone technologies. The novel PPB process introduced by AWMC is a possible alternative, able to remove COD, N and P in one step.

Waste and wastewater originates from several major process operations at a slaughterhouse including cattle preparation, cattle slaughter, recovery of by-products and reprocessing of by-products (Liu and Haynes, 2011). Generally, waste streams from different processing areas are transported separately within the site then combined for bulk treatment (e.g. in an anaerobic lagoon). The structure of waste and wastewater handling processes varies between sites; however a recent investigation of 6 Australian meat processing facilities identified common trends (Jensen et al., 2014a). A general structure of wastewater handling practices is presented in Figure A.1. Combined slaughterhouse wastewater is composed of a mixture of grease, fat, protein, blood, intestinal content, manure and cleaning products (Johns, 1995). It contains high concentrations of organic matter (represented by chemical oxygen demand, COD); oil and grease (FOG); nitrogen (N); phosphorus (P) and other trace metals.

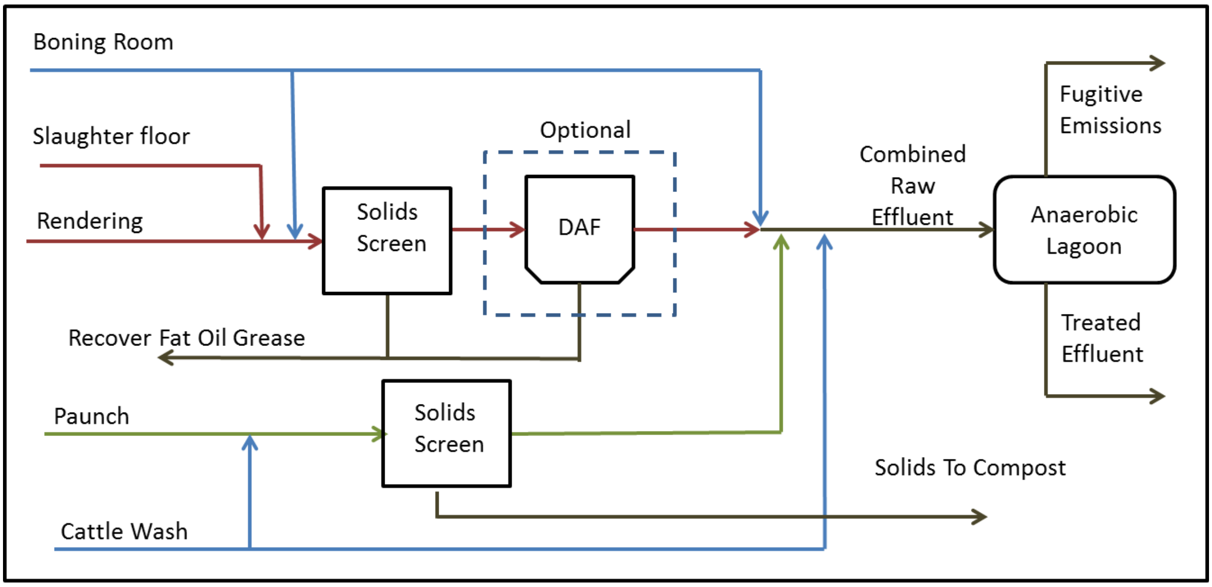

Figure A.1: Major wastewater sources and generalised structure of waste and wastewater handling practices at Australian red meat processing sites (Jensen et al., 2014b).

The composition of combined wastewater at these Australian red meat processing facilities is shown in Table A.1 while the compositions of slaughterhouse wastewater as reported in international studies are shown in Table A.2. The comparison shows that wastewater from Australian slaughterhouses is concentrated by international standards, both in regards to organic contaminants (COD) and nutrient (N and P).

Table A.1. Characteristics of Australian slaughterhouse wastewater after primary treatment/solids removal (A.ENV.0131 and A.ENV.0151).

	Volume m^3 d^{-1}	TCOD mg L^{-1}	sCOD mg L^{-1}	FOG mg L^{-1}	N mg L^{-1}	P mg L^{-1}	*TCOD:TN:TP ratio
Literature Concentration	-	2,000-10,000	-	100-600	100-600	10-100	100:6.0:1.0
Site A	2420	12,893	1,724	2,332	245	53	100:1.9:0.4
Site B	3150	9,587	1,970	1,300	232	50	100:2.4:0.5
Site C	2110	10,800	890	3,350	260	30	100:2.4:0.3
Site D	2150	12,460	2,220	3,300	438	56	100:3.4:0.4
Site E	1600	12,200	1,247	2,380	292	47	100:2.4:0.4
Site F	167	7,170	1,257	2,258	182	27	100:2.5:0.4

*based on maximum values

Table A.2. Characteristics of slaughterhouse wastewater after primary treatment/solids removal (Lemaire, 2007).

Reference	Country	TCOD mg L^{-1}	SCOD mg L^{-1}	FOG mg L^{-1}	TKN mgN L^{-1}	TP mgP L^{-1}	*TCOD:TKN:TP ratio
Borja et al. (Borja et al., 1994)	Spain	5,100	-	-	310	30	100:6.1:0.6
Caixeta et al. (Caixeta et al., 2002)	Brazil	2,000-6,200	-	40-600	-	15-40	100:XX:0.7
Li et al. (Li et al., 1986)	China	628-1,437	-	97-452	44-126	10-16	100:8.6:1.1
Manjunath et al. (Manjunath et al., 2000)	India	1,100-7,250	-	125-400	90-150	8-15	100:5.5:0.2
Martinez et al. (Martinez et al., 1995)	Spain	6,700	2,400	1,200	268	17	100:4:0.3
Nunez and Martinez (Núñez and Martínez, 1999)	Spain	1,440-4,200	720-2,100	45-280	-		
Russell et al. (Russell et al., 1993)	NZ	1,900	-	-	115	15	100:6.1:0.8
Sachon (Sachon, 1986)	France	5,133	-	897	248	22	100:4.9:0.4
Sayed et al. (Sayed et al., 1987)	Holland	1,500-2,200	-	-	120-180	12-20	100:8.2:0.9
Sayed et al. (Sayed and De Zeeuw, 1988)	Holland	1,925-11,118	780-10,090	-	110-240	13-22	100:2.2:
Stebor et al. (Stebor et al., 1990)	US	4,200-8,500	1,100-1,600	100-200	114-148	20-30	100:1.7:0.4
Thayalakumaran et al. (Thayalakumaran et al., 2003)	NZ	490-2,050	400-1,010	250-990	105-170	25-47	100:8.3:2.3

*based on maximum values

10.2 Current wastewater treatment practices at red meat processing facilities

Generally, waste streams from different processing areas are transported separately within the site then combined for bulk treatment (e.g. in an anaerobic lagoon). The structure of waste and wastewater handling processes varies between sites but the general processes in Australia include dissolved air flotation (DAF) as a pre-treatment to remove fat, oil and grease (FOG) and total suspended solids (TSS) (Figure A.2).

The DAF effluent is fed to an anaerobic treatment step. Anaerobic lagoons with hydraulic retention times (HRT) ranging between 7 and 14 days (Lemaire et al., 2009) are commonly used in tropical and equatorial temperate zones and engineered reactor systems (including activated sludge and UASB reactors) are commonly used in polar equatorial temperate zones. Anaerobic lagoons are effective at removing organic material (COD); however lagoon based processes also have major disadvantages including large footprints, poor gas capture, poor odour control, limited ability to capture nutrients and expensive desludging operations. Even in warmer climates, there is an emerging and strong case for reactor based technologies with focus on anaerobic biogas generation.

In the anaerobic step, organics will be converted to biogas and the organic bound nitrogen will be released as ammonium. Reliable biological COD and nitrogen removal systems have been successfully developed and applied for abattoir wastewater treatment using continuous activated sludge systems (Beccari et al., 1984; Frose and Kayser, 1985; Willers et al., 1993). However, removal of nitrogen through reactive biological processes requires energy input in aeration and carbon chemical addition. Novel removal technology such as the anammox process offer economic nitrogen removal with no need of external COD addition, but reactively removes ammonium as nitrogen gas. PPB is another emerging option to replace these existing (conventional) technologies for COD, N and P removal, with reductions in cost, energy consumption, footprint and elimination of chemical addition.

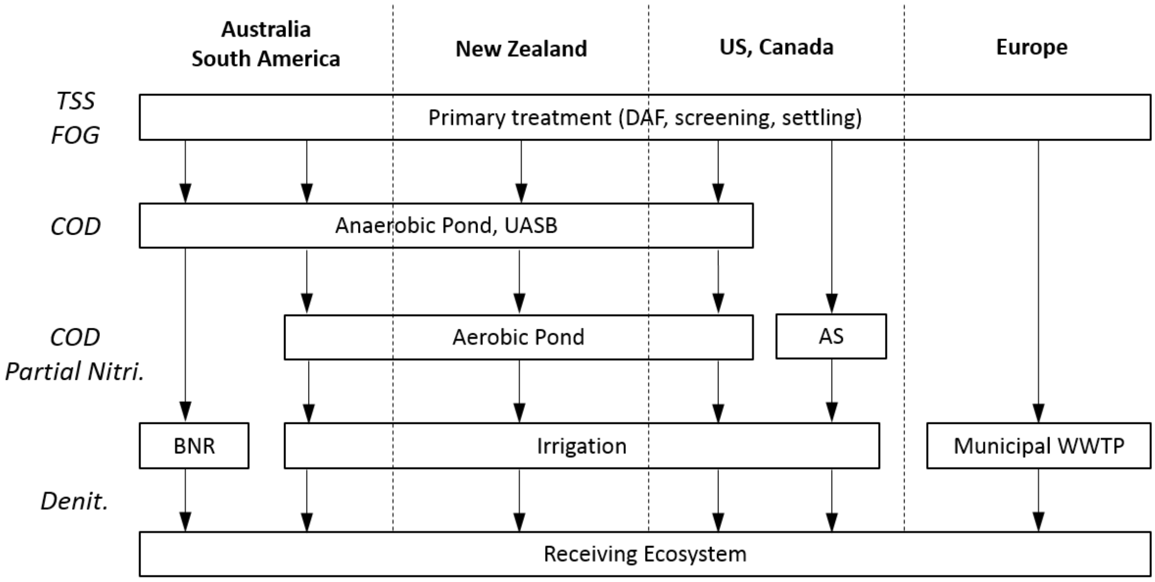

Figure A.2. Principal wastewater treatment set-up of the meat industry (Lemaire, 2007). Note: At some smaller Australian plants, primary treatment may be bypassed and/or raw effluent may be used for irrigation or land application.

10.2.1 Technologies for Removal of Organics

A brief summary of technologies for removal of organic contaminants and operational considerations for application to meat processing wastewater is shown in Table A.3.

Table A.3. Summary of anaerobic digestion technologies.

Technology	Principle	Advantages	Disadvantages	Loading rate (kgCOD.m^{-3}d^{-1})	COD removal efficiency
Crusted Anaerobic Lagoon	Large retention time, partially mixed vessel.	Very low capital cost	Very high footprint. Must be desludged. No methane capture/high carbon liability. Can produce odours. Very limited controllability	0.1	70-80%
Covered Anaerobic Lagoon	Large retention time, partially mixed vessel.	Low capital cost	Very high footprint. Must be desludged. Methane capture average. Can produce odours. Very limited controllability	0.1	70-80%
High Rate Anaerobic (Granular)	Mainly liquid wastewater flows upwards through a granular bed.	Low footprint, low capital cost, very stable, produces good effluent.	Intolerant to solids. Intolerant to fats.	10 (UASB) 20 (EGSB/IC)	80-90%
Anaerobic Membrane Bioreactors	Mainly liquid wastewater flows through a membrane that retains solids.	Low footprint, low capital cost, very stable, produces good effluent.	Moderate to high operating costs related to membrane.	3-6	>95%
Mixed Liquor digesters	Dilution to 3-6%, and continuous feed in mixed tank. Retention of 20 days. Used across many industries	Established tech Easy to control Continuous gas production	Poor volumetric loading rate Expensive tanks Need dilution liquid Liquid (not solid) residue	1-3	60-80%

Table A.3. Summary of anaerobic digestion technologies (next).

Technology	Principle	Advantages	Disadvantages	Loading rate ($kgCOD.m^{-3}d^{-1}$)	COD removal efficiency
Aerobic lagoons	Large retention times partially mixed vessel	Low capital costs Less odour problems	Very high footprint Must be desludged no methane production series of lagoons necessary	0.1 -0.3	80-90%
Conventional Activated sludge	Medium retention times Biomass settling with clarifiers and sludge recycling	Medium footprint Low capital costs Low operating costs produces good effluent	High sludge production Produces sludge side-stream No methane production	0.2 – 0.6	80-90%
PPB	IR light is used to drive uptake of COD, N and P into biomass	Simultaneous removal in one step, Low N and P	New technology, research needed Potential for high capital costs	1.0-10	Up to 95%

10.2.2 Technologies for Removal of Nutrients

A brief summary of technologies for removal of nutrient contaminants and operational considerations for application to meat processing wastewater is shown in Table A.4.

Table A.4. A comparison of the process features of different nutrient removal technologies.

Technology	Volumetric loading rates (kg.m^{-3}d^{-1})	TN removal (%)	Energy demand (kWh kgN$_{removed}^{-1}$)	Chemical Costs ($\$$ kgN $_{removed}^{-1}$)	Sludge Production (kgTSS kgCOD^{-1}.d^{-1})	Start-up (months)	Other process issues
Anammox	0.7-2.0	70-90% TN	1.0-1.8	-	~0.05	Up to 4 months	Poor tolerance to FOG
Nitrification/ Denitrification	0.1-0.3	Over 95% TN	4.6	-	0.2-0.4	Less than 1 month with inoculum	Sludge disposal costs or side-stream treatment train needed
Stripping	TBC	70-90%	25 including chemicals [22]	Included in energy demand	N/A	Less than 1 month	Only feasible at high NH_4-N >3000mg L^{-1}
Wetlands	TBC	Up to 70% TN	N/A	-	N/A	>12mont h	Very large footprint, limited removal efficiency
Crystallization	3-May	TP removal above 90%, but TN removal <20%	5.8 including chemicals	Included in energy demand	N/A	Less than 1 month	Low value fertiliser
PPB	Based on COD	Over 95% TN	1-2kWh For COD, N and P removal	-	0.8-0.95	Less than 3 month without inoculum	New technology, research needed

11 Appendix B – Wastewater Analysis from Australian Red Meat Processing Plants

11.1 Site A

11.1.1 Plant Description

Site A is situated in Queensland. This abattoir is capable to process 3,350 bovines per day. The red stream is firstly screened before mixture with the green stream (Figure B.1). The combined effluent is treated by sequencing batch reactor (SBR), aerobic pond and chlorination (Cl_2 = 0.5 mg/L) before discharging to the river. The main drawback of this plant is the mixture of human waste with the processes waste limiting the reuse of the actual final product.

Green stream Red stream

Pond Chlorinated final effluent (from black pipe)

Figure B.1. Sampling points at Site A.

11.1.2 Wastewater Compositions

On the day of the visit, the morning shift was cancelled. The results of the sampling gave an information on the wastewater quality. According to Table B.1, red and green waste streams are rich of nitrogen (N), organic carbon (measured by total organic carbon - TOC) and phosphate (PO_4). The green stream is more concentrated than the red stream. The wastewater treatment train of site A was able to remove around 95% of the TOC and N, which allow its discharge in the river.

Table B.1. Wastewater characteristics at Site A.

Stream	TOC (mg/L)	O&G (mg/L)	TKN (mg/L)	NH4 (mg/L)	TKP (mg/L)	PO4 (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	pH	EC (µS/cm)
Red	599	ND	161	141	6	10	18	27	324	68	7.4	1340
Green	790	ND	356	246	48	35	9	29	631	102	6.5	2380
Final product	26	ND	5	15	8	15	56	18	391	69	7.5	2210

TOC: Total Organic Carbon; O&G: Oil & Grease; TKN: Total Kjeldahl Nitrogen; EC: Electrical Conductivity; T: Temperature.

11.2 Site B

11.2.1 Plant Description

Site B is situated in New South Wales. This abattoir is capable to proceed 12,500 bovines per week. A.ENV.0151 (site D) described in details this site. Basically, the wastewater consists of four streams: combined red effluent, paunch handling, cattle yards, and boning room and chillers.

Combined red wastewater is passed through a contra-shear to remove solids and the remaining of the wastewater is sent to the saveall operation (DAF). This effluent is sent to the final effluent mixing pit and discharged with the combined wastewater to the anaerobic lagoon.

Paunch handling passes through a course screen and paunch screw to remove foreign and coarse solids. The remaining effluent is sent to the final effluent mixing pit and discharged with the combined wastewater to the anaerobic lagoon.

Part of the cattle yard is recycled from the defrost collection pit. Combined wastewater from the cattle yards is sent to an auger screw to remove coarse solids and then to the final effluent mixing pit and discharged with the combined wastewater to the anaerobic lagoon.

Boning room and chillers wastewater is recycled to the cattle yards.

Figure B.2 presents the process schematic of water use (proportion of total water use; %) and wastewater generation (adapted from A.ENV.151). Figure B.3 presents the sampling point related to Table B.2.

11.2.2 Wastewater Compositions

According to Table B.2, recycled water has a very good water quality close to drinking water quality (except for microbial, not tested in this project). The wastewater treatment train of site B was able to remove more than 95% of the chemical oxygen demand (COD) and around 20% of P. N concentration was still high in the final treated effluent, which is not an issue as this effluent is used for irrigation.

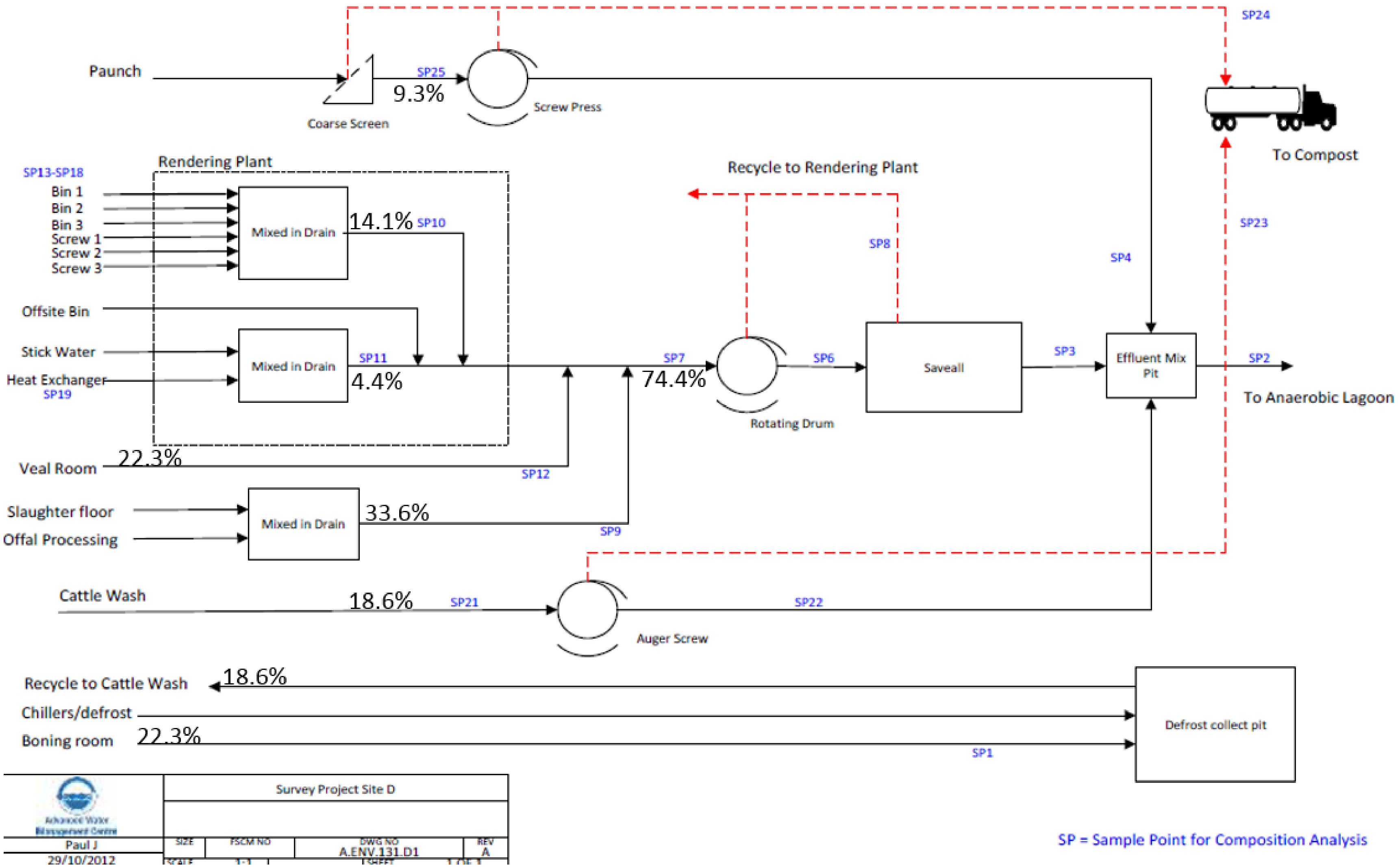

Figure B.2. Process schematic of water use (proportion of total water use; %) and wastewater generation (adapted from A.ENV.151). Sampling points (SP) are from project A.ENV.151.

Gut bin

Run off rendering screws/stick water

Bone Bin

Paunch line after grate (at railway line)

Combined paunch red stream

Stabilising settling save-all effluent before pumping to farm

Paunch effluent

Recycled reservoir

Pond

Figure B.3. Sampling points at Site B.

Table B.2. Wastewater characteristics at Site B.

Stream	TOC (mg/L)	FOG (mg/L)	TKN (mg/L)	NH4 (mg/L)	TKP (mg/L)	PO4 (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	pH	EC (µS/cm)	T (°C)
Gut bin	2342	1087	1960	185	150	92	25	46	1096	731	5	6630	65
Run off rendering screws/stick water	483	42	248	25	193	171	27	19	1694	336	7.7	3690	30.5
Bone bin	823	54	484	18	45	31	30	26	280	203	7.3	1222	65
Paunch line after grate	38	0	80	42	11	5	40	29	114	89	7.7	904	29.5
Combined paunch and red stream	693	13126	272	55	43	20	5	21	216	98	7.0	1131	44
Stabilising settling saveall effluent before pumping to farm	472	749	268	34	1	17	0	9	107	42	6.7	982	39.5
Paunch effluent	461	4554	178	38	22		10	18	146	62	7.2	816	44
Recycled water	14	0	156	2	0	0	14	8	28	2	6.8	472	Ambient
Average of 4 Ponds	20	0.2	204	188	31	27.5	21	12	120	47	7.4	2370	

TOC: Total Organic Carbon; O&G: Oil & Grease; TKN: Total Kjeldahl Nitrogen; EC: Electrical Conductivity; T: Temperature.

11.3 Site C

11.3.1 Plant Description

Site C is situated in Queensland. This abattoir is capable to proceed 1,400 cattle per day. This site uses screening, saveall, anaerobic and maturating ponds treatment processes. The trammel wash reuses water from viscera table. Figure B.4 presents a process schematic of water use and wastewater generation (adapted from P.PIP.0172).

11.3.2 Wastewater Compositions

In 2007, P.PIP.0172 project fully characterised the different wastewater streams (Table B.3) and determine the flows. According to Table B.3, boning room (5.5% of total flow) and chillers (1.5% of total flow) are very low contaminated effluents and could potential be reused directly without pre-treatment as non-potable water. Offal & pet food (2.6% of total flow) and miscellaneous (1.3% of total flow) are also low contaminated sources, but would need a screening process before reuse to remove solids. Saveall reduced total suspended solids (TSS) and FOG concentration. The anaerobic pond treatment reduces Biochemical oxygen demand (BOD) and COD concentration. Facultative and maturation ponds reduce organic loads and TSS to reach the discharge limit for irrigation to surrounding property and sewer.

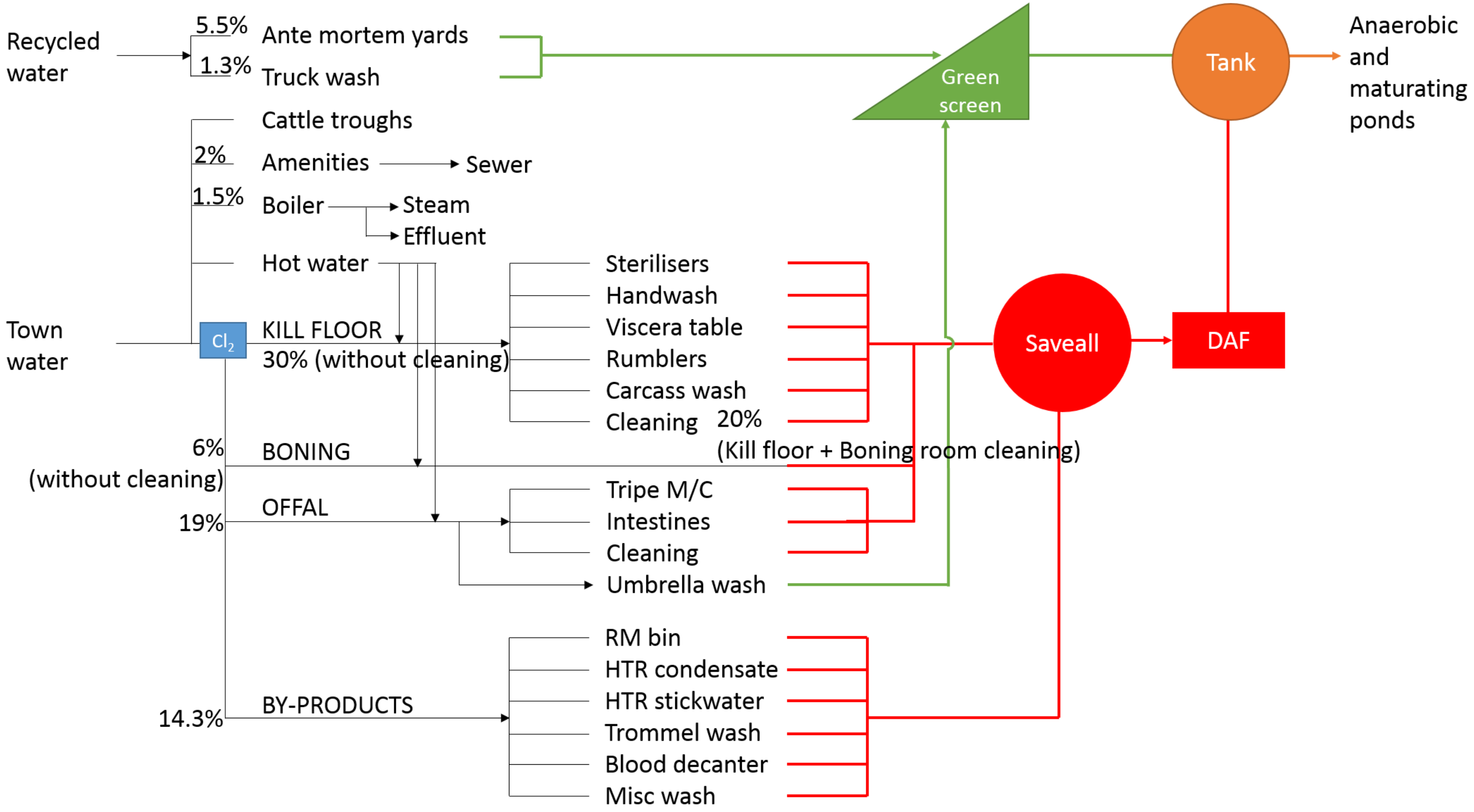

Figure B.4. Process schematic of water use (proportion of total water use; %) and wastewater generation (adapted from P.PIP.0172).

Table B.3. Wastewater characteristics at Site C (P.PIP.0172).

Stream	CODt mg/L	CODs mg/L	TSS mg/L	O&G mg/L	TKN mg/L	NH2N mg/L	TP mg/L	FRP mg/L	Cl mg/L	Ca mg/L	Mg mg/L	Na mg/L	pH mg/L	EC mg/L
Kill floor	1,550	685	505	195	100	4	3	1	32	8	3	16		
Boning room	103.5	71.5	38	35.5	3.4	0.32	0.37	0.1	32	14.5	3	18	7.13	193
Cleaning flow	6,500	1,835	4,430	670	265	10	23	15						
RM Bin (inside)	44,600	23,400	22,400	2,830	3,520	382	387.5	367	1,595	19.5	45.6	1405	6.33	10,315
RM Bin (screw outside	21,800	10,730	7,500	2,590	1,455	131.6	155.7	144	918	10	22.5	863	6.43	5,015
HTR condensate	526	394	47	148	192	182	0.3	0	91.5	0.5	0.5	0.5	9.22	931
Trommel wash	4,400	248	2,635	1,360	62	1.88	7.4	4	53.5	13	3.5	34	6.74	295
HTR stickwater	46,000	4,570	13,200	2,580	103	43.4	250	20	44	8	4	44	6.82	673
Blood decanter	42,900	7,990	11,300	29	4,200	121	120	48.7	3,590	8.5	8	2280	8.04	12,550
Misc uses	1,550	685	505	195	100	4	3.0	1.0	32	15	3	16		
Paunch drump dry	55,000	17,900	22,700	2,080	3,400	255	270	125	512	36	21	872		
Umbrella wash	1,240	1,120	3,505	293	276	137	143	102	256	18	11	436	8	3,490
Tripe processing	4,500	425	5,500	7,300	110	5	43	24	256	10	11	436		
Intestines	14,500	1,000	8,500	350	350	10	100	50	256	10	11	436		
Offal & pet food	310	214	114	106	10.2	0.9	1.1	0.31	96	43.5	9	54		
Antemortem yards	1,170	656	416	29	237	179	27	21	223	23	6	124	9	1,218
Truckwash	1,880	253	1,440	31	183	136	32	30	120	31	13	114	8	1,750
Chillers	103.5	71.5	38	35.5	3.4	0.319	0.365	0.10	32	14.5	3	18	7.13	193
WWTP use	9,245	3,605	3,980	1,510	198	33	18	12	98	6	5	87	7	866
Miscellaneous	500	300	280	20	50	32	10	6	32	14.5	3	18	7	200
Pre-anaerobic pond	5,820	2,285	1,775	344	232.5	80,8	37.5	33.6	131	5	5	172	7.22	1,885
Pre Saveall	9,245	3,605	3,980	1,510	198	33.45	25.9	11.9	97.5	6	4.5	87	6.94	866

CODt: Total Chemical Oxygen Demand; CODs: Soluble Chemical Oxygen Demand; TSS: Total Suspended Solids; O&G: Oil & Grease; TKN: Total Kjeldahl Nitrogen; NH3-N: Ammonia nitrogen; TP: Total Phosphorus; FRP: Ortho-phosphate phosphorus; EC: Electrical Conductivity.

11.4 Site D

11.4.1 Plant Description

Site D is situated in Victoria. This abattoir is capable to proceed 1,400 cattle per day. This plant has two main streams: stick water and other effluent. Only primary effluent is used to treat stick water.

11.4.2 Wastewater Compositions

Table B.4 presents the wastewater characteristics of stick water and combined effluent. These streams have a high COD and fat concentrations.

Table B.4. Wastewater characteristics at Site D (2013.5024).

Stream	CODt mg/L	CODs mg/L	Total fat mg/L	Crude protein mg/L	TN mg/L	Protein from TN mg/L	Flow rate
Combined effluent	13,500	1,000		1,170			Up to 243 kL/h
Stick water	58,200		22,000		1,980	12,000	9.4 kL/h (estimated)

12 Appendix C: Water Quality Requirements

Table C.1. Effluent discharge limits.

	Sewer[a]	Freshwater lakes & reservoirs[b,c]	Irrigation[b,d]
E. coli (CFU/100mL)		1000	
Thermotolerant coliforms (CFU/100mL)			1000[b]
EC (mS/cm)	Site specific	1	0.7-5c
Temperature (°C)	< 38		
pH	6.0 - 10.0	6.0 – 9.0	6 – 8.5
COD (mg/L)	Site specific		
BOD5 (mg/L)	Site specific		
SS (mg/L)	Site specific	< 10% change	
O&G (mg/L)	200	No noticeable film on the water, no detectable odour	
Nitrogen (mg/L)	100	1	5
Phosphorus (mg/L)	50	0.025	0.05d
Sodium adsorption ratio			18 - 102
Chlorine (mg/L)	10	0.002	
Chloride (mg/L)			230 - >460
Sulfate (mg/L)	2000		
Sulfite (mg/L)	100		
Sulphide (mg/L)	5	0.001 (as H_2S)	
Aluminium (mg/L)	100	0.055 (pH > 6.5)	20
Arsenic (mg/L)	5	0.024 (as ASIII) 0.013 (as AsV)	2
Beryllium (mg/L)			0.5
Boron (mg/L)	100	0.370	
Cadmium (mg/L)	2	0.0002	0.05
Chronium (mg/L)		1 (CrVI)	1
Cobalt (mg/L)	10		0.1
Copper (mg/L)	10	0.0014	5
Fluoride (mg/L)	30		2
Iron (mg/L)	100		10
Lead (mg/L)	10	0.0034	5
Manganese (mg/L)	100	1.9	10
Mercury (mg/L)	0.05	0.0006 (inorganic)	0.002
Molybdenum (mg/L)	Dependent on sludge guideline		0.05
Nickel (mg/L)	10	0.011	2
Selenium (mg/L)	5	0.011	0.05

Table C.1. Effluent discharge limits (next).

	Sewer[a]	Freshwater lakes & reservoirs[b,c]	Irrigation[b,d]
Cobalt (mg/L)	10		0.1
Copper (mg/L)	10	0.0014	5
Fluoride (mg/L)	30		2
Iron (mg/L)	100		10
Lead (mg/L)	10	0.0034	5
Manganese (mg/L)	100	1.9	10
Mercury (mg/L)	0.05	0.0006 (inorganic)	0.002
Molybdenum (mg/L)	Dependent on sludge guideline		0.05
Nickel (mg/L)	10	0.011	2
Selenium (mg/L)	5	0.011	0.05
Uranium (mg/L)			0.1
Vanadium (mg/L)			0.5
Zinc (mg/L)	10	0.008	5

[a] adapted from (ARMCANZ and ANZECC, 1997).

[b] adapted from (ANZECC and ARMCANZ, 2000).

[c] 95% level of protection.

[d] Long term trigger values for nitrogen, phosphorus, heavy metals and metalloids.

Table C.2. Summary of guideline values for microbial, chemical, physical and characteristics according to use.

Parameters	Livestock drinking water[e]	Cooling system[f]	Drinking water[g] for human consumption
E. coli **(CFU/100mL)**			0
Thermotolerant coliforms (CFU/100mL)	< 100	$< 10^5$	0
Coliphage (PFU/100mL)			0
EC (mS/cm)	0 – 7.5 (beef cattle)	0.05 - 0.6	Not necessary (<0.9 = good quality)
pH		7.8	6 – 8.5
COD (mg/L)		<40	
BOD_5 (mg/L)	<20		
Nitrogen			
Phosphorus			
SAR			
Chloride (mg/L)		<250	250
Calcium (mg/L)	1000		
Nitrate (mg/L)	< 1500		50
Nitrite (mg/L)	< 30		3
Sulfate (mg/L)	< 1000		500
Aluminium (mg/L)	5		
Arsenic (mg/L)	0.5 – 5		0.01
Beryllium (mg/L)	ND		0.06
Boron (mg/L)	5		4
Cadmium (mg/L)	0.01		0.002
Chronium (mg/L)	1		0.05
Cobalt (mg/L)	1		
Copper (mg/L)	1		2
Fluoride (mg/L)	2		1.5
Iron (mg/L)	Not sufficiently toxic		
Lead (mg/L)	0.1		0.03
Manganese (mg/L)	Not sufficiently toxic		0.5
Mercury (mg/L)	0.002		0.001
Molybdenum (mg/L)	0.15		0.05
Nickel (mg/L)	1		0.02
Selenium (mg/L)	0.02		0.01
Uranium (mg/L)	0.2		0.017
Vanadium (mg/L)	ND		
Zinc (mg/L)	20		

[a] Long term trigger values for nitrogen, phosphorus, heavy metals and metalloids.

[b] Pasture and fodder (for grazing animals except pigs and dairy animals, i.e. cattle, sheep and goats).

[c] For pastures from an average root zone leaching fraction of 0.33 (loam).

[d] To minimise bioclogging of irrigation equipment only.

[e] Adapted from (ANZECC and ARMCANZ, 2000).

[f] Adapted from (Lenntech, 2016).

[g] Adapted from (NHMRC and NRMMC, 2011).

Table C.3. Class A and A+ water quality objectives and treatment processes (Coliban Water, 2012).

Class	Water quality objectives	Treatment process
A	<10 *E. coli* org/100 mL pH 6 – 9 7 – log virus reduction 6 – log bacteria and protozoa reduction	Tertiary treatment and pathogen reduction with sufficient log reduction to achieve bacteriological parameters
A+	0 *E. coli* org/100 mL (test based on weekly basis) pH 6 – 9 9.5 – log virus reduction 8 – log bacteria and protozoa reduction	Tertiary treatment and pathogen reduction with sufficient log reduction to achieve bacteriological parameters. Online monitoring of processes.

13 Appendix D: Common Water Recycling Technologies

Table D.1. Summary of treatment technologies used in water recycling.

	Technology	Removal mechanism	Contaminant removal	Advantages	Disadvantages	Readiness
Pre-treatment	**Coagulation/flocculation**	Electrostatic Adsorptive Precipitation	Turbidity Suspended particles Colloidal Dissolved organic matter	Good pre-treatment. Low maintenance.	Chemical cost (coagulant + pH regulation)	Well established in drinking and recycled water treatment
	Granular activated carbon (GAC)	Adsorption	Turbidity Taste Odour Some organic contaminants Colour	Simple operation. Low maintenance. Low capital cost.	Large pore (> 30 µm). Water able to channel around GAC avoiding filtration. Limit of adsorption capacity.	Well established in drinking water treatment
	Biological activated carbon (BAC)	Biological	Turbidity Taste Odour Colour	Simple operation. Long life. Low maintenance. Low capital cost.	Limited adsorptive capacity. Main target compound removal by biodegradation.	Well established in drinking water treatment
	Sand filtration	Size exclusion	Protozoa Bacteria Turbidity Colour Taste Odour (only biofiltration rapid and SSF) Organic matter (only biofiltration)	Low capital cost. Low maintenance.	High footprint for slow sand filtration (SSF).	Well established in drinking water treatment

Table D.1. Summary of treatment technologies used in water recycling (next).

	Technology	Removal mechanism	Contaminant removal	Advantages	Disadvantages	Readiness
	Ion exchange resin	Charge attraction	Taste Odour Organic matter	Low maintenance.	Expensive. Brine disposal. Resin fouling. Not effective for high concentration of Fe, Mn and Al.	Used in the USA water treatment.
	Membrane Bioreactors (MBR)	Biological + Size exclusion	Protozoa Bacteria Virus Turbidity	Low footprint. Low capital cost. Very stable. Produces good effluent.	Moderate to high operating costs related to membrane.	Well established in water treatment
Membrane filtration system	**Microfiltration (MF)** Pore size > 0.05 – 10 µm	Size exclusion	Protozoa Bacteria Turbidity	Low energy consumption. Low surface space.	High chemical cleaning cost due to fouling. Feed temperature < 50ºC. High maintenance.	Well established in drinking and recycled water treatment
	Ultrafiltration (UF) Pore size > 0.01 – 0.05 µm	Size exclusion	Protozoa Bacteria Some virus Colloids	Low energy consumption. Low surface space.	High chemical cleaning cost due to fouling. Feed temperature <50ºC. High maintenance.	Well established in drinking and recycled water treatment
	Nanofiltration (NF) Pore size > 0.001 – 0.01 µm	Size exclusion Charge repulsion Diffusion Adsorption	Protozoa Bacteria Virus Up to Divalent ion Turbidity	Low surface space. Good removal using less energy than RO.	Sensitive to chlorine. High chemical cleaning cost. High fouling rates: Pre-treatment necessary. Feed temperature < 50ºC. High maintenance.	Well established in drinking and recycled water treatment

Table D.1. Summary of treatment technologies used in water recycling (next).

	Technology	Removal mechanism	Contaminant removal	Advantages	Disadvantages	Readiness
Membrane filtration system	**Reverse osmosis (RO)** Pore size < 0.002 µm	Size exclusion Charge repulsion Diffusion Adsorption	Protozoa Bacteria Virus Up to monovalent ion Colour Organic matter Odour Heavy metal Turbidity	High removal efficiency. Produce high quality water Low surface space.	High energy consumption Sensitive to chlorine. High chemical cleaning cost. High fouling rates: Pre-treatment necessary. Feed temperature < 50°C. High maintenance.	Well established in drinking and recycled water treatment
	Ceramic membrane Pore size > 0.001 µm	Size exclusion	Depending on pore size: Protozoa Bacteria Virus TSS Turbidity Divalent ion	Very robust membrane to pH, chemicals, temperature. Low surface space. Easy to clean. Inert surface.	High capital cost related to membrane.	Not as popular as polyamide membranes, but becoming more affordable
	Metallic membrane Pore size: 0,5 µm to < 1 nm	Size exclusion	Depending on pore size: Protozoa Bacteria Virus TSS Turbidity Divalent ion	Very robust membrane to pH, chemicals, temperature. Cost-effective Low fouling rates Easy to clean	High capital cost. Low surface membrane per module volume. Possible toxicity.	Not as popular as polyamide membranes. Commercially available.

Table D.1. Summary of treatment technologies used in water recycling (next).

	Technology	Removal mechanism	Contaminant removal	Advantages	Disadvantages	Readiness
	Forward osmosis (FO)	Osmosis gradient	Protozoa Bacteria Virus Colour Organic matter Odour Heavy metal Turbidity Salt	Low energy consumption. Work with dirty water.	Lower water flow than RO. Not as competitive as RO. Industrial acceptance.	Not as widely used as RO, but few commercialisation (new technology)
	Membrane Distillation (MD)	Mass transfer induce by vapour pressure difference	Ion Heavy metal Turbidity TSS Protozoa Bacteria Virus Organic matter	Only gas water going through membrane	Expensive technique. High energy demand. Pro to fouling	Widely employed in desalination and food industries
Disinfection system	**Chlorination**	Inactivation	Bacteria Virus Colour	Cost effective technique. No maintenance.	Does not remove/inactivate protozoa. Formation of disinfection by-products in presence of organic matter. Long residual. pH dependent.	Well established in drinking and recycled water treatment

Table D.1. Summary of treatment technologies used in water recycling (next).

	Technology	Removal mechanism	Contaminant removal	Advantages	Disadvantages	Readiness
	Ozone	Oxidation	Protozoa Bacteria Virus Organic matter Taste Odour Colour	Short residual.	Complex technology. High maintenance. Aggressive odour.	Well established in drinking and recycled water treatment
	UV	Irradiation	Bacteria Virus	Short residual.	Only efficient in low UV transmittance waters	Well established in drinking and recycled water treatment

Table D.2. Summary of removal efficiency of the different water treatment technologies based on tertiary effluent quality.

	Coagulation/flocculation	Granular activated carbon (GAC)	filtration with biological activity	filtration without biological activity	Ion exchange/MIEX (magnetic IEX)	Membrane bioreactor (MBR)	Microfiltration	Ultrafiltration	Nanofiltration	Reverse Osmosis	Forward Osmosis	Distillation (MED, MSF)	Chlorination	Ozonation	UV treatment
Bacteria	3	4	3	2	4	1	1	1	1	1	1	1	1	1	1
Protozoa	3	4	3	2	4	1	1	1	1	1	1	1	3	1	1
Viruses	4	4	4	3	4	1	2	1	1	1	1	1	1	1	1
Turbidity/Suspended solids	2	2	2	2	3	1	1	1	1	1	1	1	4	4	4
Taste & odour	4	2	2	4	3	4	4	4	2	1	1	2	3	1	2
Colour	2	3	3	4	3	2	4	2	1	1	1	1	2	1	3
Heavy metals	2	3	4	4	2	2	4	4	2	1	1	1	4	4	4
Manganese	2	3	3	2	2	2	4	4	2	1	1	1	4[b]	4	4
Salinity	4	4	4	4	4	4	4	4	2	1	2[a]	1	4	4	4
Algal cells	2	3	2	2	3	2	1	3	1	1	1	1	2	1	4
Dissolved organic matter	1[c]	3	3	4	2	2	4	3	1	1	1	1	3	2	4
Organic pesticides	4	2	3	4	4	4	4	4	2	1	1	1	3	2	4

[a] Depending on the draw solution.

[b] Chlorination oxidises Mn to precipitate it and to remove it by filtration.

[c] It is the major technique to remove DOM before membrane treatment.

1: good removal.

2: Fairly good removal.

3: poor removal.

4: no removal.

14 Appendix E: Review of Water Recycling Case Studies

Indirect and direct potable reuse (IPR and DPR) plants are built around the world to produce high quality potable recycled water fit-for-purpose from wastewater as an alternative to natural sources. Always used as a multi-barrier approach the most common technologies applied in the treatment trains are: membrane filtration (microfiltration (MF)/ reverse osmosis (RO)) and several disinfection systems, such as chlorination, ultraviolet light (UV), and advanced oxidation processes. RO filtration is often used as the last physical barrier and generally placed before final disinfection due to its high capacity to remove pathogens and salt. However, this technology is costly due to it is high energy demand (high pressure membranes), high maintenance requirements and high chemical use for cleaning purposes essentially.

Two Queensland food industries successfully implemented a water recycling scheme in their factory which are detailed below. To successfully implement a potable water recycling plant, it is necessary to monitor the different processes/barriers to assure their integrity for contaminant removal. Australia has started to develop national guidelines to monitor different water treatment technologies such as ozone, membrane bioreactor and reverse osmosis (AWRCoE, 2014). The main interests of these guidelines are to reduce the commissioning time and cost of a water treatment plant and to hopefully help to increase the public acceptance toward water recycling.

14.1 CUB Yatala brewery, QLD

Yatala Brewery (Hertle et al., 2009) is a prime example of the successful application of a water recycling scheme. To avoid the cost of the expansion of the city wastewater treatment plant, Yatala brewery decided to build a wastewater treatment plant within its factory in 1993. Because of the drought, the brewery opted for a water recycling plant to save on extensive costs in water and wastewater discharge. The domestic sewage was excluded from the recycling reducing regulatory compliance requirements and the risk of adverse public perceptions. The treatment plant includes a primary clarifier, anaerobic sludge blanket, dissolve air flotation, microfiltration, reverse osmosis and disinfection (Figure C.1). The end uses of the recycled water are cooling systems, boiler feed, cleaning in place system, pasteurization, pre-cleaning vessels and pipes (but not the final rinses), floor washing, toilet flushing and irrigation. The recycled water is not used to produce beer because of international regulation limitations (especially EU), which continues to be the main challenge. Even with the water quality meeting the Australian drinking water guidelines. The upflow anaerobic sludge blanket allows to recover 90% of the energy contained in the wastewater and the reverse osmosis brine. Captured biogas is used to gas-fire boiler. The cost of building their own wastewater plant was $4.3 million (in 1993) to compared to $3 - 4 million (in 1993) of avoided headwork charges, and trade waste discharge fees. The capital costs associated to the water recycling plant was around $15 million including all the approvals, planning, design and construction of the plant and integration of recycled water and biogas into the brewery. Queensland government provided $5 million support through the business water efficiency program. The operating and maintenance costs of the water recycling plant are around $1.2 million/annum, while the water consumption, wastewater discharge and energy savings are more than triple around $4.2 million/annum. Thus, the water recycling plant had a payback period of only 5 years. The actual water recycling cost is *ca.* $1.6/kL.

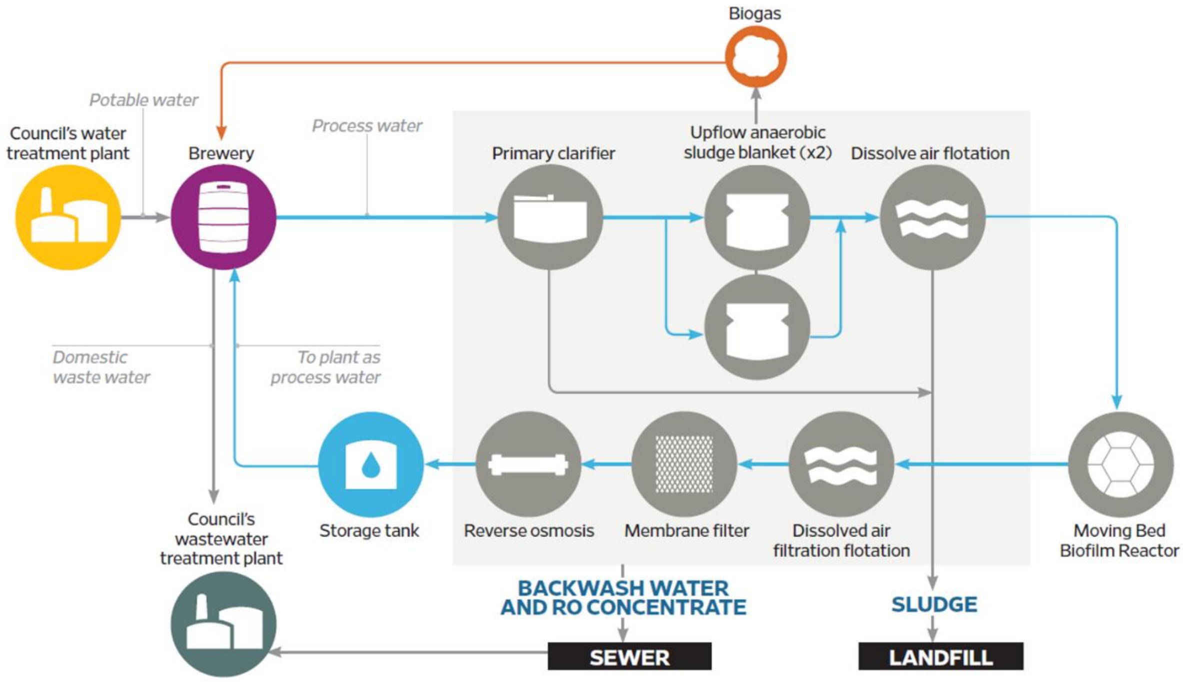

Figure E.1. Treatment train at Yatala brewery, QLD (Hertle et al., 2009).

14.2 Ingham poultry, Murarrie QLD

Ingham poultry is a successful example of the implementation of potable recycled water in its process factory. In 2009, Ingham poultry opened an advanced water treatment plant (AWTP) at Murarrie site (QLD) to reuse its process waste (no human waste) reducing 70% of its water supply (72% in 2016). The treatment train includes biological nutrient removal (anaerobic pound, DAF, SBR and decantation tank), membrane separation processes (sand filter, MF and RO) and disinfection (ultraviolet and chlorination) (SAI Platform Inc, 2016). The AWTP can produce up to 4 ML/day of high quality recycled water. Today, the recycled water costs around $3.6/kL (including waste disposal and acid costs) in comparison to $4.1/kL for town water (waste disposal cost excluded: $0.91/kL volume discharge + $1/kL penalty for quality changed). This site already decreased its water usage by 20% by adopting water saving protocols such as trigger guns on hoses, water efficient sprays on processing equipment and internal recycling through liquid ring vacuum pump (Seddon, 2012). However, Murarrie site increases its electricity usage by 8%, but recovered it by using biogas. Finally, another advantage of the AWTP is the reduction of nitrogen load to sewer decreasing the disposal costs. A two pipe system has been implemented in the factory avoiding the mixture between recycled water and drinking water. The recycled water is not used for drinking water, amenities (to avoid worker reluctance), safety shower, ice and during chicken slaughter process. Before permission to use the recycled water in processing, extensive microbial and chemical tests were undertaken for three months to demonstrate that the final quality product met the Australian drinking water guidelines (NHMRC and NRMMC, 2011). The final recycled water is tested before use for pH, turbidity and chlorine (target 1 mg/L). Microbial tests (*E. coli*, total coliform, *Salmonella*, *Staphylococcus* and *Clostridium*) are conducted weekly and somatic coliphage every six months. The total cost of the AWTP was $16 million (around $5 million support received from the government) and the estimated payback is of 10 years. Ingham poultry is an example of the possibility to use recycled potable water on site in contact with meat.