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Treatment Technologies for Feedlot Effluent Reuse

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Abstract

The project examined the sustainable effluent yields for a 5,000, 10,000 and 25,000 head feedlot located in each of the five major lot feeding regions of Australia and technologies that could be used to treat this effluent to a stage where it could be reused for cattle drinking water.

Modelling indicated the sustainable yield of effluent for reuse within the feedlot can meet about 20% of the total water requirement for most locations. However, only 10-12% of the total water requirement can be met for a feedlot in the Riverina (represented by Charlton for the modelling exercise).

While technologies exist that are capable of treating feedlot effluent to the required standard, capital expenditure costs for a suitable treatment train are likely to be around $1500 to $5000 per ML, with operating costs of around $2000 to $3500 per ML depending on the degree of process automation implemented. This makes for an overall cost of $3500 to $8500 per ML with considerable uncertainty around this range of costs. This cost is very high relative to typical water prices and would put those installing such a plant at a commercial disadvantage compared to feedlots that have access to cheaper water. Consequently few individual feedlots would be likely to take this step at current water prices.

Executive Summary

Water availability and cost of supply is changing rapidly, driven by increased demand for industry, urban needs and providing for environmental flows. During the recent prolonged drought, water supplies became limited in many feedlot regions. Capped water supply and water trading in the Murray Darling Basin have increased the value of water significantly. These pressures are promoting careful management of water resources throughout the industry to ensure continued supply and to minimise costs. It has also prompted interest in the reuse of treated effluent as a water supply for the feedlot.

Water is used within feedlots for cattle consumption, feed processing, administration (staff amenities, lawn and garden watering), cattle washing, sundry uses (trough cleaning, evaporative losses from storages, cleaning facilities and vehicles, dust control in pens and drinking water for other stock) and for shandying effluent for irrigation. Recent Australian research (Meat & Livestock Australia (MLA) projects B.FLT.0339 and B.FLT.0350) has shown that cattle drinking water represents about 90% of the total water usage in the months when no cattle washing is occurring dropping to around 75% when it does occur.

For this project, MEDLI modeling was used to find the long-term sustainable effluent yield that could provide an additional water source for the feedlot. For this exercise, we modeled 5000, 10,000 and 25,000 Standard Cattle Unit (SCU) feedlots located in each of the five main lot feeding regions of Australia (central Queensland, southern Queensland / northern New South Wales, central New South Wales, Riverina (represented by Charlton in central Victoria) and south-western Western Australia.

This project found that in most locations, the long-term sustainable yield of effluent is around 2.5-5 ML / 1000 head per year. Consequently, reuse within the feedlot could meet around 20-30% of the total drinking water requirement. This suggests that stock drinking water, and possibly cattle washing, should be the target for reuse of treated effluent within the feedlot.

Feedlot effluent is a rather concentrated wastewater with considerable colour. The concentrations of both inorganic and organic nutrients are high. Microbiological contamination is a key parameter pertaining to the treatment requirements and safe reuse of effluent. There are few literature data on pathogens in feedlot effluent and most studies have measured only bacterial indicator organisms. These bacterial counts are fairly high. However, a range of pathogens has been measured in manure, soils and water bodies impacted by feedlot run off. These include *Salmonella spp.*, pathogenic *Escherichia coli H157:O157*, *Leptospira spp.*, *Campylobacter spp.*; *Cryptosporidium parvum*, *Giardia lamblia* and *Helminth* worms. Pathogenic contamination of recycled feedlot effluent and the associated risk of disease outbreaks are the most concerning aspects of using recycled water for a cattle drinking supply. A crude assessment of the scarce existing data shows that the pathogen load in raw effluent can be quite high.

Extensive tertiary treatment of effluent would be needed to allow for its safe usage in applications involving high exposure of cattle. Either dilution or partial salt removal may be needed to ensure the recycled effluent is suitable for cattle consumption. All treatment must also considerably reduce organic matter, colour and nutrients, mainly to be able to ensure effluent stability and efficient disinfection.

In this context, no specific guidelines for treated water quality exist. Risk control through the approach outlined in the National Guidelines for Water Recycling, Phase 1 seems to be the most appropriate approach. Health risks to the cattle and to any humans exposed to the recycled water would determine treatment requirements that will need to be agreed in cooperation with relevant regulatory bodies.

Given that the product will have high exposure for humans or animals, multi-barrier protection against risks from the raw water source is certainly needed to make the effluent fit for purpose. Treatment trains including primary, secondary and tertiary treatment are included in the Milestone 3 report for this project. All include some sort of filtration and at least two disinfection processes, either UV disinfection or ozone or both followed by chlorination. If partial or complete desalination is desired, the treatment train includes low and high pressure membrane filtration. The inclusion of this process results in superior treatment but adds significant capital and operating cost.

Energy consumption of secondary treatment should be around 0.5 – 1.5 kWh/m^3 depending on the aeration requirements. Energy requirements for tertiary treatment would vary depending on the complexity of the treatment train and could be as low as 0.15 – 0.3 kWh/m^3 for a treatment train based on granular filtration and UV disinfection, 0.2 – 0.5 kWh/m^3 if either low pressure membranes or ozonation are added to the treatment train and 1 – 1.5 kWh/m^3 for a treatment train including low and high pressure membranes and UV disinfection.

Capital expenditure costs for a suitable treatment train are likely to be around $1500 to $5000 per ML, with operating costs of around $2000 to $3500 per ML depending on the degree of automation. This makes for an overall cost of $3500 to $8500 per ML with considerable uncertainty around this range of costs. This cost is very high relative to typical water prices and would put those installing such a plant at a commercial disadvantage compared to feedlots that have access to cheaper water. Consequently few individual feedlots would be likely to take this step at current water prices.

Finally, as the recent public debates about recycled water have shown, there are other factors to be considered, regardless of whether the risks associated with recycled water are perceived or real. Water recycling in the beef industry is unlikely to be an option for the majority of the industry at this point in time. However, as water prices increase this situation may change.

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1 INTRODUCTION

The objectives of the project, as stated in the tender, were to:

- Provide estimates of the sustainable effluent yields for a 5,000, 10,000 and 25,000 head feedlot located in each of the five major lot feeding regions of Australia (Central Queensland, Southern Queensland / Northern New South Wales, central New South Wales, Riverina and South-West Western Australia).
- Provide typical nutrient composition and microbial contamination profiles for feedlot effluent based on review of known sample analyses and values recorded in the literature.
- Define the quality standards that must be complied with for treated effluent to be considered suitable for use as 1) potable water and 2) cattle drinking water.
- Provide a comprehensive overview of the technologies and systems available that would be suitable for treatment of feedlot effluent to the above standards.
- Based on the above, provide recommendations on the most appropriate technology for feedlots of different sizes, including details of design and throughput considerations, other parameters (e.g. requirement for skilled operators, cleaning frequency, disposal of waste) that need to be considered, and likely capital, installation and operating costs.
- On a state-by-state basis, outline the regulatory compliance requirements for the development, construction and operational phases of an onsite feedlot effluent treatment facility capable of producing water to the above standards (outlined separately if they differ for potable water and cattle drinking water).

Two milestone reports (2 and 3) were prepared as part of this project. The Milestone Report 2 focussed on the first three objectives. It identified that the sustainable effluent yield could only meet a modest portion of the cattle drinking water requirement. In consultation with MLA, it was decided that there was no point in considering administration (potable) water treatment requirements further since these would likely require a higher standard of treatment than cattle drinking water. The Milestone 3 report addressed the remaining objectives. Another output of this project was a series of Tips & Tools notes.

2 SUSTAINABLE EFFLUENT YIELDS

2.1 INTRODUCTION

Feedlot effluent production relates closely to the feedlot pad hydrological cycle. This cycle includes water inputs through rainfall and water used within the feedlot that is largely deposited to the manure pad; and outputs via evaporation, manure harvest and runoff to the effluent management system. To estimate the effluent yield to a feedlot holding pond, a water balance for the feedlot pens and surrounding catchment area is required. Hence, effluent production rates for any particular feedlot are site specific and need to be modeled using a feedlot hydrology model.

Two Australian feedlot hydrology models are available for estimation of runoff volume. These are the FSIM (Lott 1998) and MEDLI (Gardner *et al.* 1996) feedlot models. Both of these models are daily time step simulation models that analyse feedlot hydrology and the water balance in the feedlot catchment.

The hydrology components of both models have only been calibrated in summer-dominant rainfall regions (FLOT323) i.e. northern Australia. However, FSA Consulting has undertaken MEDLI modeling for a Western Australian feedlot and qualitatively checked the models output against several years of actual experience. Although this exercise was not scientifically robust, the results were nevertheless believable.

Recent RIRDC-funded research (Davis et al. 2010) has demonstrated that the excretion rate for total solids (TS) in feedlot cattle manure is much less than previously estimated. This affects the manure accumulation rate on the pen surface and the hydrology cycle. This source of error can easily be corrected in MEDLI by using total solids data generated by BEEFBAL as an input. BEEFBAL is a spreadsheet model specifically designed to estimate the quantity and composition of manure produced by beef cattle feedlots (QPIF 2004).

The MEDLI model was chosen for this project due to its flexibility, the ability to easily over-ride the manure accumulation rate and the previous work undertaken to partially calibrate it in the winter-dominant rainfall region.

2.2 MODELLING METHODOLOGY

MEDLI modeling was used to simulate the sustainable effluent yield from 5000, 10,000 and 25,000 Standard Cattle Unit (SCU) feedlots located in each of the five main lot feeding regions of Australia. Modelling was undertaken for the following locations:

1. Central Queensland (Comet)
2. Southern Queensland (Dalby)
   Northern New South Wales (Moree)
3. Central New South Wales (Quirindi)
4. Riverina (represented by Charlton which is located in Central Victoria)
5. South-West Western Australia (Mt Barker)

Details of the model inputs are provided in the Milestone 2 report for the project.

2.3 MODELLING RESULTS

The results of the MEDLI modelling undertaken to determine the long-term sustainable effluent yield are provided in Table 1 to Table 3.

Table 1 shows the feedlot pond water balance of model 5,000 SCU feedlots in each location. The long-term annual average volume of water extracted for treatment ranges from 14.0 ML/yr for location 5 (Charlton) up to 25.5 ML/yr for Location 1 (Comet).

TABLE 1 – FEEDLOT POND WATER BALANCE FOR A 5,000 SCU FEEDLOT

Long term Annual Average		Location 1 Comet	Location 2 Dalby	Location 3 Moree	Location 4 Quirindi	Location 5 Charlton	Location 6 Mt Barker
Inflows	Rainfall on Pond (ML)	13.2	8.3	6.9	9.5	2.9	6.6
	Inflow of Effluent (ML)	33.0	34.4	31.5	30.7	15.9	23.8
Outflows	Evaporation (ML)	24.0	16.3	12.9	13.8	4.3	6.1
	Seepage (ML)	0.6	0.4	0.4	0.5	0.3	0.2
	Overtopping (ML)	0.2	0.2	0.3	0.2	0.2	0.1
	Extracted (ML)	**21.4**	**25.5**	**24.8**	**25.6**	**14.0**	**24.0**
	(% of inflow)	**46%**	**60%**	**65%**	**64%**	**75%**	**79%**

Table 2 shows the feedlot pond water balance of model 10,000 SCU feedlots in each location. The long-term annual average volume of water extracted for treatment ranges from 25.0 ML/yr for location 5 (Charlton) up to 50.5 ML/yr for Location 2 (Dalby).

TABLE 2 – FEEDLOT POND WATER BALANCE FOR A 10,000 SCU FEEDLOT

Long term Annual Average		Location 1 Comet	Location 2 Dalby	Location 3 Moree	Location 4 Quirindi	Location 5 Charlton	Location 6 Mt Barker
Inflows	Rainfall on Pond (ML)	27.7	21.4	15.4	18.0	8.9	16.2
	Inflow of Effluent (ML)	65.2	69.2	63.4	61.8	32.1	47.5
Outflows	Evaporation (ML)	52.6	44.9	31.3	28.2	15.4	17.1
	Seepage (ML)	1.3	1.1	0.8	0.8	0.5	0.7
	Overtopping (ML)	0.2	0.2	0.2	0.2	0.1	0.1
	Extracted (ML)	**38.7**	**44.4**	**46.6**	**50.5**	**25.0**	**46.0**
	(% of inflow)	**42%**	**49%**	**59%**	**63%**	**61%**	**72%**

Table 3 shows the feedlot pond water balance of model 25,000 SCU feedlots in each location. The long-term annual average volume of water extracted for treatment ranges from 69.0 ML/yr for location 5 (Charlton) up to 125.6 ML/yr for Location 2 (Dalby).

TABLE 3 – FEEDLOT POND WATER BALANCE FOR A 25,000 SCU FEEDLOT

Long term Annual Average		Location 1 Comet	Location 2 Dalby	Location 3 Moree	Location 4 Quirindi	Location 5 Charlton	Location 6 Mt Barker
Inflows	Rainfall on Pond (ML)	61.2	38.5	31.2	42.9	11.2	44.1
	Inflow of Effluent (ML)	163.6	172.6	157.9	153.7	80.0	119.7
Outflows	Evaporation (ML)	122.4	83.1	66.9	72.2	20.8	50.7
	Seepage (ML)	3.1	1.9	1.7	2.1	0.7	2
	Overtopping (ML)	0.3	0.5	0.8	0.5	0.7	0.3
	Extracted (ML)	**99.0**	**125.6**	**119.7**	**121.8**	**69.0**	**110.8**
	(% of inflow)	**44%**	**59%**	**63%**	**62%**	**76%**	**68%**

3 Feedlot Effluent Quality

3.1 Introduction

A review of the literature identified limited data on feedlot effluent quality. This was bolstered by in-house data collected by FSA Consulting over the past 18 years. In particular there is very little data for microbial parameters. During this project, we opportunistically collected samples for analysis. However, the capacity to analyse samples for microbial parameters was limited by laboratory sample submission restrictions.

3.2 Nutrient Composition of Feedlot Effluent

Feedlot effluent is a rather concentrated wastewater with considerable colour. The concentrations of both inorganic and organic nutrients are high. Salinity (EC) can also be quite high. Table 4 shows the typical nutrient composition of feedlot effluent based on samples collected from holding ponds and evaporation ponds at 18 Queensland and New South Wales feedlots; and other data from Australian and international sources.

Table 4 – Chemical composition of Australian feedlot effluent

	FSA Consulting data			A			B	C		
Parameter	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Avg.	Min.	Max.
DON (mg/L)	63.3	0.8	3090	720.55	286	1155	145	85.7	19.2	173
Total Kjeldahl nitrogen (mg/L)	134	2.0	3100							
Ammonia nitrogen (mg/L)	41.0	0.1	670							
Nitrate nitrogen (mg/L)	1.2	0.1	78.7							
Nitrate (mg/L)								3.4	<0.04	23.5
Total phosphorus (mg/L)	61	0.2	440	103.76	26	440	43	35.3	2.1	61.2
Orthophosphate-P (mg/L)	17.7	1.5	133							
Orthophosphate (mg/L)								5.8	0.9	22.7
K^+ (mg/L)	665	1.2	9100	2370	985	9102	445	515	13.3	1255
Ca^{2+} (mg/L)	110	8.0	597				99	148	32.5	1760
Cl^- (mg/L)	716	8.0	12800	420	333	674	623	604	8.5	1448
Mg^{2+} (mg/L)	80	2.4	805				72	96.1	8.3	345
Na^+ (mg/L)	180	9.8	6700				256	246	8.0	443
SO_4^{2-} (mg/L)	45.2	2.0	378							
Total dissolved solids (mg/L)	4 330	1 000	18 600					2670	1331	4467
pH	7.8	6.8	9.6	7.43	6.9	8.1		8	7.6	8.4
EC (mS/cm)	6.3	0.1	37.8	13,190	3880	37,800	4500	4.2	2.1	7.0
SAR	3.1	1	65.7				4.6	4.3	0.3	9.0
COD (mg O2/L)	1 950	450	4 680	9579.2	4862	16,806				
Apparent Colour (mg/L Pt-Co)	13 400	1 980	30 100							
True Colour (mg/L Pt-Co)	2 500	820	5 600							
Turbidity (NTU)	1 100	98	2 860							

Sources: FSA Consulting data. **A**: Powell E pers. comm. (1993) cited by Watts et al. (1994): Australian holding pond effluent. **B**: Rhoades et al. (2003): effluent samples collected in Texas during drought conditions. **C**: Miller et al. (2006, cited in Gilley *et al.* 2009): a series of effluent samples collected from a catch basin at Lethbridge Research Centre Feedlot in Alberta, Canada after runoff events between 1998 and 2002.

3.3 Biological parameters

Microbiological contamination is a key parameter pertaining to the treatment requirements and safe reuse of effluent. However, few literature data are available on pathogens and most studies measure only bacterial indicator organisms. Analysis results collected as part of this project are shown in Table 5. These bacterial counts are fairly high.

Table 5 – Bacterial indicator organisms in feedlot effluent

	Enterococcus faecalis (CFU/100 mL)	*Escherichia coli (CFU/100 mL)*	*Total Coliforms (CFU/100 mL)*	*Total Plate Count (CFU/100 mL)*
Median	80,000	250,000	250,000	45,000,000
Min.	2,000	22,000	2,000	4,800,000
Max.	310,000,000	56,000,000	560,000	120,000,000
No of Samples	13	11	9	9

Source: FSA Consulting.

Some additional bacterial data are also available from the MLA project FLOT.333. Effluent was sampled from holding ponds at three feedlots in southern Queensland after a significant runoff event. Seven days later another set of samples was collected from the same sampling locations. All samples underwent microbial analysis.

Table 6 shows the analysis results for *E. coli* and *Enterococcus*. The results show high bacterial loads initially but suggest that pond storage produces significant reductions in these microorganisms.

Table 6 – Microbial analysis results from Australian feedlot effluent samples

	Escherichia coli **(CFU/100 mL)**			***Enterococcus faecalis*** **(CFU/100 mL)**		
Sample ID and Date	**Avg.**	**Min.**	**Max.**	**Avg.**	**Min.**	**Max.**
Feedlot 1 (04-03-2010)	18,600,000	8,000,000	26,000,000	104,000,000*	56,000,000	>200,000,000
Feedlot 1 (11-03-2010)	83,000	30,000	170,000	2,340,000	840,000	4,200,000
Feedlot 2 (04-03-2010)	12,700,000	4,900,000	22,000,000	50,000,000	44,000,000	60,000,000
Feedlot 2 (11-03-2010)	980,000	420,000	2,000,000	13,200,000	8,400,000	16,400,000
Feedlot 3 (04-03-2010)	2,160,000	200,000	4,600,000	2,167,000	1,040,000	2,820,00
Feedlot 3 (11-03-2010)	88,000	10,000	30,000	442,000	318,000	528,000

* assuming 200,000 CFU/mL is the upper value

Analysis of Australian feedlot manure samples collected as part of the same project showed that manure commonly contains the pathogenic *E. coli* (EHEC and EPEC), *Listeria moncytogenes* and *Campylobacter jejuni*, followed by the protozoan pathogens *Giardia* and *Cryptosporidium* (Klein *et al.* 2009). It is likely that some of these pathogens would be present in the effluent. Pathogenic contamination of recycled feedlot effluent and the associated risk of disease outbreaks are the most concerning aspect of using recycled water for a cattle drinking supply.

3.4 PESTICIDES, STEROIDS AND PHARMACEUTICALS

We are not aware of any analysis results for pesticides, steroids or pharmaceuticals in feedlot effluent. However, analysis of Australian feedlot manure samples collected as part of the MLA FLOT.333 project confirmed the presence of both pesticides and steroids at very low levels in pad manure. It is possible that these chemicals could be present at very low levels in the effluent. However, this is very unlikely to be a concern.

4 FEEDLOT WATER QUANTITY REQUIREMENTS

Water is both the most important nutrient for cattle and the most valuable natural resource (after land) in Australia. Hence, it is of critical importance to lot feeders.

Two MLA research projects B.FLT.0339 (Davis et al. (2008) and B.FLT.0350 (Davis *et al.* 2009)) were recently undertaken to identify the total water use and the water used in individual feedlot activities. Eight feedlots were selected to provide a sample group representative of the geographical, climatic and feeding regime diversity within the Australian feedlot industry. At seven of these feedlots, water meters were installed to allow an examination of water usage by individual activities. The major water usage activities (drinking water, feed management, cattle washing) were monitored and recorded.

Estimates of water requirements at cattle feedlots by major use categories are detailed in Table 7.

TABLE 7 – WATER USE REQUIREMENTS FOR TYPICAL AUSTRALIAN FEEDLOTS

Water use requirement (quantity)	L/hd/day	Range (L/hd/day)		Reference
	Average	Min.	Max.	
Cattle drinking water	40	31	46	Davis et al. (2009)
Feed processing		90	390	Davis et al. (2009)
Administration	0.18			Davis et al. (2009)
Cattle washing		700	2 500	Davis et al. (2009)
Sundry uses				
Trough cleaning		0.005	0.1	Davis et al. (2009)
Evaporative losses		0.4	3.9	Davis et al. (2009)
Cleaning		0.006	0.04	Davis et al. (2009)
Vehicle washing		0.01	0.03	Davis et al. (2009)
Dust control	0.1			Davis et al. (2009)
Supplementation of effluent irrigation	Variable[a]			

[a] It is difficult to generalise on the quantity of water used to supplement effluent that is irrigated, due to the large variation in requirements between feedlots.

A breakdown of the major water usage activities at each feedlot studied is shown in Figure 1.

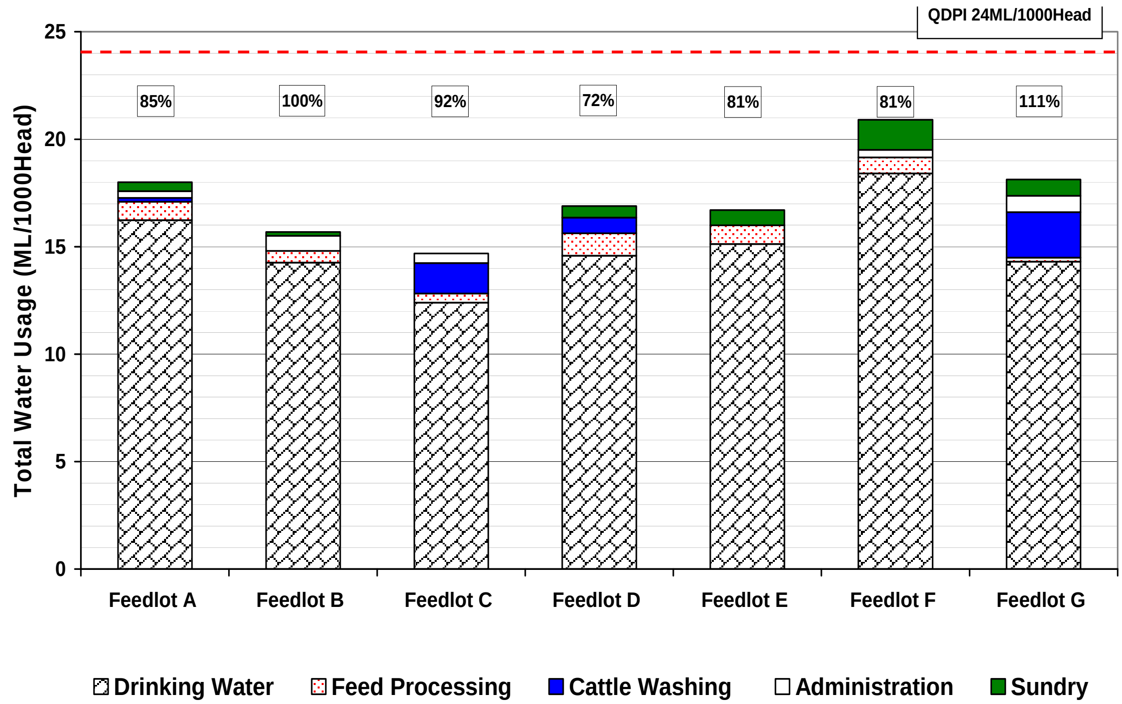

FIGURE 1 – BREAKDOWN OF WATER USAGE RATE BY ACTIVITY FOR SEVEN AUSTRALIAN FEEDLOTS

Figure 2 provides a breakdown of total water usage as megalitres per 1000 head on feed for the seven feedlots along with the average occupancy (mean number of cattle on hand divided by the licensed pen capacity expressed as a percentage).

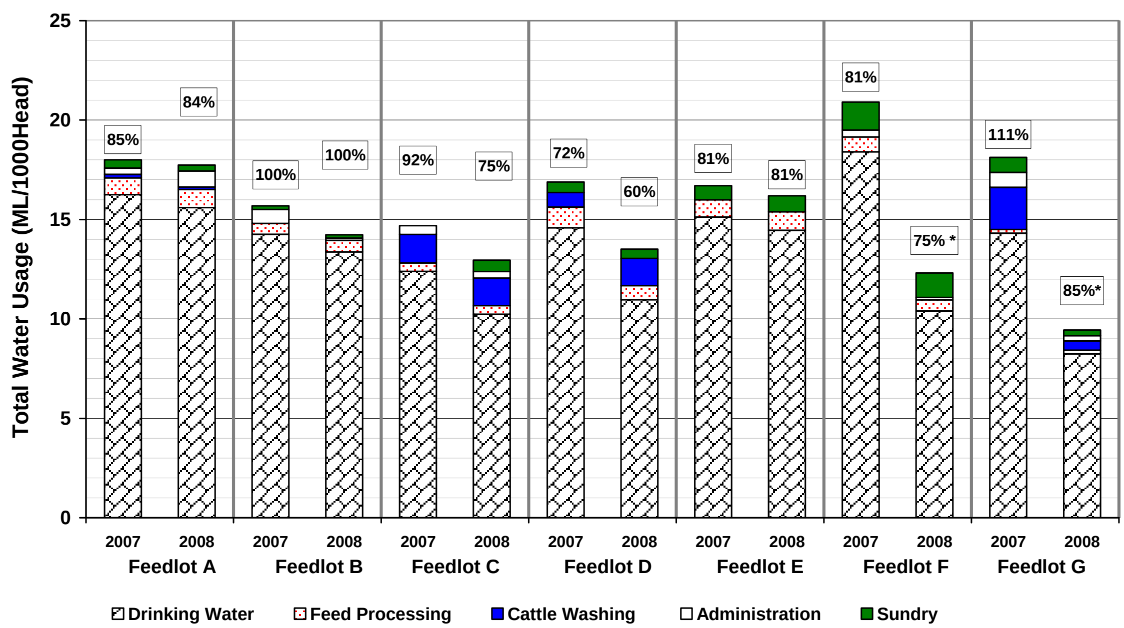

FIGURE 2 – TOTAL WATER USAGE (ML/1000 HEAD-ON-FEED) AND OCCUPANCY.
SOURCE: DAVIS *ET AL.* (2010)

From B.FLT.0339 and B.FLT.0350, the total water usage in Australian feedlots ranges from 14.5-20.5 ML/1000 head. About 90% of the total water requirement is for cattle drinking water when cattle washing is not being undertaken, falling to 75% of total water usage when cattle washing is occurring. This suggested to us that cattle drinking water, and possibly cattle washing, should be the targets for reuse of treated effluent within the feedlot.

5 FEEDLOT WATER QUALITY REQUIREMENTS

The literature was reviewed to identify the water quality standards applicable to the different water uses within a feedlot. Cattle drinking water is the major use within the feedlot. Good quality stock drinking water is imperative for animal productivity and welfare. The various codes and guidelines for Australian feedlots provide only general information on water quality requirements for stock drinking. The best information is presented in the ANZECC guidelines (2000).

5.1 CATTLE DRINKING WATER

Good quality stock drinking water is imperative for animal productivity and welfare. Most guidelines focus on ion levels in cattle water with little information on microbial levels. Many ions are essential for animal health. However, elevated concentrations of certain ions in stock drinking water may result in chronic or toxic effects in livestock (ANZECC 2000). Table 8 provides trigger levels for various ions taken from the ANZECC guidelines (2000).

Total dissolved solids (TDS) is a measure of all dissolved solids in water including all inorganic salts. Saline water is generally unpalatable to stock and can cause gastronintestinal upsets and reduced performance through to death in extreme cases. Pregnant, lactating or rapidly growing animals are more susceptible. However, animals can acclimatise to saline water to an extent if it is gradually introduced (ANZECC 2000). Recommendations for maximum TDS or salinity levels vary between references. According to the ANZECC guidelines (2000), no adverse effects are expected for beef cattle drinking water containing less than 4000 mg/L TDS. For water with a TDS of 4000-5000 mg/L, beef cattle may show initial reluctance to drink but stock are expected to adapt without loss of production. At TDS levels of 5000-10,000 mg/L it is expected that animal condition, production and health will decline. Stock may tolerate these elevated levels for short periods if gradually introduced to the water supply (ANZECC 2000).

TABLE 8 – CATTLE DRINKING WATER QUALITY TRIGGER LEVELS FOR MAJOR IONS

Parameter	Trigger level
Calcium	1000 mg/L
Magnesium	none specified
Nitrate	400 mg/L
Nitrite	30 mg/L
Sulfate	1000 mg/L
Total dissolved solids	4000 mg/L

Source : ANZECC (2000)

A wide range of microorganisms can affect stock drinking water quality. Many microbial pathogens can be transmitted to stock through faecal contamination of their water supplies. The bacteria of most importance to stock drinking water supplies include *Escherichia coli* (*E. coli*) and *Salmonella* and then *Campylobacter jejuni*, *Campylobacter coli*, *Yersinia entercolitica* and *Yersinia pseudotuberculosis*. Other bacteria that may be transmitted through water supplies include *Leptospira*, *Burkholderia (Pseudomonas) pseudomallei*, *Clostridium botulinum*, *Mycobacteri, Pseudomonas* and Cyanaobacteria (blue-green algae) (ANZECC 2000).

Mycobacterium paratuberculosis, which causes Bovine Johne's disease, may be present in animal faeces and could be present in feedlot effluent if infected cattle have been held in the feedlot in the preceding 12 months. Because animals less than 12 months of age are more susceptible to infection they should not be supplied with recycled drinking water (NRMMC & EPHC 2006).

Many stock pathogens spend part of their life cycles in water. It is generally not practical to test cattle drinking water for a wide range of pathogenic organisms. However, testing for the presence of thermotolerant (faecal) coliforms provides an indication of faecal contamination and hence the possible presence of pathogens. A stock drinking water quality trigger value of less than 100 thermotolerant coliforms /100 mL of water (median value) is specified (ANZECC 2000).
Most modern guidelines recognise that recycled water needs to be treated to a standard that makes it "fit for purpose". A crude assessment of the scarce existing data shows that the pathogen load in raw effluent can be quite high. Extensive tertiary treatment of effluent would be needed to allow for its safe usage in applications involving high exposure of cattle.

The other main question around water quality relates to salt concentration. Depending on the salinity (TDS /EC) of the effluent, either dilution or partial salt removal may be needed to ensure the recycled effluent is suitable for cattle consumption.

5.2 Cattle washing water

Some feedlots wash cattle to remove manure and dags so that they are presented in a clean condition for slaughter. Depending upon the cattle washing method and the extent of human exposure there may be occupational health and safety risks if the water is not of a minimum standard. There are no guidelines that suggest water quality parameters for cattle washing water. In the absence of specific water quality requirements for this purpose, an exposure risk assessment is needed.

6 Primary, Secondary and Tertiary Water Treatment Options

6.1 Primary treatment

Effluent from Australian feedlots typically passes through a sedimentation basin or trap and into a holding pond. These facilities mainly provide for containment of feedlot runoff but do offer some primary treatment. Table 9 provides a summary of the functions of these primary treatment facilities.

Table 9 – Summary of primary treatment processes currently utilised for feedlot effluent

Treatment step	Purpose	Description
Sedimentation basins	Removes entrained settable solids and organic nutrients from effluent runoff.	Low flow velocity in the runoff in the sedimentation basin to provide enough detention time for optimal settling of solids.
Holding ponds	Protecting water resources, contain the effluent until it can be irrigated and / or evaporated.	Current design standards refer to sizing holding ponds to contain either a major storm event (e.g. 1 in 20 year; 24 hour duration) or annual runoff volume.

6.2 SECONDARY TREATMENT

Further treatment would be needed to produce water suitable for cattle consumption. Secondary treatment generally involves the removal of dissolved and colloidal material typically by aerobic treatment processes. Table 10 provides a summary of secondary treatment options that could be used at a feedlot.

6.3 TERTIARY TREATMENT

Tertiary treatment typically tries to achieve one or more of the following aims:

- further reductions of COD or nutrients
- salt removal
- micropollutant removal
- disinfection.

Table 11 provides a summary of secondary treatment options that could be used at a feedlot.

TABLE 10 – SUMMARY OF SECONDARY TREATMENT OPTIONS

Purification step	Purpose	Description
Secondary	Further improve the quality of effluent that has undergone primary treatment.	
Anaerobic ponds	Treatment of effluent with relatively high organic matter content by anaerobic bacteria	Step1: breakdown of carbohydrates, fats and proteins to (mostly) organic acids. Step 2: stabilisation of organic acids to methane and CO_2.
Activated sludge	Series of separate chambers or tanks for aeration, sedimentation and clarification	Small aggregates of suspended colloidal organic matter (floc) are formed, and organic matter is removed by bacteria and protozoan within the floc
Trickling filters	Trickling filter consists of a tank, tower or other enclosure containing a fixed bed of medium (e.g. rock), over which effluent flows. This causes a microbial slime or biofilm to grow and cover the media bed	Up to 85% of the organic matter is removed from the effluent through both absorption and adsorption onto the microbial biofilm. Organic matter is broken down yielding carbon dioxide, water and other oxidised end products
Rotating Biological Contactors (RBC)	Series of closely spaced plastic discs (medium) mounted on a rotating shaft move in and out of effluent in a tank.	Microorganisms that grow on the disks form a slime layer that aerobically digests the biological material within the effluent.
Moving Bed Biofilm Reactors (MBBR)	Modern advancement of the trickling filter, incorporates a number of reactor tanks operating in series.	MBBR systems have a smaller footprint than the traditional activated sludge systems and can provide nitrogen removal.
Sequencing Batch Reactors (SBR)	A variation of MBBR methodology, SBR operates with one reactor vessel and establishes different conditions in the reactor to modify effluent quality.	The conditions inside the reactor may be controlled to create aerobic, anoxic or anaerobic conditions which provide flexibility in the control strategy enabling optimisation of effluent quality.

TABLE 11 – SUMMARY OF TERTIARY TREATMENT OPTIONS

Purification step	Purpose	Description
Granular filtration	Granular filters can be divided into two categories based on the rate at which they are fed, rapid and slow.	Rapid and slow granular filters use different removal processes, bed materials and modes of operation. Details of their respective design and operation are detailed in Milestone 3 report.
Membrane filtration	In membrane filtration, a thin semi-permeable membrane is used as a barrier to remove contaminants from water. Indeed, membranes act as selective barriers, allowing some compounds to pass through while blocking the passage of others (e.g. such as heavy metals or organic micropollutants).	The most commonly used membrane processes in recycled water production are microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). MF, UF, NF and RO membranes, also referred as pressure membranes. They are pressure-driven processes where the driving force is a pressure difference across the porous (MF, UF) or non-porous dense (NF, RO) membrane. These membranes are categorised based on their selectivity and consequently their pore size.
Oxidative treatment	Ultraviolet (UV) light and ozone are both used as oxidative agents against bacterial pathogens.	**UV:** The germicidal wavelength range lies between 220 to 320 nm, in the regions of UV-B and UV-C. Electromagnetic radiation in this range alters cellular proteins and nucleic acids (i.e., DNA and RNA) through dimerisation of the thymine nucleic acids on DNA molecules. **Ozone:** Ozone is relatively unstable and rapidly decomposes in water to form free radicals, including the hydroxyl radical (OH•). Both ozone and the resulting free radicals are stronger oxidisers than chlorine and can oxidise many organic and inorganic compounds in water and wastewater.

7 POTENTIAL TREATMENT TRAINS

7.1 TREATMENT TARGETS

For the purpose of this study, the treatment train needs to produce water that is suitable for cattle consumption. Given that the product will have high exposure for humans or animals, multi-barrier protection against risks from the raw water source are needed in accordance with HACCP principles. No single process unit can deal with all different types of contamination at once, therefore a specific treatment train must be designed. This needs to use compatible and feasible unit processes.

For the purpose of designing treatment trains, the following principles were used:

- pathogens log removal targets of 7 for bacteria, 6 for protozoa and 9.5 for viruses
- salts: partial desalination or shandying may be needed

- organic matter and nutrients: no specific guideline could be found, but for various reasons, in particular efficient and lasting disinfection, both need to be reduced considerably
- inorganic and organic micropollutants do not seem to provide any constraints for water recycling

Figure 3 shows several potential treatment trains to generate recycled water able to meet the treatment requirements for cattle drinking purposes. Treatment trains A, B and C do not have the capacity to remove salts. Therefore, opportunities for shandying and the target maximum total dissolved solids will determine if these treatment trains are feasible.

7.2 TREATMENT TRAIN A

Treatment train A is the simplest treatment train. Granular media filtration could be a biological activated carbon filtration, which could help in providing a stable effluent by increasing the reduction of biodegradable matter. In terms of pathogen removal this is the train with least redundancy with two proper disinfection processes preceded by granular media filtration, particularly with regards to virus removal. Its feasibility may depend on actual required log removal credits required and granted by the responsible authority.

7.3 TREATMENT TRAIN B

Treatment train B is similar to train A, but includes low pressure membranes as an additional barrier against pathogens. Since another filtration process is included, the necessity of dissolved air flotation and granular media filtration depends largely on the effluent quality provided by the secondary treatment step.

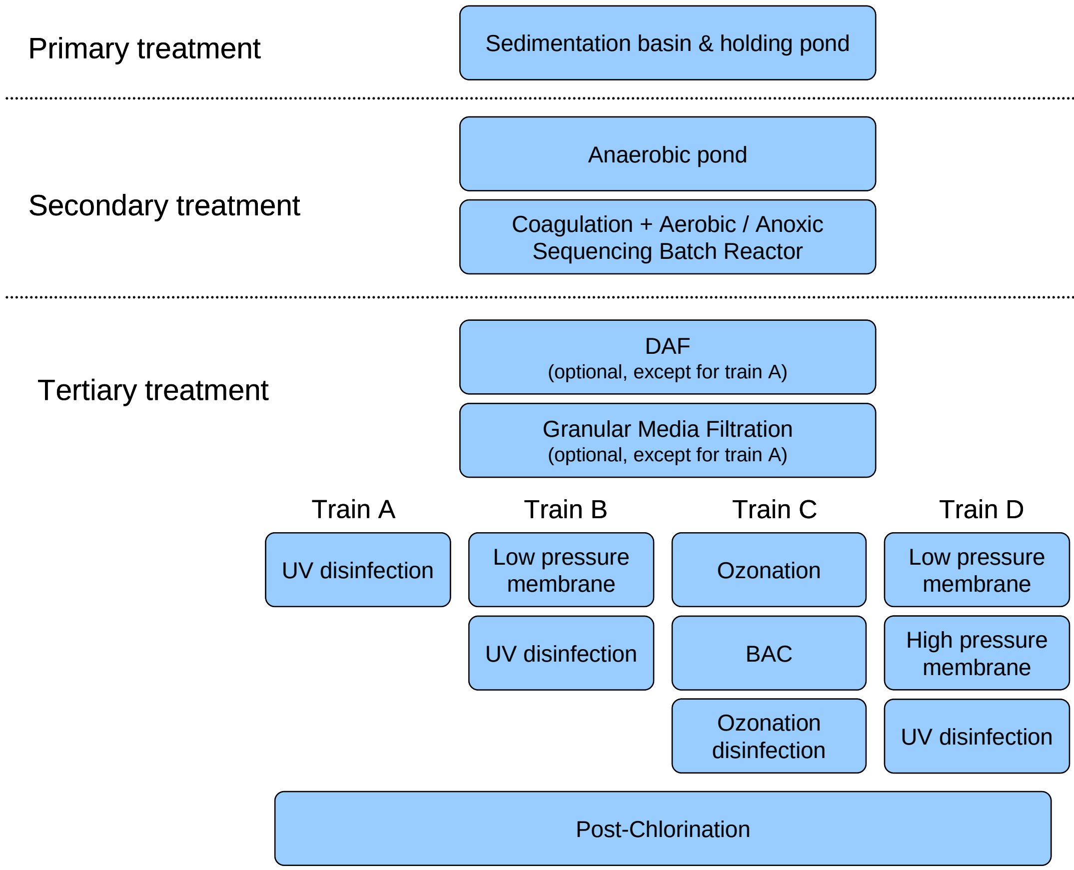

FIGURE 3 – POTENTIAL TREATMENT TRAINS TO GENERATE RECYCLED WATER SUITABLE FOR CATTLE DRINKING PURPOSES.

7.4 TREATMENT TRAIN C

Treatment train C is different as it provides an oxidative treatment to degrade dissolved organic matter and micropollutants. Biological activated carbon is required to remove the generated biodegradable matter in the primary ozonation step. Ozonation is applied twice to ensure organic matter removal in primary ozonation and disinfection in secondary ozonation.

7.5 TREATMENT TRAIN D

Treatment train D is the only treatment train that includes desalination by high pressure membranes. If only partial desalination is required the inclusion of nanofiltration could be an option as this would enhance process recovery and alleviate concentrate disposal issues. This treatment train effectively also has a number of barriers against pathogens. Large scale low pressure / high pressure membrane plants have been applied around the world for municipal water recycling, but also widely to satisfy industry needs for clean water. It is therefore likely to be well accepted from a regulatory point of view. At the same time, it is also the most expensive and energy consuming process.

7.6 ENERGY CONSUMPTION BY SECONDARY AND TERTIARY TREATMENT

Energy consumption of secondary treatment should be around 0.5 – 1.5 kWh/m^3 depending on the aeration requirements. Tertiary treatment would vary depending on the complexity of the treatment train and could be as low as 0.15 – 0.3 kWh/m^3 for treatment train A, 0.2 – 0.5 kWh/m^3 for treatment train B and C and 1 – 1.5 kWh/m^3 for treatment train D.

8 ECONOMIC ASSESSMENT OF WATER TREATMENT

8.1 CAPITAL INVESTMENT

The sustainable yield of effluent was determined to be around 2.5 – 5 ML / 1000 head per year, which would mean a total effluent volume of 12.5 – 25 ML / year for a 5000 head feedlot and 62.5 – 125 ML / year for a 25,000 head feedlot. This means that feed flow rate would be in the range of tens to hundreds of cubic metres per day, which is fairly small scale for complex advanced water treatment systems. Since economy of scale is important, this suggests that feedlot effluent recycling will only be feasible for bigger feedlots, if for any at all. Nevertheless, experience shows that if there is a suitable driving force, even considerably smaller, complex systems are being installed.

Capital costs are difficult to predict, since many site specific factors including scale and water quality and of course the chosen treatment train affect the capital investment per installed capacity significantly. In any case, we can assume that secondary treatment and tertiary treatment together will cost between $5M and $15M per installed ML/d treatment capacity.

8.2 OPERATIONAL COSTS

Operational costs are again difficult to estimate as they depend considerably on how the plant is operated, particularly for human resources. Trade-offs between operation automation (i.e. in theory reduced human resource cost) and increased capital investment will influence both contributions to the overall treatment cost.

Chemical costs for a process like treatment train D and of a size comparable to a potential advanced water treatment plant at a feedlot including low pressure and high pressure membranes were reported as around $0.80-$1.00 per cubic metre ($800-$1000/ML). Sludge handling was around half of that and maintenance and energy were somewhat lower again. Overall, these costs would sum up to around $2.00 - $2.50 per cubic metre ($2000-$2500/ML).

Required labour inputs are also difficult to estimate. In fact, the operation and control of the wastewater and advanced water treatment process poses a serious challenge to the whole concept as considerable expertise is required to optimise and control the system. Given that most feedlots are located some distance from large cities, such specialised expertise may not be easily available. On the other hand, the produced water quantities cannot bear the burden of a full scale engineer devoted to the advanced water treatment process. A high degree of automation would be necessary.

In summary, we can estimate that the capital expenditure costs will be $1.50 to $5.00 per cubic metre ($1500-$5000/ML), whereas operation costs will likely be between $2.00 and $3.50 per cubic metre ($2000-$3500/ML) depending on the degree of automation, which makes for an overall cost of $3.50 to $8.50 per cubic metre ($3500-$8500/ML). There is a considerable portion of uncertainty around this range of costs.

9 REGULATORY COMPLIANCE REQUIREMENTS

The reuse of treated feedlot effluent for cattle drinking water is yet to be implemented in Australia. Thus far government agencies have not considered how to regulate this use. Consequently there is no clear regulatory path. It is recommended that feedlot managers who are interested in treating and recycling effluent for reuse should enquire with their local council as a first step.

10 CONCLUSIONS

There is a reasonable body of data for the nutrient composition of effluent from Australian feedlots. However, more data is needed about the microbial load and other properties important to water treatment (e.g. total organic carbon / COD, full colour absorbance spectrum, turbidity).
In most locations, the sustainable yield of effluent for reuse within the feedlot can meet about 20% of the total water requirement. However, only 10-12% of the total water requirement can be met for a feedlot in the Riverina (represented in the modelling by Charlton).

About 90% of the total water requirement is for cattle drinking water when cattle washing is not being undertaken and falls to 75% of total water usage when this is occurring. This suggests that stock drinking water, and possibly cattle washing, should be the target for reuse of treated effluent within the feedlot.

With regards to water quality and treatment requirements, pathogenic contamination and the associated risk of disease outbreaks are the most concerning aspects if recycled water is to be used for cattle drinking. While there are some standards for cattle drinking water, microbial standards are limited. A site-specific exposure risk assessment is needed to determine the required water quality.

The main other question around water quality relates to salt concentration. Feedlot effluent has a considerable salinity and the information in the literature and guidelines is contradictory with regards to salt tolerance of cattle. Significant dilution or partial salt removal may be needed. All treatment must also considerably reduce organic matter, colour and nutrients, mainly to allow achieving effluent stability and efficient disinfection.

Several treatment trains including primary, secondary and tertiary treatment have been suggested. All tertiary treatment trains include some sort of filtration and at least two disinfection processes, either UV disinfection or ozone, both followed by chlorination. If partial or complete desalination are desired, the treatment train includes low and high pressure membrane filtration. This treatment train is the best proven treatment train of all the suggested, but it is also the most expensive and energy consuming one.

We estimated that the capital expenditure costs will be $1500 to $5000 per megalitre (ML), whereas operation costs will likely be between $2000 and $3500 per ML depending on the degree of automation, which makes for an overall cost of $3500 to $8500 per ML with considerable uncertainty around this range of costs. This is expensive relative to the current market value for water. Access to maintenance contractors may present some issues.

Another challenge is the lack of a clear regulatory path in relation to the treatment and reuse of feedlot effluent for cattle drinking or washing water. This is a new concept in water recycling and, in most cases, the regulatory requirements are yet to be developed. In the absence of specific relevant requirements it is likely that anyone proposing to develop such a system would need to provide a case-specific risk assessment. In any case the implementation of such a project will require thorough engagement with stakeholders, in particular with government agencies, which should provide guidance to apply an adequate risk assessment framework to the project.

Finally, as the recent public debates about recycled water have shown, there are other factors to be considered, regardless of whether the risks associated with recycled water are perceived or real. There is a significant risk that the major retailers would either refuse to market beef produced using recycled treated feedlot effluent in the cattle drinking water supply or specify a very high treatment standard. There is also a risk of a broader consumer backlash.

Water recycling in the beef industry is unlikely to be an option for the majority of the industry at this point in time. In any case, individual feedlot owners probably would not take this step unless they were forced to, since in principle it puts them at a commercial disadvantage towards other meat producers, who have access to cheaper water. However, as water prices increase this situation may change.

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