AMPC

Investigating water and wastewater reuse and recycling opportunities: identification and segregation of various waste streams

PROJECT CODE:	2017.1042
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DATE SUBMITTED:	12/2017
DATE PUBLISHED:	07/18
PUBLISHED BY:	AMPC

AUSTRALIAN MEAT PR

The Australian Meat Processor Corporation acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

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ABBREVIATIONS

AAR	Anaerobic Ammonium oxidation Reactor
AL	Aerobic Lagoon
AnL	Anaerobic Lagoon
AnMBR	Anaerobic Membrane Bioreactor
AWTP	Advanced Water Treatment Plant
BNR	Biological Nutrient Removal
BOD	Biochemical Oxygen Demand
CAL	Covered Anaerobic Lagoon
CBA	Cost Benefit Analysis
COD	Chemical Oxygen Demand
HSCW	Hot Standard Carcass Weight
LRV	Log Removal Value
MBR	Membrane Bioreactor
MF	Microfiltration
NPV	Net Present Value
SBR	Sequential Batch Reactor
TSS	Total Suspended Solids
RO	Reverse Osmosis
UF	Ultrafiltration
UV	Ultraviolet

1.0 EXECUTIVE SUMMARY

In Australia, the red meat processing industry has undergone significant change in the past 20 years from basic to more sophisticated wastewater management practices. However, water recycling is still not well implemented due to the treatment cost and the stringent legislation.

The objectives of this project focused on the development of comparison and assessment tools in the form of cost-benefit analysis (CBA) models for wastewater treatment and water recycling options based on literature data.

Three high level of treatment process flowsheets were developed for abattoirs processing 500 – 1500 heads per day of beef cattle:

// Option 1: Covered anaerobic lagoon followed by biological nutrient removal technology (CAL-BNR);

// Option 2: Lagoon system anaerobic and aerobic ponds (AnL-AL);

// Option 3: Anaerobic membrane bioreactor followed by anaerobic ammonium oxidation (AnMBR-AAR).

After consultation with AMPC members, options 2 and 3 were selected to further develop the CBA models for water recycling options:

// Non-potable water recycling: more than 40% of the town water consumption can be saved by using non-potable water for truck washing, amenities, fire control, cleaning in place system, inedible offal processing, steam production (not in contact with meat and meat products), cattle drinking water, animal washing (not final) and floor washing.

// High quality water recycling: around 70% of the town water consumption can be saved by using high quality water. However, depending on the export country, abattoir cannot use the recycled water as a direct ingredient in meat products or use it for drinking water at the establishment.

The treatment trains developed were:

// Option 1:

CAL, SBR, MF/UF and chlorine for non-potable reuse;

CAL, SBR, MF/UF, RO, UV/H_2O_2 and chlorine for high quality water reuse.

// Option 3:

AnMBR, AAR, MBR and chlorine for non-potable reuse;

AnMBR-AAR, MBR, RO, UV/H_2O_2 and chlorine for high quality water reuse.

This report describes how to use the CBA model spreadsheets for decision making on future implementation of water recycling scheme in abattoir. It has to be noted that no detailed quotation has been obtained for this project, and the cost estimate is a preliminary estimate only. It is recommended to involve AQIS and Queensland health at an early stage of the process to ensure their

agreements to use water recycling within the abattoir.

2.0 INTRODUCTION

The main objective of this project is to progress water recycling and reuse in the red meat industry by providing a selection and assessment tool, incorporating cost benefit analysis (CBA), that will enable AMPC and industry members to evaluate specific water treatment options with consideration of raw water quality and desired end use application.

Both water supply and wastewater treatment/disposal represent substantial costs to Australian meat processors. This project will evaluate the cost of common wastewater treatments used in abattoirs and their potential associated benefits (e.g. energy and water saving) depending on the end-use (river discharge, sewer discharge, irrigation or internal reuse as potable or non-potable water). When considering the benefits of water recycling, the quality of wastewater from existing treatment systems has a significant impact on additional treatment required to enable recycling. This influences the cost of further treatment and therefore the value proposition of water recycling. This work builds on previous research and investment by AMPC (A.PIA.0086, 2016.1021) that identified wastewater segregation and recycling as a potentially advantageous option, warranting future investigations with the goal of reducing water usage and increasing recycling and reuse.

Recent advances in technologies and operating strategies for water recycling have initiated the uptake of safe, economic solutions across many food and beverage industries. The meat processing industry, with its large water footprint, can potentially gain substantial economic and operational benefits, whilst not compromising food safety from such an approach.

While water recycling options are increasingly being implemented in other industries, and occasionally also in meat processing operations, it is crucial that a strategic and well-structured approach is taken to maximize the achievable benefits and successful implementation across the sector. This project will take a broad, strategic look at the opportunities and constraints for improved water efficiencies at abattoirs using diverse water recovery options.

This report describes how to use the CBA model spreadsheets created during this project.

3.0 PROJECT OBJECTIVES

The objectives of this project focused on the development of comparison and assessment tools in the form of CBA models for wastewater treatment and water recycling options.

3.1 Wastewater treatment

// Develop a CBA model (energy and water saving) using a nominal (industry "average") raw wastewater and treated water quality.

3.2 Water recycling option

// Develop a CBA model to assess reuse of treated wastewater with conventional advanced treatment (UF/RO/disinfection) at both non-potable and highly purified recycled water standards.

// Consider and discuss new or emerging advanced treatment options and the potential 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 higher impact on the future of the recycling in the red meat industry.

4.0 METHODOLOGY

4.1 Wastewater characteristics and treatment processes

The raw wastewater pollutant loads were estimated from previous AMPC reports (AMPC report 2013-5047, A.ENV.131; A.ENV.151; P.PIP.0172; M.445). The following values were adopted for this study:

- // Average clean water usage: 8.6 kL/t HSCW (AMPC report 2013-5047);
- // Average weight of one animal = 0.6 t (A.ENV.131);
- // HSCW = 60% beef weight (A.ENV.131);
- // Average weight of one head = 0.360 t (A.ENV.131).

The concentration of contaminants was determined assuming that all treatment plants have screening and fat removal as pre-treatment. Table 1 summarises the principle contaminants used to design the concept treatment processes. A detailed wastewater characterisation is presented in Appendix 1, including an estimation of pathogens concentration based on one sampling event (UQ internal data).

Table 1. Wastewater flow, concentration and load for the development of treatment process flowsheets.

	Concentration	*Load (example)*
Production level		1,000 head.d^{-1}
Wastewater production		3,096 kL.d^{-1}
COD	8,500 mg.L^{-1}	26,316 kg.d^{-1}
TSS	3,000 mg.L^{-1}	9,288 kg.d^{-1}
Nitrogen	250 mg.L^{-1}	774 kg.d^{-1}
Phosphorus	45 mg.L^{-1}	139 kg.d^{-1}

COD: Chemical Oxygen Demand.
TSS: Total Suspended Solid.

From this typical raw wastewater characteristics, three high level of treatment process flowsheets were developed for abattoirs processing ~1000 heads per day of beef cattle.

- // Option 1: Covered anaerobic lagoon followed by biological nutrient removal technology (CAL-BNR);
- // Option 2: Lagoon system anaerobic and aerobic ponds (AnL-AL);
- // Option 3: Anaerobic membrane bioreactor followed by anaerobic ammonium oxidation (AnMBR-AAR).

Table 2 summarises the design basis and the contaminant removal efficiency adopted to create wastewater treatment flowsheets. The treated wastewater quality of the three options is compared to the effluent discharge limits for sewer, irrigation and surface water (10.1 Appendix 1).

Table 2. Wastewater process design and contaminants removal estimation.

	Design		*Contaminant removal*	
Treatment process	*Estimation*	*Reference*	*Value*	*Reference*
Aerobic lagoon (AL)	HRT = 3 d	Dr P. Jensen	COD = 97%	Dr P. Jensen
	N loading rate = 0.1 kg/m^3/d		TSS effluent = COD effluent / 1.4	
			N = 90%	
			P = P influent – (TSS solids * 0.02)	
Anaerobic ammonium oxidation (AAR)	AAR loading rate = 0.3	Dr P. Jensen	COD = 20%	Dr P. Jensen
			TSS removal = 20%	
			Final N concentration = 50 g/kL	
Anaerobic lagoon (AnL)	HRT = 20 d	Dr P. Jensen	COD = 80%	Dr P. Jensen
	Depth = 5 m		TSS = 80%	
Anaerobic membrane bioreactor (AnMBR)	OLR = 6 kg/kL/d	Dr P. Jensen	COD = 95%	Dr P. Jensen
	Flux = 10 L/m^2 h		TSS removal = 80%	
Covered anaerobic lagoon (CAL)	HRT = 20 d	Dr P. Jensen	COD = 80%	Dr P. Jensen
	Depth = 5 m		TSS = 80%	
Sequential batch reactor (SBR)	MLVSS = 4 kg/L	A.ENV.0044	BOD_5 effluent = 10 mg/L	NSW EPA (MLA enviro best practice manual)
	N loading rate = 0.04	(Metcalf & Eddy, 2004) Table 8-16, p747	TSS effluent = 15 mg/L	
	F/M > 0.04 d^{-1}		N effluent = 10 mg/L	
Struvite removal	HRT = 2 h	Dr P. Jensen	$[P]_{effluent} = 10/V_{effluent} * 1000$ (kg/d)	Dr P. Jensen
	Mixing HRT = 0.5 h			
	Chemical dosing ratio = 2			

4.2 Advanced water treatment processes

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 of 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 come into contact with meat or meat surfaces to avoid the risks of meat contamination. Therefore, this non-potable water can be used for such activities as:

- Stockyard wash,
- Truck wash,
- Amenities,
- Irrigation.

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). Red meat processors 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.

Non-potable water and high quality recycled water can be safely produced from abattoir treated wastewater effluent following the Australian guidelines for water recycling (NRMMC et al., 2006, NRMMC et al., 2008). According to this document, a multiple-barrier approach should be used to ensure public health, as no single barrier is effective against all hazards or all of the time (NRMMC et al., 2008). Conventional advanced water treatments including membrane filtration and disinfection systems are used to produce safe recycled water fit-for-purposes. Table 3 summarises the treatment processes used in CBA models to produce non-potable water and high quality recycled water. Other polishing treatment might be needed essentially to protect membrane filtration and are not included in the model.

Table 3. Advanced water process design and contaminants removal estimation.

	Design		*Contaminant removal*	
Treatment process	*Estimation*	*Reference*	*Value*	*Reference*
Ultrafiltration/microfiltration (UF/MF)	Recovery = 90%	(Wilf, 2010) Table F.2, p774	V = 2.5 LRV	(NRMMC et al., 2006)
	Permeate flux = 40 L/m^2 h		B = 3.5 LRV	
	Membrane are = 50 m^2		P = 4 LRV	
	Number of train = 1+1			
Membrane bioreactor (MBR)	Permeate flux = 15 L/m^2 h	(Wilf, 2010)	V = 4 LRV	(WaterSecure, 2017)
	MLVSS = 4 kg/m^3		B = 4 LRV	
	N loading rate = 0.04		P = 4 LRV	
	F/M = 0.1 d^{-1}			
Reverse osmosis (RO)	Recovery = 75%	(Wilf, 2010) Table F.2, p774	TDS removal = 98%	(NRMMC et al., 2006)
	Permeate flux = 17.5 L/m^2 h		V = 4 LRV	
	Membrane area = 40 m^2		B = 4 LRV	
	Number of train = 1+1		P = 4 LRV	

Table 3. Advanced water process design and contaminants removal estimation (continued).

	Design		*Contaminant removal*	
Treatment process	Estimation	*Reference*	*Value*	*Reference*
Ultraviolet/hydrogen peroxidase (UV/H_2O_2)	UV dose = 40 mJ/cm^2 UV transmittance = 75% Max. hydraulic loading rate = 15 L/min lamp Number of reactor 1= H_2O_2 dose = 6 mg/L	(USEPA, 2006)	V = 0.5 LRV B = 4 LRV P = 4 LRV	(USEPA, 2006)
Final chlorination (storage tank)	[$NaOCl^-$] = 1 mg/L Contact time = 60 min	(NHMRC and NRMMC, 2011)	V = 2 LRV B = 2 LRV P = 0.5 LRV	(NHMRC and NRMMC, 2011) Table 3.4, p95

4.3 Limitations

The University of Queensland has prepared preliminary cost estimates as part of developing a cost benefit analysis (CBA) tool for recycled water implementation at red meat abattoirs using information reasonably available to the University of Queensland employee(s) who prepared this report; and based on assumptions and judgments made by the University of Queensland, which are detailed within the CBA tool.

The CBA tool has been prepared for the purpose of assessing the potential viability of adopting wastewater treatment and recycled water at red meat abattoirs and should not be used for any other purpose.

The Cost Estimate is a preliminary estimate only. Actual prices, costs and other variables may be different to those used to prepare the Cost Estimate and may change. Unless as otherwise specified in the CBA tool, no detailed quotation has been obtained for actions identified in this report. The University of Queensland does not represent, warrant or guarantee that any future project can or will be undertaken at a cost which is the same or less than the Cost Estimate generated by the CBA tool.

Where estimates of potential costs are provided with an indicated level of confidence, notwithstanding the conservatism of the level of confidence selected as the planning level, there remains a chance that the cost will be greater than the planning estimate, and any funding would not be adequate. The confidence level considered to be most appropriate for planning purposes will vary depending on the conservatism of the user and the nature of the project. The user should therefore select appropriate confidence levels to suit their particular risk profile.

5.0 CBA DEVELOPMENT

5.1 Wastewater treatment

In abattoirs, the composition of waste streams and the treatment processes are site dependent. Generally, these streams are collected from the different processing and transported separately. There are two broad categories of waste streams:

- 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.

Typically, they are combined and pre-treated to remove coarse, fat, oil and grease to feed an anaerobic process. In the anaerobic treatment, organics will be converted to biogas and organic bound nitrogen will be released as ammonium. The conventional anaerobic process used in the Australian meat industry is the anaerobic lagoon (with or without a cover). Following anaerobic treatment, the effluent feeds to an aerobic/facultative treatment step to remove nitrogen and residual organic carbon. The final effluent is generally discharge to sewer, waterway, or reused for irrigation and stockyard and truck washing.

Three CBA models were developed in Microsoft Excel assuming that all treatment plants have screening and fat removal as pre-treatment:

- // Option 1: Covered anaerobic lagoon followed by biological nutrient removal technology (CAL-BNR);
- // Option 2: Lagoon system anaerobic and aerobic ponds (AnL-AL);
- // Option 3 (emerging scenario): Anaerobic membrane bioreactor followed by anaerobic ammonium oxidation (AnMBR-AAR).

Option 1 is a common scenario using CAL followed by a BNR plant. CAL is widely used in the red meat industry due to its high capacity to remove biochemical oxygen demand (BOD) and COD efficiently and at relatively low cost. By covering the anaerobic lagoon, biogas generated can be captured and reused within the abattoir for energy generation. For the CBA, CAL efficiency was set to 80% of COD and TSS removal. The theoretical yield of methane (CH_4) from the CAL was set at 0.35 m^3/kg COD removed. The BNR process selected was a sequential batch reactor (SBR). Basically, SBR is an activated sludge system where the clarification and oxidation steps occur in the same tank (Metcalf & Eddy, 2004). The efficiency was set to 90% for COD and TSS removal, and 80% for nitrogen removal. To recover phosphorus, a struvite crystallization process was selected using $Mg(OH)_2$. Phosphorus removal was calculated following Equation 1.

$$P_{effluent} = \frac{10}{Q_{effluent} \times 1000} \qquad (1)$$

Where $P_{effluent}$ is the concentration of phosphorus in the effluent (kg/d) and $Q_{effluent}$ the effluent flow (kL/d).

Figure 1a presents the concept flowsheet for this option. In this process, a flow deviation line was included to direct some raw wastewater flow to the SBR to supply sufficient carbon for denitrification (food microorganism ration > 0.04 d^{-1}) (Metcalf & Eddy, 2004).

Option 2 used an anaerobic lagoon (AnL) followed by an aerobic lagoon (AL). Lagoon systems are often used for the treatment of red meat processing wastewater due to their efficiency to remove high level of COD, TSS and nitrogen at low cost. AnL efficiency was set to 80% of COD and TSS removals. AL efficiency was set to 97% of COD removal and 90% of nitrogen removal. Figure 1b presents the flow diagram of this option.

Option 3 used an anaerobic membrane bioreactor (AnMBR) followed by an anaerobic ammonium oxidation (AAR) process. AnMBR is an alternative to lagoon for high solids and fatty wastewaters. It integrates membrane filtration with anaerobic digestion combining energy recovery and solids retention. Its efficiency was set to 95% of COD removal and 80% of TSS removal. AAR is an anaerobic process oxidizing ammonium directly to nitrogen gas using nitrite as electron donor (A.ENV.0162). Its loading rate was set to 0.3 kg/m^3/d with a final concentration of 50 mg/L of nitrogen, and 20% of COD and TSS removals. AAR is not well established in Australia and is still under development. The treatment of slaughterhouse wastewater might be challenging for this process but still feasible as the COD:N ratio of AAR influent is under 2, which is the threshold limit to suppress AAR activity (Chamchoi et al., 2008). Furthermore, AnMBR pre-treatment transforms the majority of total nitrogen in the form of ammonia (NH_3), which is the recommended form for AAR reaction (A.ENV.0162). To recover phosphorus, struvite removal process was selected and phosphorus removal was calculated following Equation 1. Figure 1c presents the flowsheet of this option.

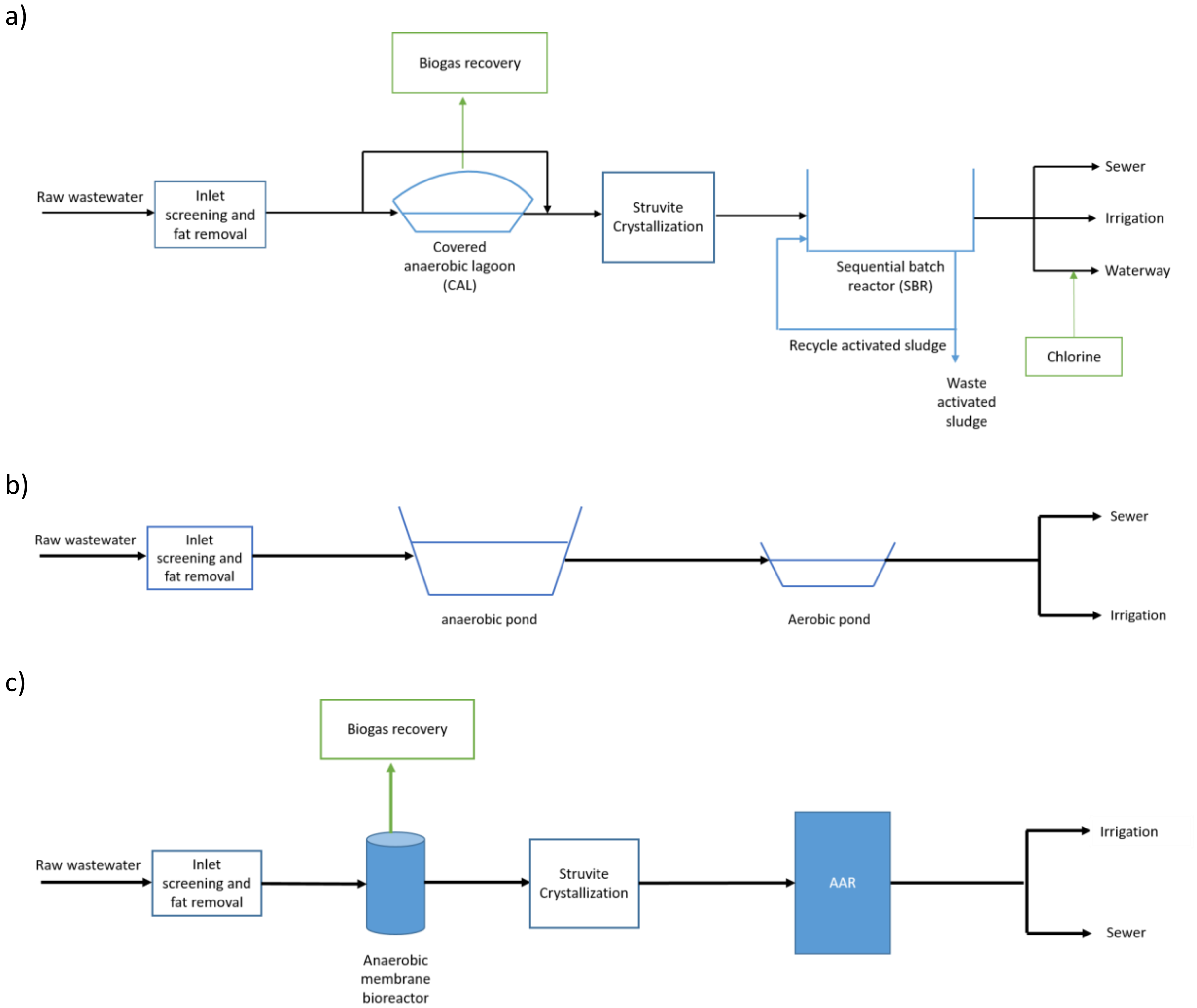


Figure 1. Block flow diagram of option 1 (a), 2 (b) and 3 (c).

Options 1 and 3 were selected during the workshop on "investigating water and wastewater reuse and recycling opportunities" held at the University of Queensland on the 3rd of May 2017 (minutes in Appendix 2) for further CBA model development to reuse treated wastewater with conventional advanced treatment (UF/RO/disinfection) at non-potable and highly purified recycled water standards.

5.2 Advanced water treatment technology selection

In this project, advanced technologies have been selected for options 1 and 3, to ensure that final water quality meet the water recycling guidelines (NRMMC et al., 2006, NRMMC et al., 2008). Project 2017 1034 developed a "guideline for water recycling and reuse in red meat processing". It is recommended to refer to this project report for any information regarding plant development and risk assessment.

The CBA model for non-potable water quality was developed using the water quality needed for dual reticulation (Appendix 1) (NRMMC et al., 2006). Feed water for boilers and cooling towers does not need to be at potable standard. However, the primarily concern for these equipment is scale formation and pathogen growth or corrosion. Feed water quality should follow manufacturer recommendation and might need to be of higher quality than the dual reticulation one proposed in the CBA.

To produce non-potable water, ultrafiltration (UF) or microfiltration (MF) and UV are generally used. These processes allow achieving the necessary pathogen's log reduction (Appendix 1). According to NRMMC et al. (2006), the treatment processes to produce non-potable water for dual reticulation (including toilet flushing) should include:

- secondary, coagulation, filtration and disinfection; or
- secondary, membrane filtration and UV light.

In option 1, SBR is used for nitrogen removal during the wastewater treatment. SBR can also be used as membrane pre-treatment to avoid membrane fouling. MF or UF membrane follow by UV disinfection are used to produce non-potable water (Figure 2a). Secondary treatment is able to remove 0.5 log (~68% removal) of virus and protozoa and 1 log (90% removal) of bacteria.

In option 3, the level of nitrogen is still high in the effluent treated by AnMBR and AAR. For this reason, biological system is needed to remove nitrogen as MF or UF are not efficient. Instead of using a clarifier and a MF/UF membrane, a membrane bioreactor (MBR) was selected (Figure 2b). This technology integrates biological treatment with membrane filtration, decreasing the footprint. The biological part of the MBR reduces the level of nitrogen and COD typically to < 10 mg/L and < 30 mg/L, respectively, and the membrane reduces the level of pathogen (Metcalf & Eddy, 2004).

a)

b)

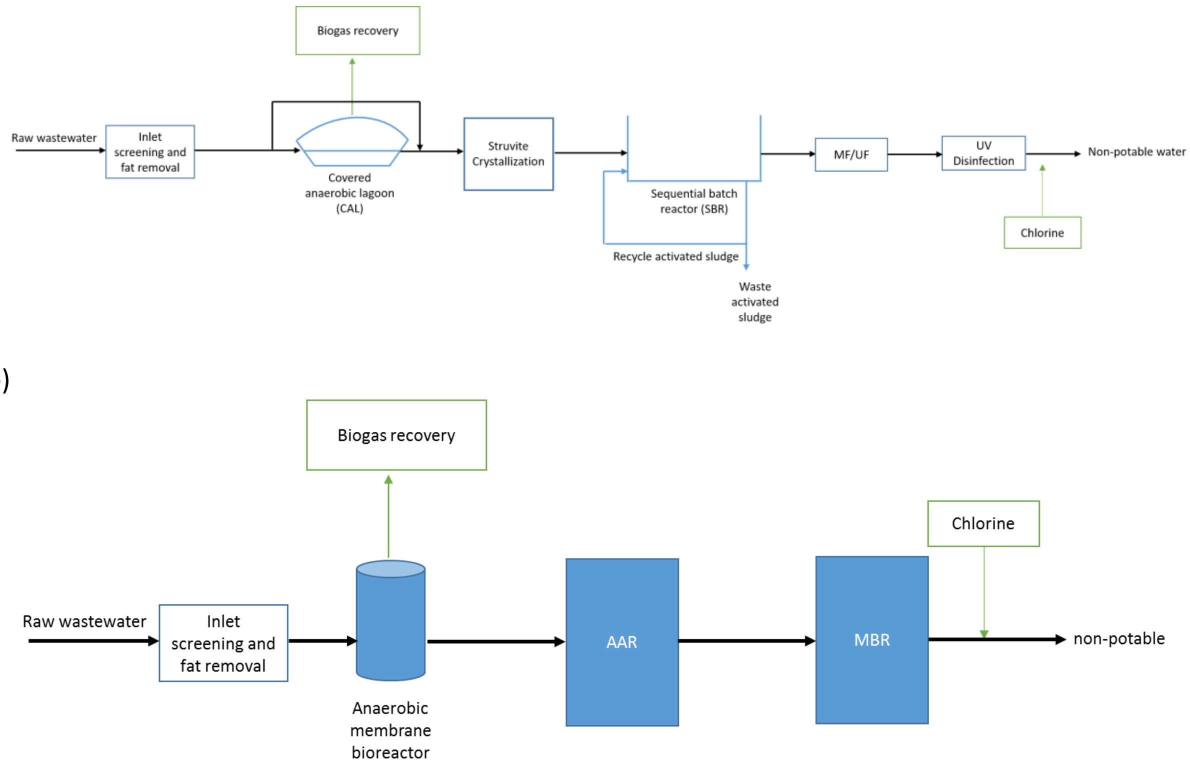


Figure 2. Wastewater and advanced water treatment block flow diagram for a) option 1 and b) option 3 non-potable reuse.

5.3 High quality recycled water

The CBA model was developed using the quality needed for augmentation of drinking water supplies presented in Appendix 1 (NRMMC et al., 2008).

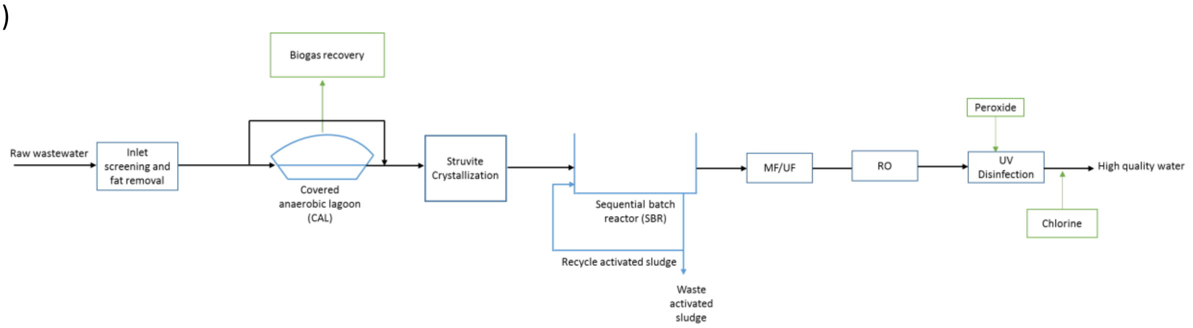
To produce high quality recycled water, ultrafiltration (UF) or microfiltration (MF), reverse osmosis (RO) membrane and UV/H_2O_2 are generally used. These processes allow achieving the necessary pathogen's log reduction required by NRMMC et al. (2008):

- Virus = 9.5 LRV
- Bacteria = 8.1 LRV
- Protozoa = 8 LRV

Figure 3 presents a schematic of options 1 and 3 high quality water.

Membrane filtration and advanced oxidation process (AOP) systems are generally used in advanced water treatment schemes. In particular, RO is the current "gold standard" due to its capacity to remove monovalent ions and pathogens. Depending on the quality of the effluent, other technologies can be selected and are summarised in Appendix 3. These technologies are generally used in drinking water and water recycling treatment trains.

a)



b)

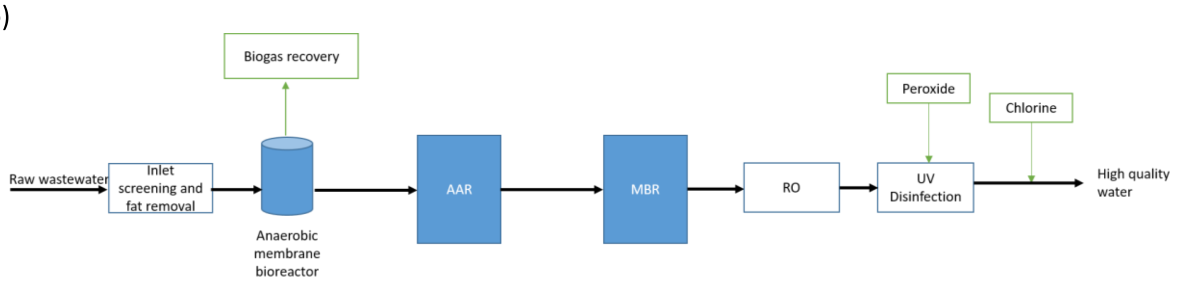


Figure 3. Wastewater and advanced water treatment block flow diagram for a) option 1 and b) option 3 high quality water reuse.

6.0 CBA SPREADSHEET

6.1 Contents

All CBA Excel spreadsheets were developed under the same format:

// *Introduction & Instructions:* this sheet contains general information regarding the CBA model such as the table of contents, legend, limitation, glossary of terms, etc.

// *1. Input to flow and Load Basis:* this sheet contains all the information regarding the wastewater flow and characteristics. In orange: current information found in the literature, but can be modified with specific value. In yellow, a key parameter or selection must be selected. The findings of the CBA are also summarised by selecting the end use (i.e. sewer, waterway, non-potable reuse and highly treated water), the solid treatment (i.e. none, compost, combustion) and the solid disposal (i.e. reuse or landfill).

// *2. Cost Benefit NPV:* this sheet presents all calculations for the CBA model.

// *3. Flowsheet:* a block flow diagram of the different technologies used for the option with the effluent characteristics.

// *4. Summary fit-for-purposes:* this sheet summarises all the water quality needed according to the end use. For each block of water quality (treated wastewater, non-potable and high quality water), the effluent characteristic is compared to the guidelines to determine if 'YES' or 'NO' the effluent is fit-for-purposes.

- // *5. Estimation:* this sheet summarises the production conditions, the costs of the different components (e.g. water price, energy cost, etc.), the energy equivalent and the land requirement for nitrogen and phosphorous water irrigation.

6.2 Cost Benefit NPV

To calculate the cost benefit of each option, the following have been taken into account:

- // Capital cost (CAPEX) spent over 2 years (construction phase). It includes allowance for processes, pumps, piping, electrical installation, civil works and engineering (estimated at 10% of total installed capital).
- // Operating cost (OPEX) includes operator salary, process maintenance, pump and energy mixing, dosing and cleaning chemicals and membrane replacement (consumable).
- // Benefit includes biogas recovery, nutrient recovery, wastewater (volume and load) discharge saving and water consumption saving due to on-site water reuse.
- // The CBA models are developed for abattoirs processing between 500 and 1500 heads per day of beef cattle.
- // The payback period is calculated from year 1 including the time taken to construct the plant.
- // All high quality treated water produced is reused on-site.
- // The cost of the implementation of critical control points (CCP) and monitoring of the effluent quality are not included to the CBA.

An example of a NPV analysis using option 3 is presented in Appendix 4.

7.0 CBA VALIDATION

Two sites were visited on the 8th June 2017 to validate the CBA models developed during this project. Information from this visit, along with other information provided by the site, has been used to inform the concept design of the recycled water facility. For the purposes of this design, it was assumed that all water will be treated to a high quality, to allow potential for this water to be used in a wide range of applications, including those that generate aerosols (e.g. wash-down and cooling sprays). From this design, a high-level order of magnitude cost estimate was developed, using information reasonably available to GHD and based on the assumptions and judgements made by GHD. To evaluate the potential savings associated with implementing a recycled water treatment plant and energy recovery plant (i.e. biogas from CAL), a net present value (NPV) analysis was undertaken, using a discount rate of 3.66% over a 15-year period and using existing operational costs as a basis. Benefits of implementing this approach include savings associated with water production or consumption costs, waste water disposal costs and biogas production.

Wastewater quality data provided by the sites was used in the CBA model developed during this project. NPV analysis from the sites' visit and the NPV of the CBA model were compared in Table 4. The two NPV analysis results had close results validating the CBA models.

Table 4. Comparison of NPV analysis obtained from site visit and CBA model.

	Site 1		*Site 2*	
	From site visit	*CBA model*	*From site visit*	*CBA model*
Total present value of costs	+$26.5 M	+$21.5 M	+$22 M	+$17.5 M
Total present value of benefits	+$9.7 M	+$8 M	+$13 M	+$10.8 M
Benefit to cost ratio	0.37	0.37	0.6	0.6
NPV	-$16.8 M	-$13.5	-$8.7 M	-$6.7 M

8.0 CONCLUSIONS/RECOMMENDATIONS

Water recycling is not a new concept for alternative water supply. South East Queensland (SEQ) has three advanced water treatment plants able to produce 232 ML/d of water from secondary treated effluent. Ingham poultry is a successful example of the implementation of potable recycled water in its process factory. The three CBA models can be modified according to red meat processor case. However, the model is limited to 500 – 1500 cattle per day or 1548 – 4644 kL of wastewater produced/day.

It is recommended to involve AQIS and Queensland health at an early stage of the process to ensure their agreements to use water recycling within the process. It is also highly recommended to run a pilot for at least 3 months before thinking of a large-scale implementation. Chemical and microbial analysis needs to be taken at a regular basis to ensure that the desired water quality is reached. This pilot trial will help to determine further polishing treatments such as the addition of powdered activated carbon (PAC) and 5µm cartridge before membrane filtration. The pilot will also determine the frequency of cleaning-in place (CIP). The formation of disinfection by-products (DBPs) should also be monitored during the pilot trial. Organic matter with chlorine can form disinfection-by-products (DBPs) such as trihalomethanes (THMs), haloactic acids (HAAs), and N-Nitrosodimethylamine (NDMA). It has been demonstrated that DBPs in drinking water have been associated with possible public health risks (Richardson et al., 2007, Sedlak and von Gunten, 2011); therefore, the control of their formation is required. Chlorine is not only used at the end of the treatment train, but also before membrane filtration to avoid the formation of biofouling. Unfortunately, RO membrane does not remove effectively DBPs (Doederer et al., 2014). Thus, it is necessary to remove dissolved organic carbon before chlorine addition to avoid the formation of DBPs. For this reason, another step to remove organic matters (e.g. ferrate or improve the coagulation step) might be necessary to limit the formation of DBPs and to protect membranes from fouling. Also, the formation of NDMA can be reduced by limiting the disinfection contact time with chlorine to less than 2 hours (Farré et al., 2011). The presence of NH_3 in the effluent can react with chlorine to form monochloramine. Monochloramine is also used in SEQ as agent of disinfection instead of chlorine. Monochloramine has been proved to form less DBPs than chlorine. NH_4 can be removed at ~95% by RO membrane (Kurama et al., 2002). However, the concentration of NH_4 is generally less than 10 mg/L. Thus, the impact of high NH_3/NH_4 level on membrane filtration needs to be studied.

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10.0 APPENDICES

10.1 Appendix 1: Guidelines used for the CBA models.

	Wastewater [b]	Irrigation[c]	Sewer[d]	Waterway[e]	Dual reticulation (non-potable reuse)[f]	Highly treated water[g]
Temperature	37°C		<38°C			
pH	7	6-8.5	6-10.5	6.5-8.5	6-9	6.5-8.5
COD (mg/L)	8500	ND	3000	ND	ND	ND
BOD (mg/L)	4250	ND	2000	10	ND	ND
TSS (mg/L)	3000	ND	1000	15	ND	ND
Oil & Grease (mg/L)	1500	ND	200	2	ND	ND
Total N (mg/L)	250	40	2000	10	ND	ND
Total P (mg/L)	45	4.5	50	0.3	ND	ND
Ammonia (mg/L)	60	ND	200	2	ND	0.5
TDS (mg/L)	1000	5159	4000	ND	ND	600
EC (µS/cm)[a]	1493	7700	5970	ND	ND	896
E.coli (CFU/100mL)	$1\ 10^8$	ND	ND	ND	1	***8 LRV***
Thermotolerant coliforms (CFU/100mL)	$4\ 10^7$	1000	ND	ND	***5 LRV***	***8 LRV***
Protozoa oocysts (CFU/100mL)	$1\ 10^3$	ND	ND	ND	***5 LRV***	***8 LRV***
Somatic coliphage (LRV)	$1\ 10^7$	ND	ND	ND	***6.5 LRV***	***9.5 LRV***
Turbidity (NTU)		ND	ND	50	ND	<1

[a] TDS/EC ratio = 0.67. TDS: Total Dissolved Solids.

[b] Data from reports: A.ENV.131, A.ENV.151, P.PIP.0172, M.445.

[c] (ANZECC and ARMCANZ, 2000).

[d] QUU sewer discharge limits:
https://www.urbanutilities.com.au/~/media/quu/pdfs/business/trade%20waste/trade%20waste_sewer%20acceptance%20criteria_310314.ashx

[e] Emission limit guidelines for sewage treatment plants that discharge pollutants in the coastal zone, NSW EPA, taken from 24038 - MLA enviro best practice manual (p35, Table B2, (b)).

[f] (NRMMC et al., 2006), Table 3.8 p103.

[g] (NHMRC and NRMMC, 2011) for organic contaminants. (NRMMC et al., 2008), 2007, p31.

10.2 Appendix 2: Workshop minutes: investigating water and wastewater reuse and recycling opportunities.

This workshop was held by UQ/AWMC and GHD on the 4th May 2017.

Industry experience/current operations

- JBS have 10 sites in total, five in the North, five in the South.
    - Range of disposal methods/end-uses, including sewer discharge, river discharge and irrigation.
    - Water re-used on site for cattle wash (this water is not treated to a tertiary level).
    - Have a similar operation to Option 2, with lagoons.
- NCMC use recycled water (water from hand washing and equipment sterilisation) in the yards as pre-wash and for cattle de-tagging.
    - Use roughly 500 m^3 per day in the yards
    - They currently have more recycled water than they can use (for that specific application).
    - Tannery has an IDAL as part of their wastewater treatment.
- Colac (in Victoria) is required, as per Victorian legislation, to supply cattle drinking water to a "Class A" standard.
    - Drinking water constitutes approximately 1-2% of total consumption of site
- Oakey have a similar set-up to NCMC, and similar scenario of having more water available for re-use than what is required (at existing quality).
    - 350 kL water tank (water for re-use)
    - Primary treatment and chlorination (screens ~0.7 mm, wet wire).
    - One re-use in yards, then water is sent to the sewer.
    - Town (40%) and bore (60%) water used on site (bore used for non-potable supply, run through small RO plant).
- JBS and Teys are both using a BNR process; NCMC looked into this but didn't implement (due to volume of water).

Water recycling limitation and risks

- Perception is a big factor in the re-use of water within abattoirs.
    - Murrarie (QLD) Ingham's chicken abattoir uses 100% of their produce recycled water, which represents 70% of their wastewater.
    - In the red meat industry, the use of recycled water, especially for export markets, is not readily acceptable.
- Most abattoirs seem to be using primary treatment and re-using water in the yards, but not as much treatment to the secondary and/or tertiary levels.
- The recycling of water is occurring for certain streams of water (relatively clean streams are being recycled), rather than the overall water used on site.
- Payback period of maximum 4 years for upgrade to be considered (and under 1 year would be very highly regarded).
- Limitations on use of recycled water.
    - Cannot be used for the final wash.

  - Export requirements (usually of country meat is being imported to) usually mean that recycled water cannot be used.
  - Can be used in outside areas (see project report 2016 1021).
- MLA is looking for a waste to revenue strategy.
- Options 1 and 3 are favourable from the perspective of a smaller footprint and less odour, which help in terms of perception.
- Issues with irrigation include finding enough land that can be used nearby and the nutrient loading.
  - These issues are only going to become more pressing, as land nearby to abattoirs is developed.
- AQIS is the regulator for food standards (with references/links to pertinent guidelines)
- It was questioned whether research has been undertaken assessing the impact (if any) of the use of recycled wastewater on shelf life (potential for some bacteria to exist in the wastewater that is not harmful to people and so is not monitored, but may impact shelf life?).
- MLA mentioned ‘processing aids’ (chemicals that are added to a process to improve the process’ efficiency) and the impact these might have to the meat, were recycled water to be used.
- Risks to be considered when assessing the use of recycled water:
  - Hydrocarbons
  - Pesticides from weeds/crop dusting/fly spraying, etc.
  - HSE
  - Public perception
- Plants are required to test incoming water to ensure it meets the required quality.
  - In some cases, this incoming water is chlorinated.
- Regulations surrounding the red meat industry are quite strict and are one of the major hurdles to the use of recycled water (the other being public perception).
  - It was suggested that a change in terminology, away from re-use/recycling may improve the perception.
- Potential for companies to look at nearby industries at potential customers for their recycled water.
  - To date, most abattoirs are only looking at ways to re-use the water internally.

Thoughts/impacts to the CBA tool

- The tool currently uses a range of head/day for a majority of abattoirs to calculate water consumption.
  - This is used to size the wastewater treatment process.
  - Based on feedback from industry, some water is already recycled, therefore should this amount not be removed from the total used in the tool (depending on the % used), such that the units are not oversized?
- For end-use qualities, irrigation and sewer effluent qualities may need to be editable/included in the inputs tab, as these limits will vary depending on the location of the specific site

- If an option was to be removed, this would be Option 2, as companies either have lagoons already in place, or are unlikely to want to build them (due to odour issues and space limitations, which are becoming more of an issue, as land surrounding the abattoirs starts to be developed).

10.3 Appendix 3: Summary of treatment technologies used in water recycling.

Membrane filtration and advanced oxidation process (AOP) systems are generally used in advanced water treatment schemes. In particular, reverse osmosis is the current "gold standard" due to its capacity to remove monovalent ions and pathogens. Depending on the quality of the effluent, other technologies can be selected and are summarised in the following table. These technologies are generally used in drinking water and water recycling treatment trains.

Technology	Removal mechanism	Contaminant removal	Advantages	Disadvantages	Readiness
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

Technology	Removal mechanism	Contaminant removal	Advantages	Disadvantages	Readiness
Ion exchange resin *(IEX)*	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.
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

Emerging membrane technologies, such as ceramic membranes, metallic membranes and forward osmosis membranes can also be used to produce high quality recycled water. These technologies are available in the market but are currently at higher cost than reverse osmosis membranes, increasing the cost to implement a water recycling scheme, as well as not been as broadly proven in recycled water applications.

Ceramic and metallic membranes operate under the same principle as conventional membrane filtration processes (MF, UF and RO). They are able to remove pathogens, TSS, turbidity and divalent ion depending on their pore size. The advantages of these membranes are their robustness to pH, chemicals, temperature, low surface space, easy to clean and inert surface, which decrease the operating cost. Their drawback is the capital cost for the membranes.

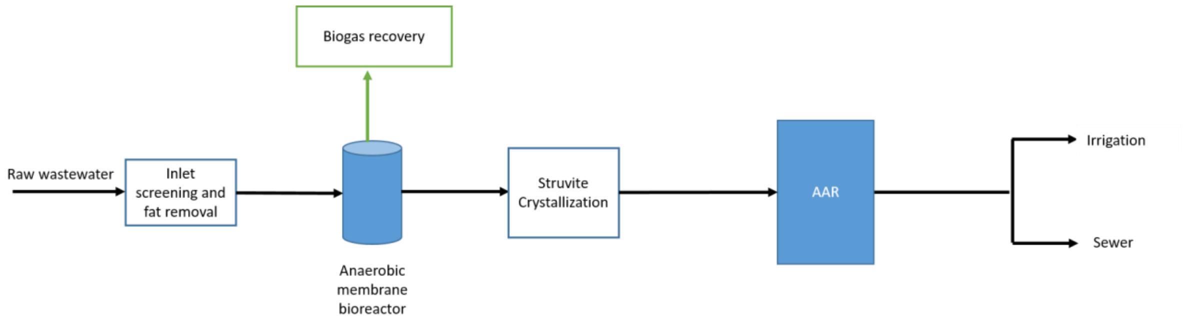
Forward Osmosis membrane (FO) is a new technology using an old principle: the osmosis gradient. This technology can remove pathogens, colour, organic matter, odour, heavy metal, turbidity and salt like reverse osmosis. Its main advantage is its low energy consumption. However, this membrane produces a lower flow than RO. This technology has not been well accepted by industrial as yet, primarily due to its high cost.

Osmotic membrane bioreactor (OMBR) combines biological treatment with forward osmosis membrane separation. This technology is able to remove >96% of COD, >82% of TN and >99% of TP (Holloway et al., 2014). The water flux is generally below 10 L/m^2 h (Wang et al., 2016), which is lower than conventional MBR (i.e. 15-25 L/m^2 h) (Metcalf & Eddy, 2004). This technology is still at lab-scale application due to the low water flux challenge. However, it is a promising technology because it produces high quality water at lower energy consumption than conventional MBR.

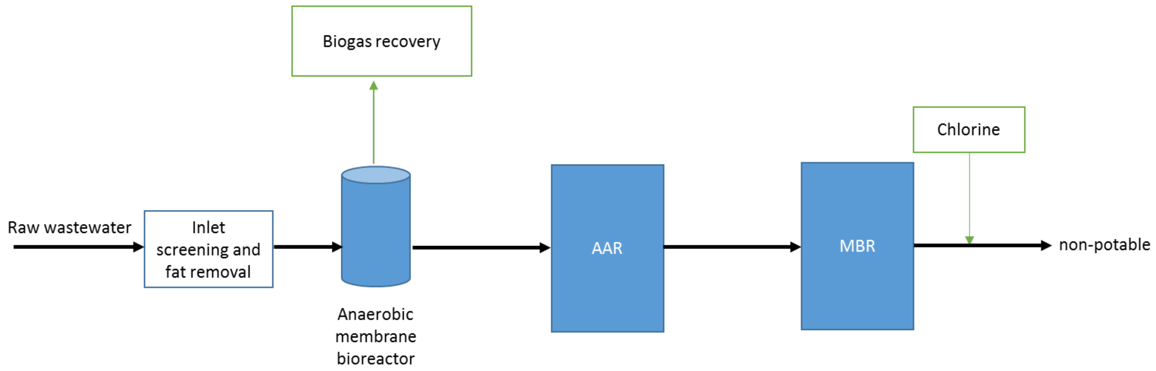
10.4 Appendix 4: Example of CBA model results.

Option 3: AnMBR – AAR

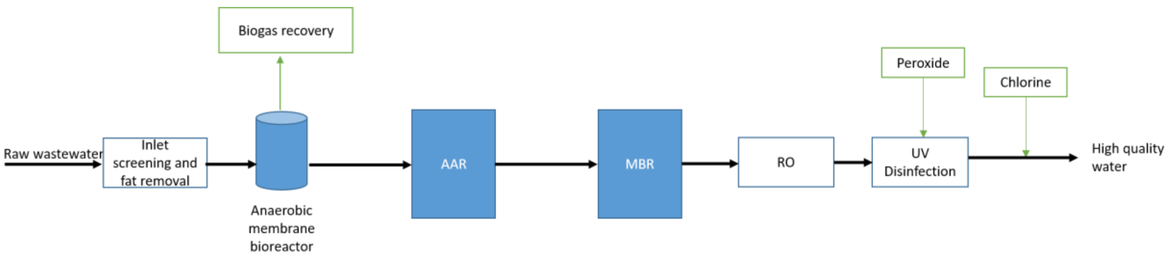
a)



b)



c)



Option 3 block flow diagram for a) sewer discharge and irrigation reuse, b) non-potable reuse and c) high quality treated water.

Influent and effluents quality.

	Raw wastewater	*Sewer/ Irrigation*	*Non-potable reuse*	*Highly treated water*
Volume production (ML/d)	3.096	3.096	3.095	2.63
COD (mg/L)	8500	0.1		
TSS (mg/L)	3000	1		
Nitrogen (mg/L)	250	50		
Phosphorus (mg/L)	45	0.3		
TDS (mg/L)	1000	1000	1000	20
E. coli (CFU/100mL)	10^{8}	10^{7}	10^{-3}	10^{-7}

To evaluate the potential savings associated with implementing a recycled water treatment plant and energy recovery plant, a NPV analysis was undertaken, using a discount rate of 3.66% over a 20-year period and using existing operational costs as a basis. Benefits of implementing this approach include savings associated with:

- Town water price: $2.8/kL.
- Waste water disposal costs.
- Wastewater discharge: $0.98/kL, COD discharge: $1/kg, TSS discharge: $0.88/kg, N discharge: $2.18/kg, P discharge: $1.78/kg.
- Energy cost: $0.20/kWh.

Based on the cost estimate and NPV developed using the raw wastewater quality previously mentioned, it is cost effective to implement irrigation > high quality water reuse > non-potable reuse options. This is largely due to the current high town water and discharge wastewater costs.

Capital and operating costs, payback period, NPV and IRR for an abattoir processing 1000 head/d of cattle beef using options 3 (without solid treatment and landfill solid disposal).

	CAPEX ($)	OPEX ($/yr)	Payback period (year)	NPV ($)	Benefit to cost ratio
Sewer	10.3M	9.7M	30	-102M	0.14
Irrigation	11.1M	500k	4	22.1M	2.31
Non-potable	13.2M	800k	11	3.6M	1.17
Highly treated water	16M	1.1M	9	8.1M	1.3

NPV: Net Present Value.
IRR: Internal Rate of Return.