Final Report

Project code: A.ENV.0151

Prepared by: Paul Jensen and Damien Batstone

Advanced Water Management Centre
The University of Queensland

Date published: TBA

PUBLISHED BY
Meat & Livestock Australia Limited
Locked Bag 991
NORTH SYDNEY NSW 2059

NGERS and Wastewater Management – mapping waste streams and quantifying the impacts

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government and contributions from the Australian Meat Processor Corporation to support the research and development detailed in this publication.

Executive Summary

The NGERS and wastewater management project is intended to identify key contributors to waste stream loads and resources, including thermal, energetic, and chemical. This was partly driven by carbon pricing, and partly driven by a lack of knowledge in this area required to guide informed decisions into building wastewater infrastructure. Project activities included a literature review, multiple site visits to 6 sites, and detailed chemical, biochemical and statistical analysis. The literature review included the formal literature (some 600 relevant articles), as well as MLA/AMPC projects (approximately 19 out of 103 environment projects) were reviewed.

From the literature it appears that wastewater strength has increased in the last 10 years from a base level of 2000-5000 mgCOD/L to >5000 mgCOD/L, with a water consumption decrease in the range of 20%. Results from this project show that overall water usage and nutrient loads were within ranges expected from literature, however wastewater strength has further increased to ~10,000 mgCOD/L and subsequently total organic loads were estimated at 2-4 times greater than the loads expected from literature.

Carbon emission liabilities under the Carbon Pricing Mechanism (CPM), which is no longer in place at the time of publication, at Sites A, C and D were approximately 20-30% greater than the NGERS and CPM default calculations. However, at Site B, where separation units are used to recover oil and grease for recycle to rendering, the estimated carbon emission liability was lower than the default NGER and CPM value (0.29 t CO_2 per t HSCW). Therefore it was concluded that the NGERs default calculation is a reasonable, but slightly conservative estimate of plant liabilities; however sites can reduce emissions below this level with appropriate waste handling strategies. In addition to mitigation of carbon liabilities, the energy and nutrient resources in cattle slaughterhouse wastewater were valued at approximately $20 per tHSCW, this corresponds to an average value of $1.2M per year for the sites investigated in this study and presents a strong argument for development and implementation of resource recovery technologies.

During sampling 6 major sources of wastewater were identified at the 6 meat processing facilities included in this investigation; Cattle Yard Wash, Slaughter Floor, Paunch Handling, Offal Processing, Boning Room and Rendering Operations. The composition of individual wastewater streams varied depending on the source within the slaughterhouses and ranged from low strength (boning) to very high strength (rendering) with TCOD over 70,000 mg/L, there were also large differences in the concentrations of key nutrients N, P and K. Biochemical methane potential varied from 250-300 L CH4 per kgVS for cattle yard and paunch wastewater to 500 L CH4 kgVS-1 for slaughter floor wastewater and over 1000 L CH4 per kgVS for rendering wastewater. However, there were also indications of oil and grease inhibition when treating rendering wastewater. Rendering and paunch wastewater were concentrated resource streams that contribute up to 75% of the methane potential, phosphorus and potassium loads, in only 20% of the volumetric flow. Compared to the final effluent, phosphorus was 2 to 4 times more concentrated in the rendering and paunch wastewater streams. These concentrated streams provide opportunities to enhance the recovery of nutrients using crystallisation technologies. Therefore source capture and specialised primary treatment of individual wastewater streams is recommended.

Based on these findings, it is recommended that Rendering, Slaughter Floor, and Paunch wastewater be treated using an anaerobic process (to remove carbon, and recover nitrogen and phosphorous). Cattle Wash and Boning Room are very high flow and low contaminant, and can therefore bypass primary treatment. A suitable polishing step may include aerobic MBR, fixed film or moving bed aerobic bioreactor, or facultative lagoons.

Table of Contents

1 Introduction and Objectives

The NGERS and Wastewater Management project is intended to identify and address knowledge gaps around the wastewater streams from mainly meat cattle and sheep processing. There are a number of motivations regarding this, including:-

(a) Australian red meat processing has a high exposure to carbon pricing due to wastewater methane emissions, and its use of coal for steam generation.
(b) There is a clear lack of published literature analysing wastewater sources; most are completely focused on treatment options.
(c) A number of new technology options have emerged that provide new opportunities for low cost treatment and resource recovery (e.g. N, P, K).
(d) There are clear gaps in knowledge of wastewater sources, as well as resources available (chemical and thermal energy, carbon, nitrogen phosphorous, and other elements.

Based on these motivations, the following objectives (and related project activities) have been conducted:-

- Literature review and interviews to determine levels of variability, uncertainty, and sources of variability contributing to final effluent streams.
- Conduct wastewater surveys and collect samples (addressing variation in flows) across three major wastewater plants.
- Conduct biochemical and chemical testing (at least 10 samples per partner site) to identify levels, form, and accessibility of energy, nutrients, and metals.

An initial literature review was aimed at broadly assessing the formal scientific literature and previous MLA and AMPC funded research for knowledge gaps, in order to further guide the project sampling programme. Its objectives were:-

- Identify international practice and variability.
- Identify information in the grey (MLA/AMPC) literature that can be integrated into the project.
- Identify key gaps for this project to address.

Outcomes of the literature review were presented in the final report to A.ENV.0131 and are not included in this report.

2 Methodology

A five-stage approach was developed for the work. This involved:

2.1 Plant Interview and Planning

An initial visit and interview was conducted at each site prior to the sampling trip. This initial visit determined:

- The structure of the waste handling operations and the level of access/location of sample points.
- Operating characteristics of the plant (operating shifts, operating days, cattle type throughout week).
- Length of visit required for representative sampling
- Equipment and safety considerations

2.2 Flow Analysis and Sample Collection

Measurement and analysis of volumetric flowrates was achieved using several different methods. Where the flow was through a closed pipe a Thermo sx30 Doppler flow meter was attached to the outside of the pipe for measurements. In cases where there was not an appropriate pipe location, excessive noise/vibration, or insufficient solids in the material, the flow could not be determined by this method. Other techniques that were employed included:

- Filling of tanks and/or mixing pits in batch operation, the change in liquid level was measured over time and combined with the diameter to determine an average volume change.
- Pump size and duty time of operation.
- Estimation by linear velocity in open channel by the cross sectional area.
- Onsite pre-installed flow meters.
- Onsite equipment flow meters.
- Mass balances around a mixing point.
- Long term averages, meter readings out of dams.
- Estimation by the filling of a 20L container.
- Estimation by the filling of a 500mL container.

Samples were generally collected from the outlet of pipes, or from mixing/pump pits. The collection of samples from pump pits was preferred as the flow was well mixed and the residence time of the pits assisted to reduce variability and improve representative nature of the samples. Due to the variability of some streams composite samples were taken over the time of the sampling trip. The samples were placed on ice at the time of collection. In most cases, a portion of sample was filtered onsite at the time of collection to preserve samples for analysis of soluble compounds. Temperature measurements were taken at time of collection by an infrared thermometer.

2.3 Stream Composition and Load

Analyses were performed for total solids (TS), volatile solids (VS), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN) and ammonium–nitrogen (NH4-N). Analytical methods were as for Standard Methods (APHA, 1998). For measurement of soluble compounds, the liquid samples were filtered through a syringe filter (0.45 um PES membrane) immediately after collection and stored prior to analysis. COD was measured on Merck Method for total (TCOD) and soluble fractions (SCOD), using an SQ 118 Photometer (Merck, Germany). NH4-N and TKN were measured using a Lachat Quik-Chem 8000 Flow Injection Analyser (Lachat Instrument, Milwaukee).

Estimates of waste loading were based on flow volumes and results of the composition analysis during the daily slaughter operations. The load of an individual contaminant was calculated using the method shown in Equation 1.

$$Load\left(\frac{kg}{d}\right) = Flow\ Rate\left(\frac{kL}{hr}\right) \times Hours\ of\ Flow\left(\frac{hr}{d}\right) \times Concentration\left(\frac{kg}{kL}\right) \qquad (1)$$

2.4 Biochemical Methane Potential B_0

Biological methane potential tests use a known good inoculum, together with the sample, in 160 mL vials to assess sample degradability. Normally it is used to assess apparent first order hydrolysis rate (k_{hyd}), as well as ultimate degradability (f_d). An example result is shown in Figure 1.

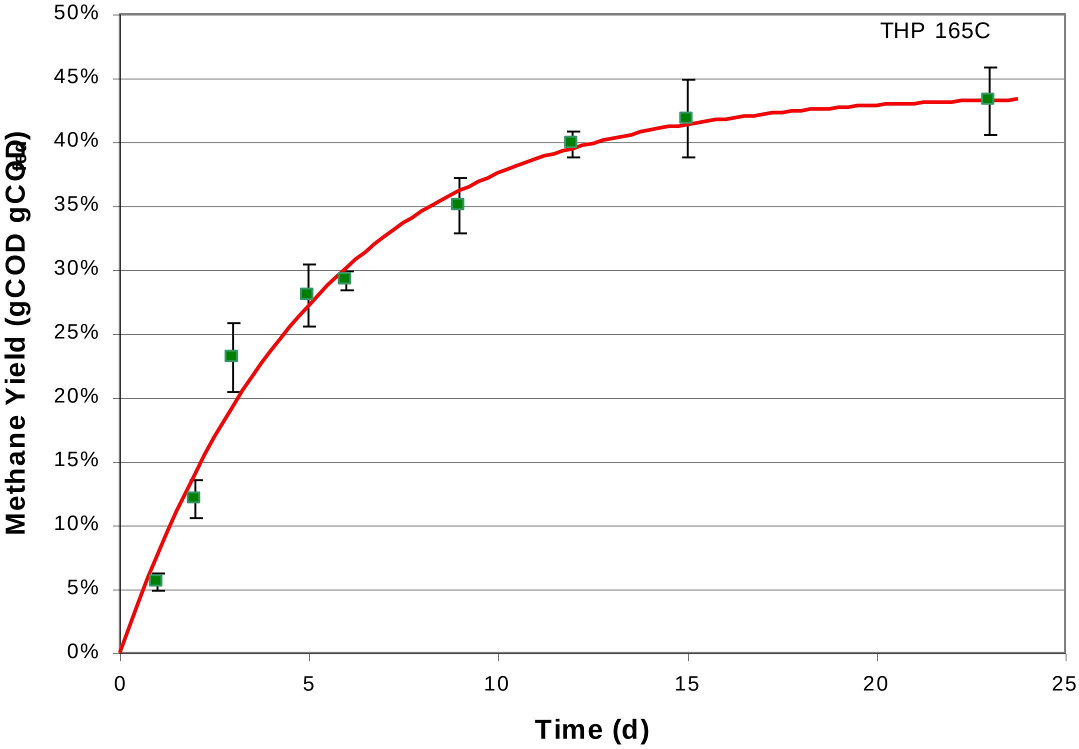

Figure 1 Example output from biological methane potential (BMP) test. Error bars indicate 95% confidence errors from triplicate batches. The line indicates the model used to return key parameters.

Batch tests were done in triplicate (3x160mL vials per BMP), using a known good inoculum from a full-scale digester in Brisbane. No-substrate blanks were done, to assess inoculum methane production, as well as a cellulose positive control. Batches were controlled at mesophilic temperatures (37°C) in an incubator.

2.5 Mass Balancing and Statistical Analysis

The reliability of contaminant load calculations was assessed by conducting a mass balance around key mix points. For the mass balance, it was assumed that contaminants do not accumulate at the mix point and are not being lost or generated due to chemical reactions taking place. Therefore, the balance will close when the load of each contaminant entering the mix point is equal to the load of that contaminant exiting the mix point. The mass balances were based on Equation 2.

$$Fraction\ from\ Closed\ Balance = \frac{in-out}{in} = \frac{\left[\sum_{i=0}^{i=1} C_{N,i}\times Q_i\right]_{In} - \left[C_{N,j}\times Q_j\right]_{out}}{\left[\sum_{i=0}^{i=1} C_{N,i}\times Q_i\right]_{In}} \qquad (2)$$

For individual streams entering the mix point:

$C_{N,i}$ = Concentration of contaminant N in stream *i* (mg/L)

Q_i = Estimated volumetric flowrate of stream *i* (kL/day)

For combined streams exiting the mix point:

$C_{N,j}$ = Concentration of contaminant N in stream *j* (mg/L)

Q_i = Estimated volumetric flowrate of stream *j* (kL/day)

Slaughterhouse wastewater streams are highly variable, therefore when applying equation 2 to assess the reliability of load calculations, <20% was considered to be a good agreement, while greater than >50% was considered to be poor agreement.

3 Results for Site D

3.1 Plant Description

Site D is an Australian livestock processing facility situated in New South Wales, Australia. Site D operates an abattoir that has the capability to process 12,500 bovines per week. The abattoir has two separate processing floors. The Beef Floor typically processes all animals over 150 kg and the Veal Floor typically processes all those under 150 kg. A summary of operations at Site D during the sample period is shown in Table 1.

Table 1 Summary of operations at Site D during sample trip (October 2012)

Site D	
Type:	Northern Beef Abattoir
Date visited:	09/10/12 - 12/10/12
Number of Streams surveyed:	23
Kill Floor Hours of operation:	06:30 - 16:00
Rendering Hours of operation:	06:00 – 01:00
Head processed / Day:	800-1400
Cattle Type:	Grass/grain fed
Clean water usage / Day	2.5-3 ML per day (wastewater ex Tannery)

In addition to the abattoir, Site D operates a tannery as part of its integrated processing service. The tannery is devoted to processing hides from the abattoir from green through to wet blue leather, as well as production from other selected producers within the area. Wastewater analysis from the tannery is not included in this report.

3.2 Description of Waste and Wastewater Operations

This section is a summary of waste and wastewater operations at the Site D abattoir, a flowsheet of waste and wastewater operation is also included as Figure 2. The waste processing operations at the Site D abattoir consists of 4 main process trains:

Combined Red Wastewater: The combined red wastewater includes all wastewater from the rendering plant, the beef slaughter floor, offal processing and the veal slaughter floor.

The rendering plant includes several wastewater sources including raw material bins, stick waters, boiler condensate etc. Individual samples were collected for each of these streams during the sample visit and will be discussed in the final report. However, in this draft report, the rendering wastewater is considered as two streams (combined bins and combined stick) based on the discharge locations from the rendering plant.

The Veal slaughter floor was collected as an individual wastewater stream. However, at the time of sampling it was not possible to separate the offal processing wastewater and the beef slaughter floor wastewater, therefore these 2 sources are presented as a single combined stream.

The red wastewater streams are combined in a flow channel to form the combined red wastewater, the combined red wastewater is passed through a Contrashear to remove course solids (recycled to rendering), the remaining wastewater is sent to the saveall operation. The saveall uses dissolved air flotation (DAF) with no polymer addition to recover fatty solids for recycling. The remaining red wastewater flows directly to the final effluent mixing pit and is discharged with the combined wastewater to the anaerobic lagoon. The red wastewater and the saveall are areas most affected during rain events, where rainwater was observed to flow directly into one of the three saveall units.

Paunch Handling: At Site D waste and wastewater associated with paunch handling typically consists of paunch, foreign objects (e.g. intestinal plugs/clamps) and wash down water/transfer water. At site D, the paunch stream typically does not include waste material from offal processing. The combined paunch stream passes through a course screen where foreign objects (such as intestinal plugs) are removed, but most paunch solids are not. The paunch stream is subsequently sent to the paunch screw press where coarse solids are removed (sent to composting), the remaining wastewater flows directly to the final effluent mixing pit and is discharged with the combined wastewater to the anaerobic lagoon. In the event of a processing issue the paunch stream may bypass the paunch screw press and be added to the combined red wastewater prior to the contrashear and saveall – however this is not typical process operation.

Cattle Yards: Wastewater from the cattle yards typically consists of spray water used to wash cattle before processing, bovine urine and manure, and wash down from cleaning operations in the cattle yards. A portion of water used in the cattle yards is recycled from the defrost collection pit (boning room wastewater and defrost from chillers). Combined wastewater from the cattle yards is sent to an auger screw where coarse solids are removed (sent to composting), the remaining wastewater flows directly to the final effluent mixing pit and is discharged with the combined wastewater to the anaerobic lagoon.

Boning Room and Chillers: Wastewater from the boning room, and defrost collection from chillers is collected in the defrost collection pit. This wastewater is recycled to the cattle yards and is not directly discharged to the anaerobic lagoon.

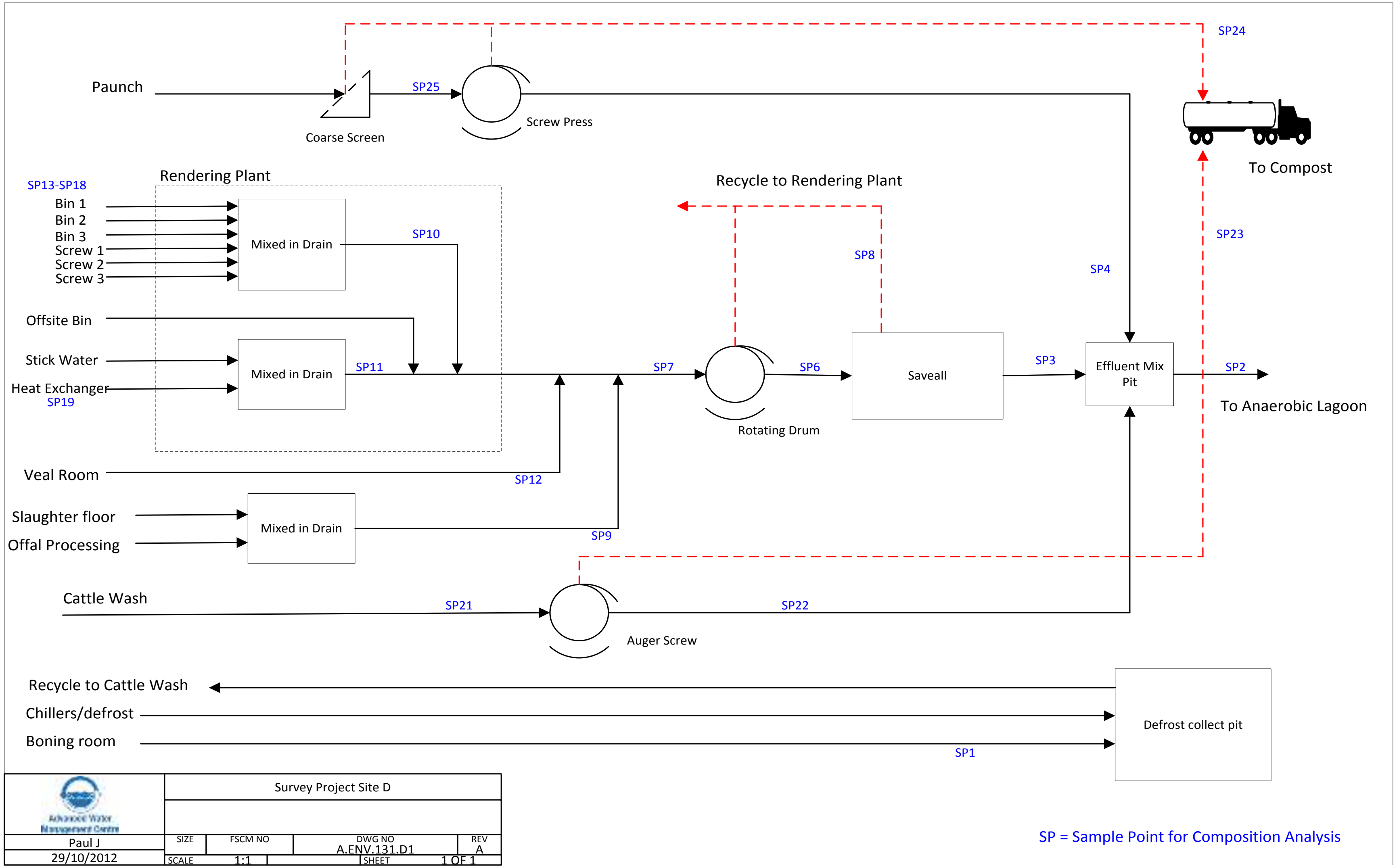

Figure 2 Flowsheet representing waste and wastewater handling operations at Site D.

3.3 Waste and Water Flows

A total of 23 individual streams (20 wastewater flows, 3 solid waste flows) were included in analysis of Site D. A summary of the major wastewater flows included in this initial report are shown in Table 2. Methodology used to estimate the flow rate and variability of each stream will be presented in detail in the final report.

Due to the nature of operations at the abattoir, there were distinct changes in the wastewater effluent throughout the day. These variations exist in both volumetric flow rate and nutrient composition. Composite sampling was utilised to account for this variation.

Table 2 Estimate of individual and combined waste stream flows

Wastewater Flows During Kill Operations (6am to 4pm)				
Stream	Hourly Flow	Measurement Technique	Estimated Daily Full Flow Operation	Daily Flow
	(kL/hr)		(Hours)	(kL/d)
Rendering Bins	30.4	Bucket Collections	10	304
Rendering Stick	9.4	Bucket Collections	10	94
Veal Room	48	Channel dimensions and velocity	10	480
Kill Floor + Offal	72.2	Channel dimensions and velocity	10	722
Combined Red	160	Channel dimensions and velocity	10	1600
Paunch	25	Ultrasonic Sensor	8	200
Cattle Yards	50	Ultrasonic Sensor	8	400
Total Effluent	215	Supplied by Site D	10	2,150

The flow volumes shown in Table 2 contribute approximately 65% of the daily flow volume at Site D. The rendering plant at Site D continues to operate between 4pm and 12am, average flow from Site D during this period is approximately 80kL/hour; the composition of rendering streams during this period is assumed to be similar to composition during the day. The remaining volumes are due to wash down and cleaning operations, wash down and cleaning contribute approximately 40kL/hour between 4pm and 6 am; the composition of wash down streams will be very strong for the first 0.5-1 hour, then very dilute for the remainder of the operation. This dilute wash down water was not captured during sampling, but is expected to have minimal impact of contaminant and nutrient loads in the wastewater.

3.4 Waste Water Compositions

Where possible, the composition of each stream was based on composite samples collected during the 4 day sample trip. Where sample composites were not available, the composition of streams was based on the average composition of available samples, the organic contaminant and nutrient results are presented in Table 3, the trace metal results are presented in Table 4. The variations in concentration of effluent streams illustrate the diverse nature of wastewater within the treatment and handling process.

When considering the wastewater streams (and excluding the screened solids) the combined rendering streams (SP10 and SP11) were found to contain the highest concentrations of both total COD and solids, whilst also featuring the highest strength streams for nitrogen and phosphorus. Boning room wastewater was very low for all metrics and is not presented in the tables.

Analysis of the cattle yard streams suggest the auger screw was effective at removal of solids (TCOD) and nutrients (N and P). While analysis of the paunch streams suggest that the paunch screw press is also effective at removing solids (and total COD), however only a small fraction of N and P was removed in the captured solids.

Table 3 Organic contaminant and nutrient composition of waste streams at Site D

Stream	**Stream**	**Flow**	**Temp**	**TCOD**	**SCOD**	**TS**	**VS**	**TSS**	**FOG**	**TKN**	**sTKN**	**NH4-N**	**TKP**	**sTKP**	**PO4-P**
		kL/hr	**°C**	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(mg/l)**	**(mgN/l)**	**(mgN/l)**	**(mgN/l)**	**(mgP/l)**	**(mgP/l)**	**(mgP/l)**
Paunch - Prescreen	25	20	33	12,190	920	15,123	12,897	N/A	142	266	N/A	18	167	N/A	99
Paunch - Post Screen	4	20	34	5,420	850	6,946	4,753	4,370	194	243	65	13	146	100	88
Paunch - Solids	24	-	N/A	147,170	N/A	249,383	236,615	N/A	1,095	776	N/A	N/A	243	N/A	N/A
Cattle Wash - Pre-auger	21	40	21	11,070	400	9,828	7,940	N/A	82	356	N/A	86	65	N/A	29
Cattle Wash - Post-auger	22	40	19	1,800	250	1,979	1,361	1,200	10	129	83	87	18	11	9
Cattle Wash - solids	23	-	N/A	89,530	N/A	155,983	136,101	N/A	380	1,922	N/A	N/A	475	N/A	N/A
Combined Bins	10	30.4	46	44,140	15,820	30,548	26,376	17,730	9,297	2,076	1,548	180	164	109	89
Combined Stick	11	9.4	39	73,420	980	33,530	32,130	32,030	21,075	492	308	215	114	17	34
Veal Room	12	48	31	14,120	2,270	9,335	8,942	276	<4	294	257	26	4	2	15
Slaughter floor/Offal	9	72.2	37	2,210	1,220	2,630	2,245	2,020	325	154	101	5	20	9	3
Combined Red - Pre-screen	7	160	38	9,950	1,910	8,489	7,827	5,820	3,751	353	227	38	39	21	16
SaveAll In	6	160	36	12,790	2,790	9,264	7,830	5,620	3,300	420	N/A	27	41	N/A	19
SaveAll Out	3	160	36	8,020	3,010	4,031	3,439	2,930	978	402	286	38	41	39	33
Total Out	**2**	**215**	**31**	**12,460**	**2,220**	**7,401**	**6,828**	**6,600**	**1,240**	**438**	**233**	**38**	**56**	**31**	**27**

1. N/A – analysis not performed for this sample

Table 4 Trace metal composition of waste streams at Site D

Stream	SP	Al	As	B	Ba	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	P	Pb	S	Se	Si	Zn
		mg/l	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Boning Room	1	0.21	0	0.02	0.03	27.2	0	0	0	0.06	0.1	2.4	16.5	0	0.1	49	0	0.17	0.02	10.43	0	9.49	0.11
Paunch - Prescreen	25	1.6	0.0	0.0	0.3	64.2	0.0	0.0	0.0	0.1	4.3	52.2	15.9	1.9	0.0	299	0.0	77.9	0.0	22.3	0.0	8.8	0.6
Paunch - Post Screen	4	2.6	0.0	0.0	0.3	75.4	0.0	0.0	0.0	0.1	5.8	119.9	20.9	2.3	0.0	606	0.0	151.3	0.0	26.5	0.0	17.1	0.7
Paunch - Solids	24	0.9	0.0	0.0	0.1	32.6	0.0	0.0	0.0	0.0	1.9	1.9	3.7	1.1	0.5	0.0	21.0	0.0	11.1	10.3	0.0	15.9	0.0
Cattle Wash - Pre-auger	21	11.6	0.0	0.1	0.7	155.3	0.0	0.0	0.1	0.2	27.1	107.1	61.5	4.1	0.1	89	0.0	65.7	0.0	62.8	0.1	17.0	1.9
Cattle Wash - Post-auger	22	1.7	0.00	0.05	0.11	46.70	0.0	0.01	0.05	0.06	4.2	60.1	23.2	0.7	0.1	70	0.01	18.0	0.01	24.5	0.02	17.22	0.50
Cattle Wash - solids	23	2.0	0.00	0.00	0.16	20.60	0.0	0.00	0.00	0.00	4.5	4.5	10.0	5.9	0.6	0.0	3.74	0.0	10.45	9.7	0.00	20.28	0.16
Combined Bins	10	1.1	0.0	0.0	0.1	73.9	0.0	0.0	0.0	0.2	21.6	304.7	26.3	0.5	0.0	561	0.0	142.4	0.0	111.5	0.1	9.6	0.9
Combined Stick	11	0.4	0.0	0.0	0.3	387.3	0.0	0.0	0.0	0.0	8.0	19.1	18.2	0.3	0.0	40	0.0	194.9	0.0	35.4	0.1	5.0	0.8
Veal Room	12	0.1	0.0	0.0	0.0	31.0	0.0	0.0	0.0	0.1	13.1	17.4	16.8	0.0	0.0	115	0.0	6.6	0.0	47.5	0.1	8.3	0.1
Slaughter floor/Offal	9	0.5	0.0	0.0	0.1	37.1	0.0	0.0	0.0	0.0	2.5	23.7	18.8	0.4	0.0	85	0.0	18.4	0.0	22.0	0.1	9.5	0.2
Combined Red - Pre-screen	7	0.4	0.0	0.0	0.1	42.0	0.0	0.0	0.0	0.1	4.2	53.1	18.2	0.4	0.0	146	0.0	39.6	0.0	29.6	0.1	9.0	0.3
SaveAll In	6	0.7	0.00	0.01	0.08	46.90	0.0	0.00	0.02	0.07	4.3	55.9	18.2	0.4	0.0	156	0.00	37.6	0.00	27.4	0.03	10.97	0.34
SaveAll Out	3	0.4	0.00	0.01	0.07	41.00	0.0	0.00	0.04	0.07	4.3	56.6	17.3	0.3	0.0	144	0.00	41.8	0.01	29.9	0.02	10.40	0.38
Total Out	**2**	**2.5**	**0.0**	**0.0**	**0.2**	**93.7**	**0.0**	**0.0**	**0.0**	**0.4**	**14.8**	**65.7**	**22.6**	**1.0**	**0.0**	**194**	**0.0**	**63.6**	**0.0**	**39.8**	**0.0**	**11.6**	**0.9**

3.5 Analysis of Waste Loadings

Table 5 presents the initial estimate of the load of organic matter and nutrients (kg/day) in each of the waste streams analysed.

The combined slaughter floor/offal processing wastewater (SP9) was the single largest contributor to volumetric load (approx. 50%) but due to the dilute nature of this stream it only contributed 10% of total daily COD and 10-20% daily nutrient load. The combined material bins are the major contributor of nitrogen in the effluent, while the cattle yards were also a major contributor of ammonia into the final effluent. The major sources of phosphorus in the wastewater effluents were the paunch and rendering streams.

Table 5 Nutrient and Organic Waste Loadings at Site D

Stream	Stream	Flowrate	Temp	TCOD	sCOD	TS	VS	TSS	FOG	TKN	sTKN	NH4-N	TKP	sTKP	PO4-P
		kL/day	°C	(kg/d)	(kg/d)	(kg/d)	(kg/d)	(kg/d)	(kg/d)	(kgN/d)	(kgN/d)	(kgN/d)	(kgP/d)	(kgP/d)	(kgP/d)
Paunch - Prescreen	25	200	33	2,438	184	3,025	2,579	0	28	53	0	4	33	0	20
Paunch - Post Screen	4	200	34	1,084	170	1,389	951	874	39	49	13	3	29	20	18
Paunch - Solids	24	18m^3	N/A	2,943	N/A	4,988	4,732	0	22	16	0	0	5	0	0
Cattle Wash - Pre-auger	21	400	21	4,428	160	3,931	3,176	0	33	143	0	34	26	0	12
Cattle Wash - Post-auger	22	400	19	720	100	791	544	480	4	52	33	35	7	4	4
Cattle Wash - solids	23	2m^3	N/A	3,581	N/A	6,239	5,444	0	15	77	0	0	19	0	0
Combined Bins	10	304	46	13,419	4,809	9,287	8,018	5,390	2,826	631	470	55	50	33	27
Combined Stick	11	94	39	6,901	92	3,152	3,020	3,011	1,981	46	29	20	11	2	3
Veal Room	12	480	31	6,778	1,090	4,481	4,292	132	2	141	123	12	2	1	7
Slaughter floor/Offal	9	722	37	1,596	881	1,899	1,621	1,458	235	111	73	4	15	7	2
Combined Red - Pre-screen	7	1600	38	15,920	3,056	13,583	12,524	9,312	6,002	565	364	61	62	34	26
SaveAll In	6	1600	36	20,464	4,464	14,823	12,528	8,992	5,280	671	0	43	65	0	30
SaveAll Out	3	1600	36	12,832	4,816	6,450	5,503	4,688	1,564	644	457	61	66	62	53
Total Out	**2**	**2150**	**31**	26,789	4,773	15,913	14,680	14,190	2,666	943	501	81	120	67	59

3.6 Analysis of Biochemical Methane Potential (B_0)

Biochemical methane potential is an indication of anaerobic biodegradability and the potential to recover energy during wastewater treatment. Methane potentials from ten streams were analysed from Site D during this study. Cumulative methane production curves (L CH_4 per kgVS) representing each processing area and a summary of B_0 values determined from parameter estimation are shown in Figure 3 and Figure 4 respectively.

When comparing processing areas, B_0 was highest in the rendering stick water and offal streams and is consistent with the higher FOG content of this wastewater. Rendering wastewater was also the most concentrated source of wastewater, resulting in high methane potential per kL wastewater. As rendering wastewater is a primary source of organics, phosphorus and nitrogen there is substantial opportunity to recover material through specialised treatment of rendering wastewater, however there was also clear evidence of inhibition in the rendering stick water sample resulting is an apparent lag time of 16 days before significant methane production was observed. Similar evidence of inhibition has been observed during A.ENV.0131 in samples where the FOG concentration in wastewater was above 10,000 mg/L (e.g. Offal processing wastewater from Site A). The potential for FOG inhibition means the best strategy would be a co-digestion strategy based around rendering wastewater.

The B_0 of cattle yard wastewater was approximately 320 L CH_4 per kgVS and is consistent with results from A.ENV.0131 and previously reported B_0 for cattle manures ranging from 220-420 L CH_4 per kgVS (*Gopalan et al. 2013, Hill 1984, Karim et al. 2007*). Cattle yard wastewater was dilute with low yields (per gVS and per kL wastewater) and slow digestion times and is therefore not an ideal candidate for dedicated treatment or use in a co-digestion strategy with rendering wastewater.

The B_0 of slaughter floor wastewater was approximately 520 L CH_4 per kgVS and is consistent with the B_0 of protein rich substrates (A.ENV.155). Slaughter floor wastewater has a very high anaerobic biodegradability and generally a faster hydrolysis rate, and would be ideal for co-digestion with rendering wastewater to reduce the impact of FOG inhibition (this is being investigated as part of A.ENV.151).

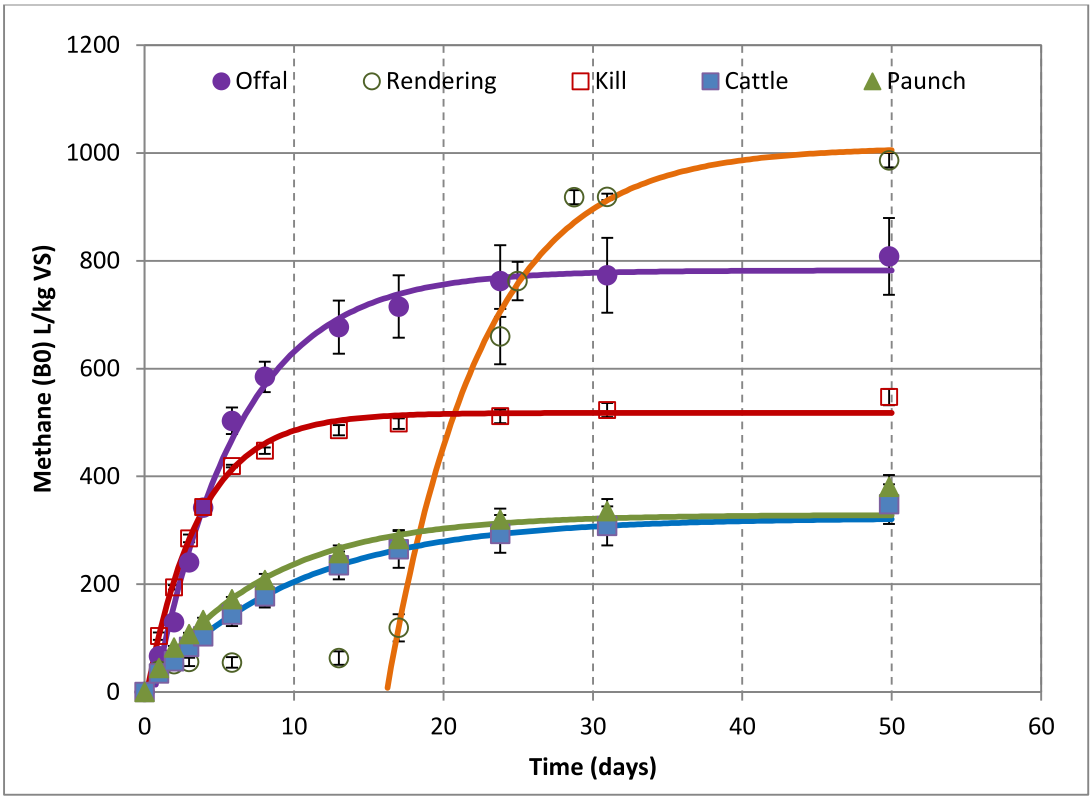

Figure 3 Cumulative methane production during biochemical methane potential (BMP) tests. Error bars indicate 95% confidence errors from triplicate batches. The line indicates the model used to return key parameters.

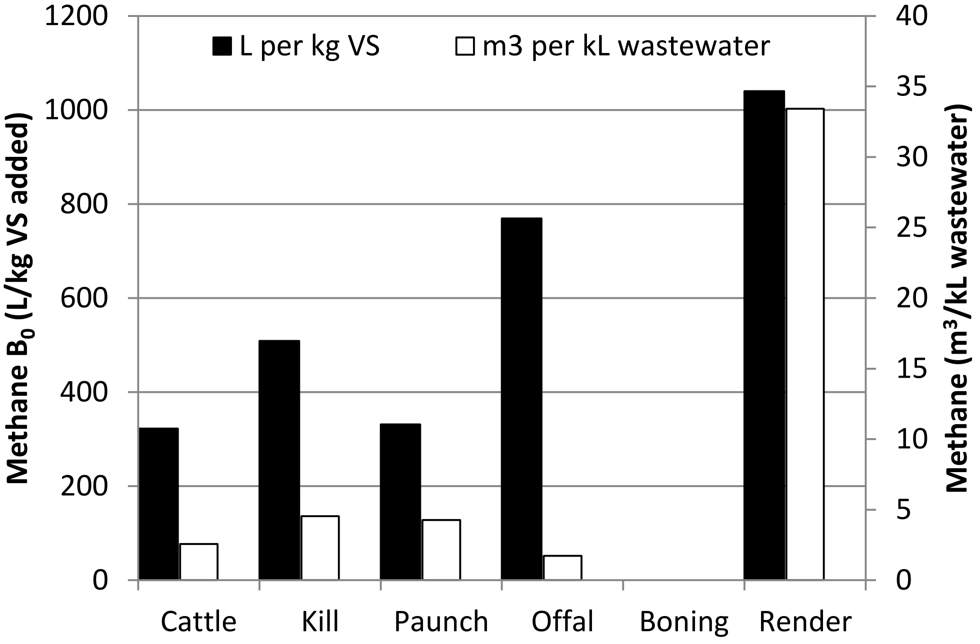

Figure 4 Summary of biochemical methane potential data determined from fitting BMP data to first order model and conducting parameter estimations.

The methane production curve for each set of BMP tests was fitted to a first order kinetic model (implemented in AQUASIM 2.1d) to estimate the methane potential (on a VS fed basis) and the hydrolysis rate coefficient (speed of degradation). For each stream, the measured methane potential was then used to estimate methane potential per kL of wastewater and the total potential methane load per day, a summary of the results is presented in Table 6. Anaerobic biodegradability of all wastewater samples tested was high (0.6-1 on COD basis) and confirms a very good potential for anaerobic digestion, energy recovery, and release of nutrients. Hydrolysis rate coefficients presented in Table 6 indicate the processing time required for anaerobic digestion of each substrate, a hydrolysis rate coefficient of 0.1 would require a reactor HRT of 20-30 days, while a hydrolysis rate coefficient of 0.3 would generally degrade in 7-10 days.

Table 6 Summary of degradation kinetics, biochemical methane potential and methane loads from site D

Site D					
Stream	**ID**	**Hydrolysis Rate Coefficient**	**Methane**	**Methane**	**Methane**
		(day^{-1})	**(m^3/t VS)**	**m^3/kL**	**m^3/day**
Paunch - Prescreen	25	0.128	380	4.90	980
Paunch - Post Screen	4	N/A	N/A	N/A	N/A
Paunch - Solids	24	0.104	313	74.06	1,333
Cattle Wash - Pre-auger	21	0.100	323	2.56	1,025
Cattle Wash - Post-auger	22	N/A	N/A	N/A	N/A
Cattle Wash - solids	23	N/A	N/A	N/A	N/A
Combined Bins	10	0.220	680	17.94	3,049
Combined Stick	11	0.158	1,010	32.45	4,219
Veal Room	12	0.280	518	4.63	1,158
Slaughter floor/Offal	9	0.176	782	1.76	1,843
Combined Red - Pre-screen	7	0.130	1,204	9.42	15,078
SaveAll In	6	N/A	N/A	N/A	N/A
SaveAll Out	3	N/A	N/A	N/A	N/A
Total Out[1]	**2**	**0.320**	**667**	**4.55**	**9,792**

1. Two separate analysis were conducted on the total effluent – results were statistically similar

The results in Table 6 show that FOG recovery from the combined red wastewater is highly effective at reducing the methane load and carbon liability of the plant. Prior to FOG recovery, the daily methane potential from the red stream was over 15,000 m^3/day and the combined methane potential for the plant was over 17,000 m^3/day (including paunch and cattle Wash). However after FOG recovery the combined methane load from the plant was less than 10,000 m^3/day (Total out – SP2).

3.7 Mass Balance and Reliability Analysis

Two mix points were selected to assess the reliability of load calculations. Mix point 1 was around the combined red wastewater and rendering operations (shown in Figure 5). Mix point 2 was around the combined effluent discharge to the anaerobic lagoon (shown in Figure 6). Results of the mass balances are presented in Table 7 and Table 8.

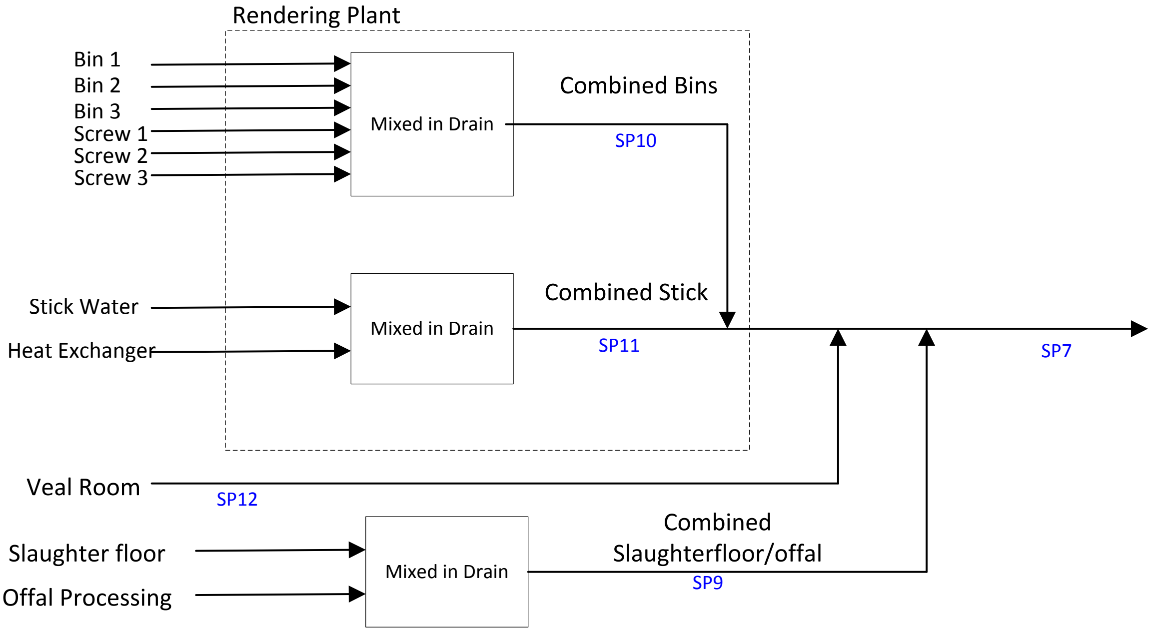

Figure 5 Flowsheet used for mass balance around red wastewater streams (SP9, SP10, SP11, SP12 were considered feed streams and SP7 was considered the mixed effluent).

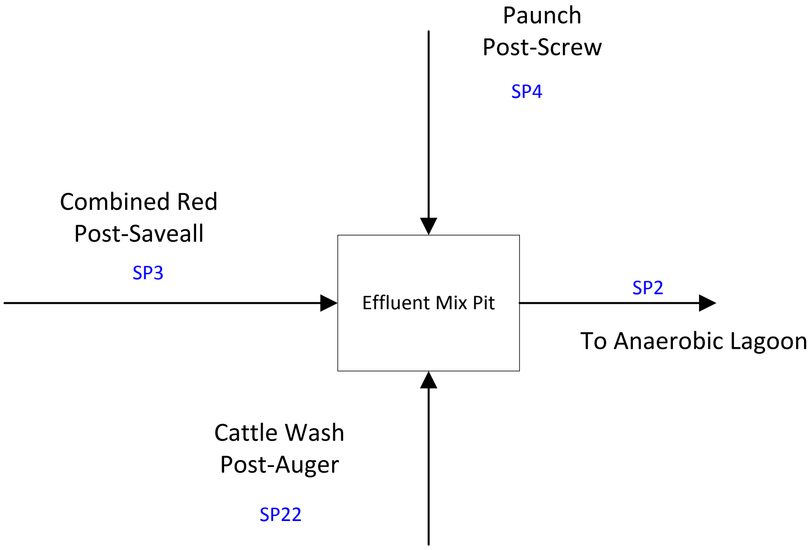

Figure 6 Flowsheet used for mass balance around final effluent discharge to the anaerobic lagoon (SP3, SP4, SP22 were considered feed streams and SP2 was considered the mixed effluent).

Mass balances show a reasonable agreement with solids and nutrients around the combined red wastewater, but highlight some issues with data around rendering and slaughter floor streams. Generally, the organic and nutrient loads from individual streams in the rendering plant were higher than the loads measured in stream 7. Individual flows in the rendering plant operated on short burst cycles and this would have contributed to variability in both sample composition and volumetric flow rate. The volumetric flowrate of SP9 could not be directly measured during the project due to the positioning of the pipe outlets and was therefore determined by balancing the volumetric flows of other streams. This is another potential source of significant error.

Mass balances also show poor agreement of COD and solids around the final effluent mixing and discharge point. The balances in Table 8 show that the COD and solids in the combined effluent (SP2) are approximately double the COD and solids in the individual streams that enter this mixing point (SP3, SP4, SP22). This suggests poor reliability of the final effluent (SP2) solids data. During the sample visit Site D had some issues with the screens used for removal of paunch solids and as a result paunch was added directly to the final mixing pit without screening, there may have been some solids accumulation on in the final mixing pit during this day and this solids accumulation may have impact data collection in the later stages of the sample visit, as the accumulated solids washed out.

Table 7 Mass balance and load reliability assessment around red wastewater streams

Stream	Stream	Flowrate	TCOD	sCOD	TS	VS	TSS	FOG	TKN	sTKN	NH4-N	TKP	sTKP	PO4-P
		kL/hr	(kg/d)	(kg/d)	(kg/d)	(kg/d)	(kg/d)	(kg/d)	(kgN/d)	(kgN/d)	(kgN/d)	(kgP/d)	(kgP/d)	(kgP/d)
Combined Bins	10	304	13,419	4,809	9,287	8,018	5,390	2,826	631	470	55	50	33	27
Combined Stick	11	94	6,901	92	3,152	3,020	3,011	1,981	46	29	20	11	2	3
Veal Room	12	480	6,778	1,090	4,481	4,292	132	2	141	123	12	2	1	7
Slaughter floor/Offal	9	722	1,596	881	1,899	1,621	1,458	235	111	73	4	15	7	2
Combined Red - Pre-screen	7	1,600	15,920	3,056	13,583	12,524	9,312	6,002	565	364	61	62	34	26
Total In	Sum	1,600	28,693	6,872	18,818	16,951	9,992	5,044	930	696	91	77	43	40
Total OUT	7	1,600	15,920	3,056	13,583	12,524	9,312	6,002	565	364	61	62	34	26
Error		0.00	0.45	0.56	0.28	0.26	0.07	-0.19	0.39	0.48	0.33	0.19	0.21	0.36

Table 8 Mass balance and load reliability assessment around combined wastewater mix point and discharge

Stream	Stream	Flowrate	TCOD	sCOD	TS	VS	TSS	FOG	TKN	sTKN	NH4-N	TKP	sTKP	PO4-P
		kL/hr	(kg/d)	(kg/d)	(kg/d)	(kg/d)	(kg/d)	(kg/d)	(kgN/d)	(kgN/d)	(kgN/d)	(kgP/d)	(kgP/d)	(kgP/d)
Paunch - Post Screen	4	200	1,084	170	1,389	951	874	39	49	13	3	29	20	18
Cattle Wash - Post-auger	22	400	720	100	791	544	480	4	52	33	35	7	4	4
SaveAll Out	**3**	1,600	12,832	4,816	6,450	5,503	4,688	1,564	644	457	61	66	62	53
Total In	Sum	2,200	14,636	5,086	8,630	6,998	6,042	1,607	744	503	98	102	86	75
Total OUT	2	2,150	26,789	4,773	15,913	14,680	14,190	2,666	943	501	81	120	67	59
Error		0.02	-0.83	0.06	-0.84	-1.10	-1.35	-0.66	-0.27	0.00	0.18	-0.18	0.22	0.21

4 Results for Site E

4.1 Plant Description

Site E is an Australian livestock processing facility situated in Queensland, Australia. Site E is a beef only facility that processes grass fed, grain fed and organic beef. The abattoir at Site E has the capability to process approximately 3,000 bovines per week; a summary of operations during the sample period is shown in Table 9.

Table 9 Summary of Site E operations during the sample period

Site E	
Type:	Beef only
Date visited:	29/04/13 - 2/05/13
Number of Streams surveyed:	14
Kill Floor Hours of operation:	06:00 - 18:00
Rendering Hours of operation:	06:00 – 00:00
Head processed / Day:	approx. 500
Cattle Type:	grass fed/grain fed/organic
Clean water usage / Day	1.5 ML per day (council metering)

4.2 Description of Waste and Wastewater Operations

The waste and wastewater handling operations at Site E were generally similar to operations observed at other sites investigated during the project. Site E had a combined Red wastewater containing streams from the Slaughter Floor, rendering plant and boning room. Site E also had a combined green wastewater containing streams from paunch handling, offal and the cattle yards. However there were some notable variations in wastewater operations at Site E during the sample trip.

1. Cattle wash was not operating during the sample period. This was a water saving measure implemented by Site E and may have reduced both the wastewater volume and the contained load associated with manure/urine from the cattle yards.
2. Site E transports cattle hides to a fleshing shed using a water slide style system, this results in an additional wastewater stream, although as this water is just use to aid transport, it is expected to be low strength. The water from the fleshing shed is added to the combined red wastewater.
3. The combined Red wastewater and the combined Green wastewater are initially treated separately in rotating drum screens to remove coarse solids. This is consistent with other processing sites assessed. The Red and Green wastewaters are then both added to the DAF, designed to remove solids and recovery FOGs. This is an area of difference between Site E and other processing sites where only the Red stream is treated using a DAF.

A flowsheet representing waste and wastewater handling operations at Site E is shown in Figure 7.

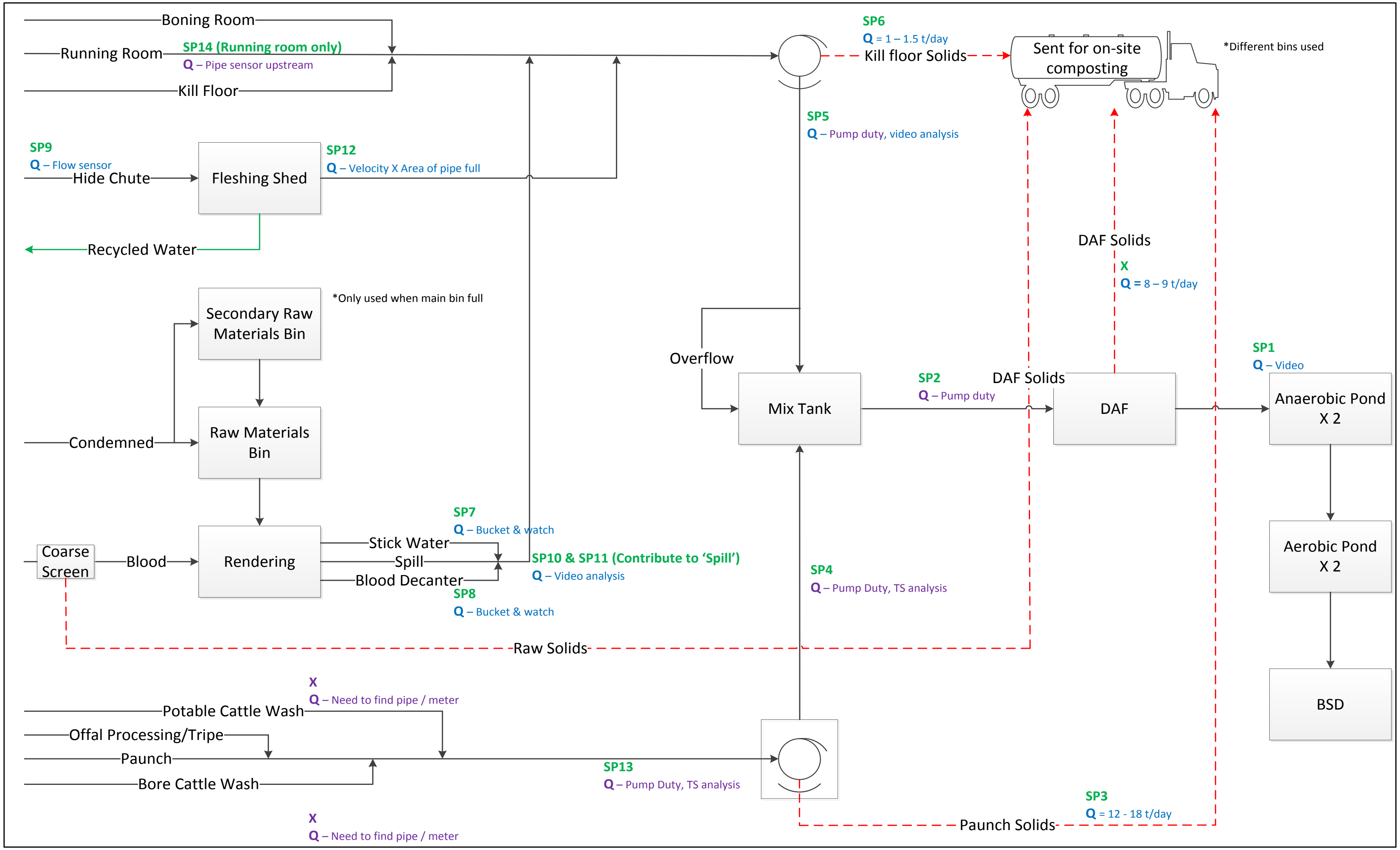

Figure 7 Flow sheet representing wastewater and solid waste handling operations at Site E

4.3 Waste and Water Flows

A total of 14 individual streams (12 wastewater flows, 2 solid waste flows) were included in analysis of Site E. A summary of the major wastewater flows are shown in Table 10.

As with other processing sites assessed during the project, there were distinct changes in the wastewater effluent throughout the day. Sample composites were prepared by collecting subsamples at multiple time points throughout the day. This allowed the project to capture average data over a broader timeframe.

Table 10 Estimate of individual and combined waste stream flows

Site E					
ID	Sample Description	Flow rate	Estimated hours of operation	Hours of operation	Total Flow
SP1	Total Effluent Out	73.9	(6:00 - 18:00) + (18:00 - 00:00 Base flow)	12 + 6	962.0
	Baseflow	12.5			
SP2	DAF In	73.2	(6:00 - 18:00) + (18:00 - 00:00 Base flow)	12 + 6	953.4
	DAF Solids	0.4	(6:00 - 00:00)	18	8.0
SP3	Paunch Solids	1.3	(6:00 - 18:00)	12	15.0
SP4	Paunch Liquid	8.7	(6:00 - 18:00)	12	103.9
SP5	Red Post-Screen	73.2	(6:00 - 18:00) + (18:00 - 00:00 Base flow)	12 + 6	953.4
SP6	Red contra solids	0.1	(6:00 - 18:00)	12	1.3
SP7	Stick Water	0.9	(6:00 - 00:00)	18	16.8
SP8	Blood Decanter	3.6	(6:00 - 00:00)	18	64.3
SP9	Hide Slide	14.9	(6:00 - 18:00)	12	179.3
SP10	Spill 1	1.6	(6:00 - 00:00)	18	27.9
SP11	Spill 2				
SP12	Fleshing shed	10.0	(6:00 - 18:00)	12	119.6
SP13	Paunch Pre Contra	9.9	(6:00 - 18:00)	12	118.9
SP14	Running Room	2.7	(6:00 - 18:00)	12	32.1

The flow volumes shown in Table 10 contribute approximately 65% of the metered daily flow volume entering Site E. The source of the remaining flow was not identified in the project, despite extensive collaboration with personnel from Site E.

4.4 Waste Water Compositions

The concentrations of organic contaminant and nutrient at Site E are presented in Table 11, the concentrations of trace metals are presented in Table 12. The stream composition data was based on the composition of composite samples collected during the 4 day sample trip and the average composition of all individual samples used to form the composite.

Wastewater from the rendering plant was very high strength (SP7 and SP8) both in terms of COD and solids. Stick Water was a rich source of FOG at over 17 g/L, while the blood decanter water was the richest source of N at 2.8 g/L. However, in both cases the volumetric flowrate of these streams was relatively low.

Comparison of the paunch streams shows that the Contrashear was generally not effective at removal of nutrients with over 90% of N and 70% of P remaining in the stream post-screen. A similar analysis of the combined DAF feed (SP2) and the total wastewater effluent sent to the anaerobic pond (DAF effluent stream – SP1) shows that the DAF at Site E is not operating effectively as a primary treatment step. Less than 10% of COD, 10% of solids and 35% of oil and grease entering the DAF is recovered. The poor performance of the DAF at Site E may be related to the operating temperature. The melting point of cattle fats varies from 29°C for subcutaneous fat to 46°C for intestinal fat and tallow (*Yilmaz et al. 2010*); the melting point influences the degree of emulsification and FOG particle size in respective DAF units. DAF units are also ineffective at temperatures above 40°C due to poor air solubility at these temperatures (*Tchobanoglous et al. 2003*) (Induced air flotation is an alternative at higher temperatures). The FOG in wastewater from Site E may be due to poor remove of intestinal fat and tallow due to the higher wastewater temperature.

Table 11 Organic contaminant and nutrient composition of waste streams at Site E

	Description	Volume	Temp	TCOD	sCOD	TS	VS	FOG	TKN	NH_3	TP	PO_4
ID		kL/d	°C	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	Total Effluent	962	44.9	10,925	1,195	6,118	4,920	1,569	272	25.1	46.7	32.4
2	DAF In	953	46.0	12,214	1,247	6,678	5,745	2,380	292	21.5	41.8	31.8
3	Paunch Solids	15	27.0	112,936	N/A	117,362	110,075	3,040	2,09	N/A	317.3	N/A
4	Paunch Liquid	104	33.3	11,788	778	8,152	6,081	900	319	56.1	107.5	43.9
5	Red Post-Screen	953	48.5	9,823	1,548	5,380	4,569	1,985	248	9.5	23.6	21.3
7	Stick Water	17	45.0	80,275	7,365	40,730	37,398	17,350	1,315	74.4	183.5	47.3
8	Blood Decanter	64	78.0	32,918	14,148	22,101	15,451	300	2,777	26.4	87.4	47.0
9	Hide Slide	179	27.6	2,193	1,500	1,916	1,280	20	166	1.9	4.5	10.9
10	Spill 1	28	49.0	388	181	684	352	24	15	0.0	1.2	0.2
11	Spill 2		79.0	180,750	3,540	124,927	122,770	72,600	2,010	53.7	211.0	26.6
12	Fleshing Shed	120	32.8	2,642	981	2,135	1,640	144	96	1.3	7.7	7.8
13	Paunch Pre-Screen	119	27.7	18,596	1,140	18,366	14,901	990	332	95.5	141.5	3.1
14	Running Room	32	38.0	10,613	3,342	7,324	5,896	366	485	30.5	72.0	25.0

Table 12 Trace metal composition of waste streams at Site E

ID	Description	Al	As	B	Ba	Ca	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	P	Pb	S	Se	Zn
		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
1	Total Effluent	0.00	0.01	0.13	0.06	59	0.01	0.12	3.5	80.4	32.6	0.46	217	0.01	47	0.10	54	0.01	0.41
2	DAF In	0.00	0.01	0.13	0.04	59	0.00	0.12	3.6	74.1	30.8	0.40	202	0.00	43	0.08	53	0.00	0.37
3	Paunch Solids	0.00	0.00	2.54	0.81	447	0.27	1.32	53	162	153.0	5.80	416	0.07	317	1.03	226	1.73	10.60
4	Paunch Liquid	1.17	0.01	0.21	0.30	128	0.01	0.18	7.2	123	56.5	1.93	384	0.02	114	0.05	46	0.01	1.00
5	Red Post-Screen	0.00	0.00	0.10	0.01	49	0.00	0.10	2.8	56.8	25.0	0.09	159	0.00	26	0.10	54	0.00	0.17
7	Stick Water	0.00	0.07	0.00	0.02	58	0.01	0.34	5.0	488	24.2	0.17	547	0.01	196	0.00	296	0.03	0.70
8	Blood Decanter	0.00	0.06	0.00	0.00	16	0.00	0.09	42.3	269	9.3	0.00	1592	0.00	95	0.01	184	0.03	0.15
9	Hide Slide	0.00	0.01	0.00	0.00	41	0.00	0.05	2.8	16.9	25.5	0.03	107	0.00	3	0.01	33	0.01	0.02
10	Spill 1	0.00	0.00	0.00	0.00	41	0.01	0.18	0.0	8.6	23.9	0.00	59	0.00	2	0.03	27	0.00	0.00
11	Spill 2	3.40	0.25	0.00	0.14	134	0.03	0.43	17.8	292	22.0	0.39	395	0.00	255	0.00	300	0.34	2.36
12	Fleshing Shed	0.00	0.00	0.00	0.00	37	0.00	0.06	3.3	17.3	24.7	0.08	95	0.00	3	0.00	30	0.00	0.08
13	Paunch Pre-Screen	0.57	0.02	0.00	0.44	123	0.02	0.20	11.7	144	35.2	2.32	535	0.01	149	0.00	53	0.00	1.16
14	Running Room	0.19	0.03	0.00	0.23	80	0.01	0.21	6.4	94.6	36.1	1.19	256	0.00	76	0.00	89	0.02	1.01

Notes: Cd was measured and was below 0.01 mg/kg for all samples, results have not been presented.
Co was measured and was below 0.03 mg/kg for all samples, results have not been presented.
Mo was measured and was below 0.04 mg/kg for all samples, results have not been presented.

4.5 Analysis of Waste Loadings

Analysis of the daily loading of organic and nutrient contaminants from Site E are presented in Table 13. The load of an individual contaminant was calculated using the method shown in Equation 1.

Table 13 Estimates for Waste Loading at Site E

ID	**Description**	**Volume**	**Temp**	**TCOD**	**sCOD**	**TS**	**VS**	**FOG**	**TKN**	**NH3**	**TP**	**PO4**
		kL/d	**C**	**kg/d**	**kg/d**	**kg/d**	**kg/d**	**kg/d**	**kg/d**	**kg/d**	**kg/d**	**kg/d**
1	Total Effluent	962	44.9	10,510	1,150	5,886	4,734	1,510	261.2	24.1	44.9	31.1
2	DAF In	953	46.0	11,645	1,188	6,366	5,477	2,269	278.1	20.5	39.8	30.3
3	Paunch Solids	15	27.0	1,694	N/A	1,760	1,651	46	31.4	N/A	4.8	N/A
4	Paunch Liquid	104	33.3	1,224	81	847	632	93	33.2	5.8	11.2	4.6
5	Red Stream post Contra	953	48.5	9,366	1,476	5,130	4,356	1,892	236.8	9.1	22.5	20.3
7	Stick Water	17	45.0	1,352	124	686	630	292	22.2	1.3	3.1	0.8
8	Blood Decanter	64	78.0	2,117	910	1,422	994	19	178.6	1.7	5.6	3.0
9	Hide Slide	179	27.6	393	269	343	230	4	29.7	0.4	0.80	2.0
10	Spill 1	28	49.0	0	0	0	0	0	0.0	0.00	0.00	0.0
11	Spill 2		79.0	5,061	99	3,498	3,438	2,033	56.3	1.5	5.9	0.7
12	Fleshing Shed	120	32.8	316	117	255	196	17	11.4	0.2	0.9	0.9
13	Paunch Pre Contra	119	27.7	2,210	136	2,183	1,771	118	39.5	11.4	16.8	0.4
14	Running Room	32	38.0	341	107	235	189	12	15.6	1.0	2.3	0.8

4.6 Analysis of Biochemical Methane Potential (B_0)

Biochemical methane potential is an indication of anaerobic biodegradability and the potential to recover energy during wastewater treatment. Methane potentials from nine streams were analysed from Site E during this project. Cumulative methane production curves (L CH_4 per kgVS) representing each processing area and a summary of B_0 values determined from parameter estimation are shown in Figure 8 and Figure 9 respectively. The methane production curve for each set of BMP tests was fitted to a first order kinetic model (implemented in AQUASIM 2.1d) to estimate the methane potential (on a VS fed basis) and the hydrolysis rate coefficient (speed of degradation). For each stream, the measured methane potential was then used to estimate methane potential per kL of wastewater and the total potential methane load per day, a summary of the results is presented in Table 14. Anaerobic biodegradability of all wastewater samples tested was high (0.6-1 on COD basis) and confirms a very good potential for anaerobic digestion, energy recovery, and release of nutrients.

When comparing processing areas, B_0 was highest in the rendering stick water and is consistent with the higher FOG content of this wastewater. Rendering wastewater was also the most concentrated source of wastewater, resulting in high methane potential per kL wastewater. However, while rendering wastewater is a concentrated source of organics, phosphorus and nitrogen, the volumetric flow rate of this stream at Site E was very low and this limits the opportunity to recover material through specialised treatment of rendering wastewater. Additionally, there was also clear evidence of inhibition in the rendering stick water sample resulting is an apparent lag time of 16 days before significant methane production was observed. Similar evidence of inhibition was observed from Site D and during A.ENV.0131 in samples where the FOG concentration in wastewater was above 10,000 mg/L (e.g. Offal processing wastewater from Site A). The potential for FOG inhibition means the best strategy would be a co-digestion strategy based around rendering wastewater.

The B_0 of paunch was approximately 280 L CH_4 per kgVS for paunch solids and is in the range reported in A.ENV.131. This range is consistent with lignocellulose based material and suggests approximately 65% of the organic solids would be converted to methane. Paunch solids had the slowest hydrolysis rate and would require a retention time in the range of 20-25 days for anaerobic treatment (based on modelled hydrolysis rate co-efficient of 0.1 day^{-1}). The B_0 of screened paunch wastewater was 480 L CH_4 per kgVS and is high for lignocellulose type materials, high B_0 values for paunch streams were also reported in A.ENV.0131 (site A) where offal streams were combined with the paunch.

The B_0 of combined wastewater at Site E was approximately 640 L CH_4 per kgVS and an estimated anaerobic biodegradability of 80-90%. These findings are consistent with the range reported at other sites in this project and A.ENV.131. The combined waster degrades 3 times faster than the paunch solids and would require a treatment time in the range of 1 week, although this may be enhanced further through process optimization and acclimatisation of the microbial community.

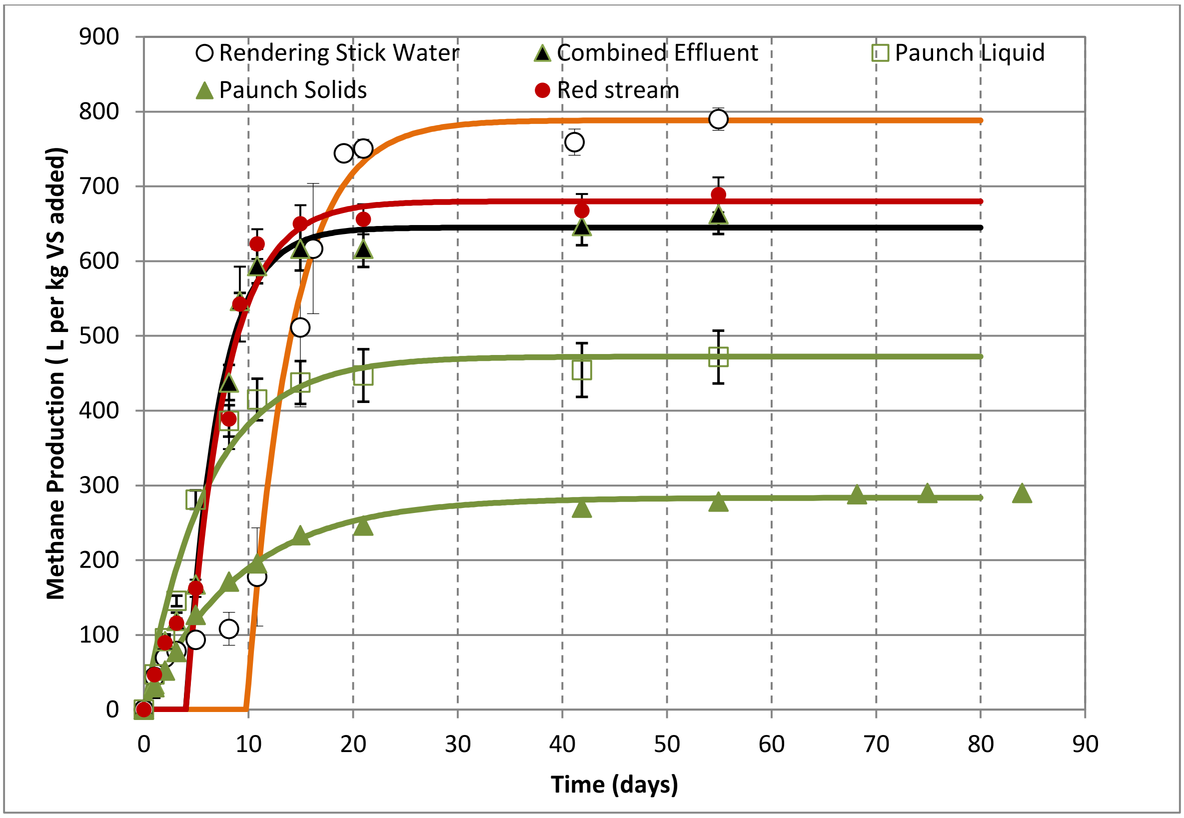

Figure 8 Results from biochemical methane potential (BMP) tests of select sample locations at Site E. Error bars indicate 95% confidence errors from triplicate batches. The line indicates the model used to return key parameters.

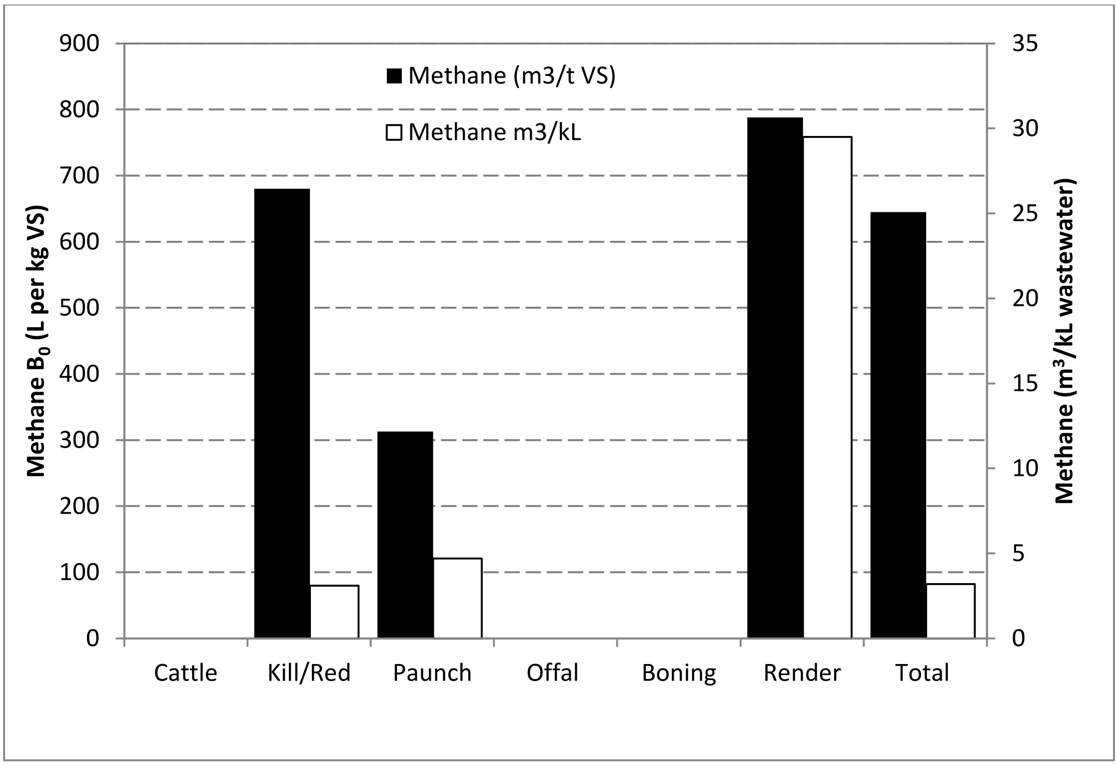

Figure 9 Summary of biochemical methane potential data determined from fitting BMP data to first order model and conducting parameter estimations.

Table 14 Summary of degradation kinetics, biochemical methane potential and methane loads from Site E

ID	Description	Hydrolysis Rate (day^{-1})	Lag days	Methane (m^3/t VS)	Methane m^3/kL	Methane m^3/day
1	Total Effluent	0.32	4.0	645	3.2	3052
2	DAF In	0.26	4.0	700	4.0	3834
3	Paunch Solids	0.11	0.0	284	31.2	468
4	Paunch Liquid	0.16	0.0	472	2.9	299
5	Red Stream post Contra	0.27	4.0	680	3.1	2961
7	Stick Water	0.24	9.8	788	29.5	501
8	Blood Decanter	0.20	0.0	390	6.0	385
9	Hide Slide	0.29	0.0	440	0.6	101
10	Spill 1	N/A	N/A	N/A	N/A	N/A
11	Spill 2	N/A	N/A	N/A	N/A	N/A
12	Fleshing Shed	N/A	N/A	N/A	N/A	N/A
13	Paunch Pre Contra	0.15	0.0	313	4.7	555
14	Running Room	N/A	N/A	N/A	N/A	N/A

N/A – refers to samples not tested during BMP trial.

The results in Table 14 provide further evidence that the DAF at Site E is not functioning at the same level as other sites assessed. At Site E, the DAF reduced the methane load and carbon liability to the anaerobic lagoon by approximately 20%, by comparison the DAF/primary treatment at Site D reduced the methane load and carbon liability of the plant by approximately 35%.

4.7 Mass Balance and Reliability Analysis

Two mix points were selected to assess the reliability of load calculations at Site E. Mix point 1 was around the combined red wastewater and rendering operations (shown in Figure 10). Mix point 2 was around the combined effluent added to the DAF and subsequently discharged to the anaerobic lagoon (shown in Figure 11). Results of the mass balances are presented in Table 15 and Table 16.

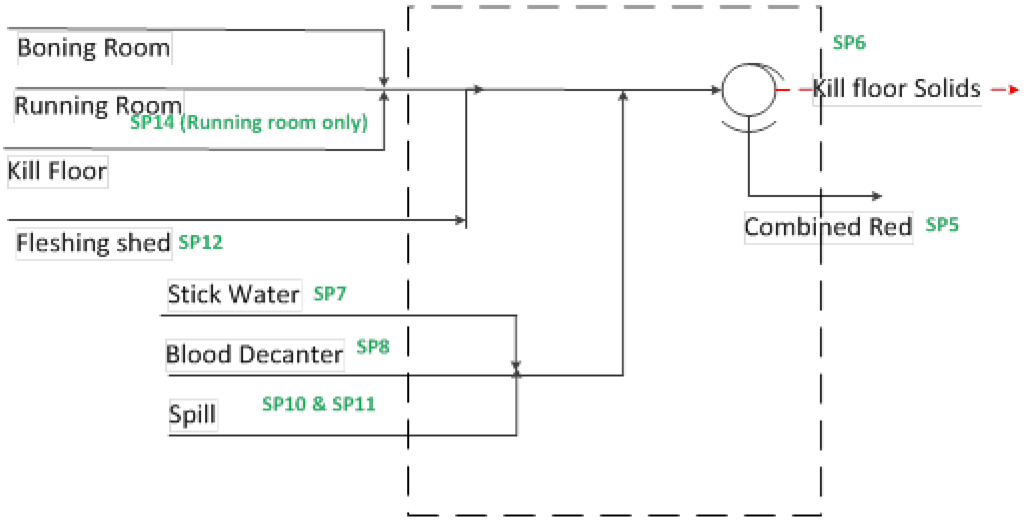

Figure 10 Flowsheet used for mass balance around red wastewater streams (SP7, SP8, SP10, SP11, SP12 and SP14 were considered feed streams; SP5 and SP6 were considered the mixed effluent).

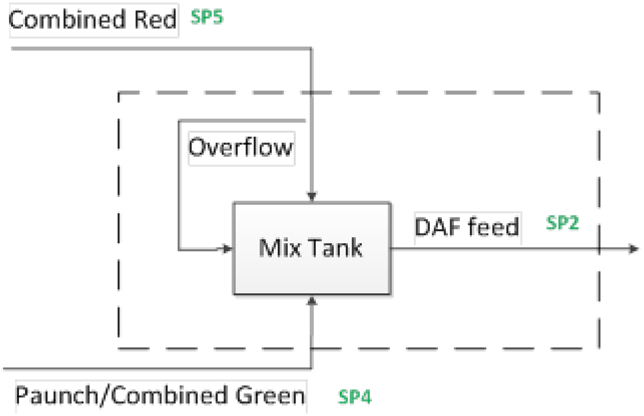

Figure 11 Flowsheet used for mass balance around red wastewater streams (SP4, SP5 were considered feed streams and SP2 was considered the mixed effluent).

Slaughter floor and boning room wastewater contributed to the combined red flow, but these streams were not accessible during the sample trip and were not included as inputs to the mass balance. The mass balance shows that the slaughter floor and boning room likely contributed approximately 70% of the volumetric load for the combined red stream, with a much lower contribution to nutrient and organic loads. This is consistent with analysis of other sites in A.ENV.131 where slaughter floor and boning room wastewater were relatively high flow, but low strength wastewater streams.

Mass balances around mix point 2 (combined effluent to DAF) showed a good agreement in terms of volumetric flow, organic load and nutrient load.

Table 15 Mass balance and load reliability assessment around red wastewater streams

Stream ID	Description	Volume	TCOD	sCOD	TS	VS	FOG	TKN	NH_3	TP	PO_4
		kL/day	kg/d	kg/d	kg/d	kg/d	kg/d	kg/d	kg/d	kg/d	kg/d
7	Stick Water	17	1,352	124	686	630	292	22	1.3	3.1	0.8
8	Blood Decanter	64	2,117	910	1,422	994	19	179	1.7	5.6	3.
10	Spill 1	0	0	0	0	0	0	0	0.0	0.0	0.0
11	Spill 2	28	5,043	99	3,485	3,425	2,026	56	1.5	5.9	0.7
12	Fleshing Shed	120	316	117	255	196	17	11	0.2	0.9	0.9
14	Running Room	32	341	107	235	189	12	16	1	2.3	0.8
	Input Sub-total	261	9169	1357	6084	5435	2366	284	5.6	17.8	6.3
5	Red Stream post Contra	953	9,366	1,476	5,130	4,356	1,892	237	9	22	20
11	Tallow Beetroot Box	1	226	4	156	153	91	3	0	0	0
	Output Sub-total	955	9591	1481	5286	4509	1983	239	9	23	20
	Error	2.66	0.05	0.09	-0.13	-0.17	-0.16	-0.16	0.64	0.28	2.22

Table 16 Mass balance and load reliability assessment around combined streams from different areas entering DAF

Stream ID	Description	Volume	TCOD	sCOD	TS	VS	FOG	TKN	NH_3	TP	PO_4
		kL/day	kg/d	kg/d	kg/d	kg/d	kg/d	kg/d	kg/d	kg/d	kg/d
4	Paunch Liquid	104	1,224	81	847	632	93	33	6	11	5
5	Red Stream post Contra	954	9,366	1,476	5,130	4,356	1,892	237	9	22	20
	Input Sub-total	1057	10590	1557	5976	4987	1986	267	15	34	25
2	DAF In	953	11,645	1,188	6,366	5,477	2,269	278	20	40	30
	error	-0.11	0.09	-0.31	0.06	0.09	0.12	0.03	0.27	0.16	0.18

5 Results for Site F

5.1 Plant Description

Site F is a small, family owned, Australian livestock processing facility situated in north Queensland. Site F is a mixed species plant that processes cattle, veal, pigs and goats. Processing volumes and species vary through a typical week; a summary of processing operations during the sample period is shown in Table 17.

Table 17 Summary of operations at Site F during Sample Trip

Site F				
	Day 1	Day 2	Day 3	Day 4
Cattle	71	88	-	91
Veal	-	-	18	-
Pigs	-	-	146	4
Total	71	88	164	95

5.2 Description of Waste and Wastewater Operations

As a very small processing facility, the waste and wastewater handling operations at Site F did not follow the same structure observed at other sites investigated during the project. Key differences in the waste handling structure were:

1. Blood streams did not pass through the rendering plant.
2. Paunch solids and blood streams did not pass through the wastewater treatment train and were handled using direct land application.
3. Rendering wastewater was treated using a DAF designed to remove solids and recovery FOGs. This primary treatment was done on the rendering effluent only and is an area of difference between Site F and other processing sites where the combined red wastewater (slaughter floor, boning room, rendering) is treated using a DAF.

A flowsheet representing waste and wastewater handling operations at Site F is shown in Figure 12.

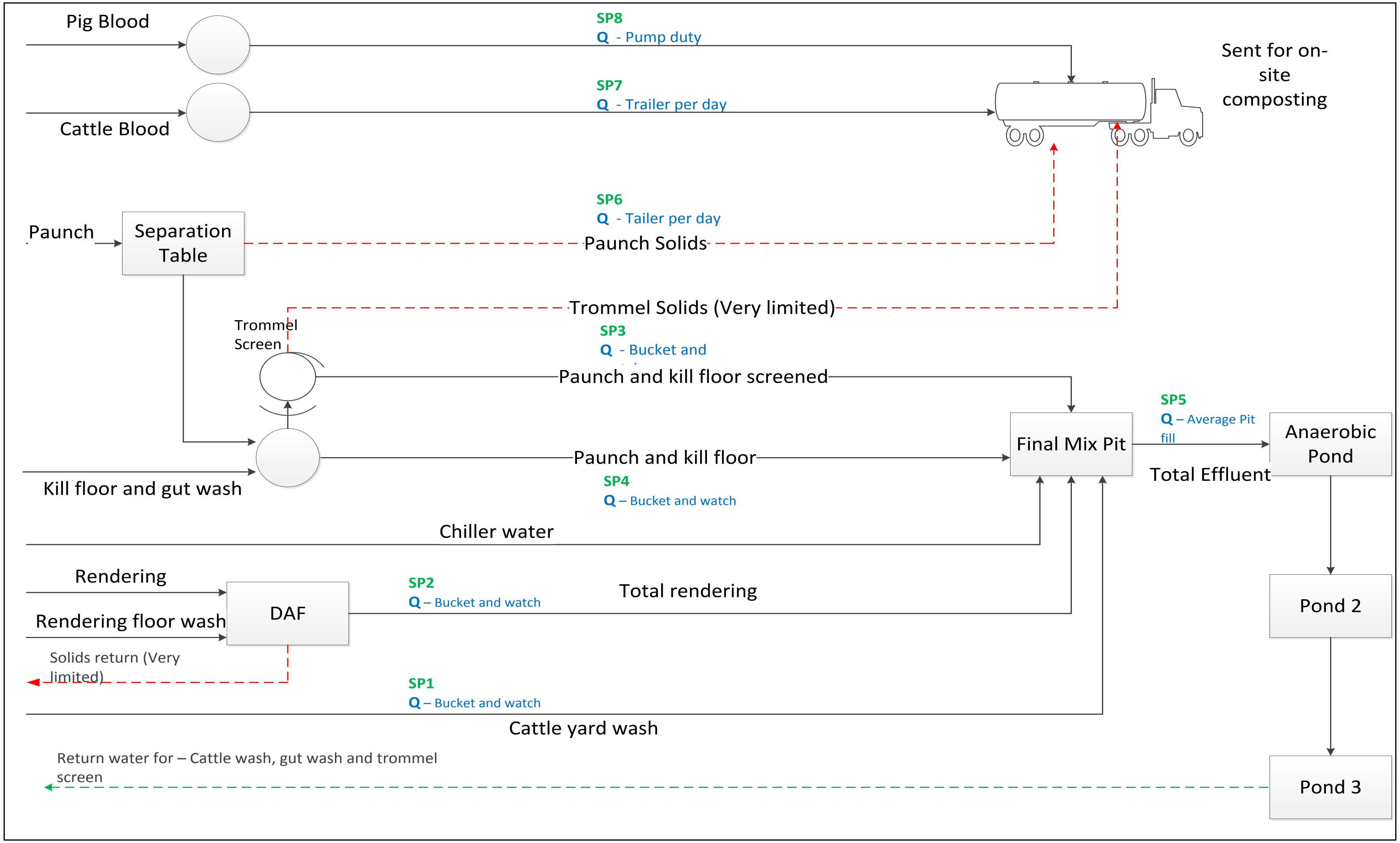

Figure 12 Flow sheet representing wastewater and solid waste handling operations at Site F

5.3 Waste and Water Flows

A total of 9 individual streams (8 wastewater flows, 1 solid waste flows) were included in analysis of Site F. A summary of the major wastewater flows included in this initial report are shown in Table 18. Composite sampling was used to assist in representative analysis over the 3 day sample trip.

Table 18 Estimate of individual and combined waste stream volumetric flows

Wastewater Flows During Kill Operations					
SP	**Description**	**flow**	**Flow regime**	**Estimated Daily Full Flow Operation**	**Daily Flow**
		(kL/hr)		**(Hours)**	**(kL/d)**
1	Cattle Wash	1.2	(6:00 - 12:00 partial flow)	3	3.5
2	Total Render	2.8	(8:00 - 15:00 continual flow)	6	16.7
	Tallow wash out	2.4	(5:00 - 16:30 continual flow)	1.5	3.6
3	Paunch & KF - screened	14.2	(6:00 - 14:00 continual flow)	7	99.1
4	Paunch and KF pit	5.0	(6:00 - 14:00 continual flow)	7	34.9
5	Total effluent	23.9	(6:00 - 14:00 continual flow)	7	167.6
	Total effluent (render only)	2.5	(15:00 - 16:30 continual flow)	2.5	6.4
7	Cattle paunch	3.6	(6:00 - 14:00 continual flow)	7	25.5
8	Cattle blood				
9	Pig blood	1.8	(6:00 - 14:00 continual flow)	7	12.7

5.4 Waste Water Compositions

The organic contaminant and nutrient results from Site F are presented in Table 19, the trace metal results are presented in Table 20. The variations in concentration of effluent streams illustrate the diverse nature of wastewater within the treatment and handling process.

The paunch solids and the cattle blood streams were the highest strength streams at Site F, however it is important to note that these streams were handled using direct land application and did not enter the wastewater treatment train at Site F. The rendering wastewater was the most concentrated stream that contributed to the wastewater load and also contained a high concentration of FOG.

Table 19 Organic contaminant and nutrient composition of waste streams at Site F

		Volume	Temp	TCOD	sCOD	TS	VS	FOG	TKN	NH3	TP	PO4
ID	**Description**	**kL/h**	**C**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
1	Cattle wash	1.2	19.1	4,347	1,013	4,117	2,939	60	217.6	115.3	33.1	12.7
2	Total render	2.8	37.0	21,936	2,370	10,241	9,631	9,578	512.8	152.7	69.8	33.8
3	Paunch & KF after trommel	14.2	36.6	2,631	708	2,086	1,734	148	98.4	48.7	15.0	6.2
4	Paunch & KF pit	5.0	29.5	4,773	834	3,499	3,076	578	212.6	125.9	36.9	15.4
5	Total effluent	23.9	32.5	6,719	1,148	3,471	3,038	2,258	177.7	74.0	26.9	11.8
7	Paunch solids	3.6	28.8	121,030	n/a	118,765	103,036	2,094	2,790.0	n/a	982.5	n/a
8	Cattle blood		32.8	43,065	2,128	21,873	20,785	864	4,092.5	384.8	50.0	36.0
9	Pig blood	1.8	35.5	3,906	3,252	2,968	2,704	24	375.0	25.3	8.7	3.9

Table 20 Trace metal composition of waste streams at Site F

	Description	**Al**	**As**	**B**	**Ba**	**Ca**	**Cr**	**Cu**	**Fe**	**K**	**Mg**	**Mn**	**Mo**	**Na**	**Ni**	**P**	**Pb**	**S**	**Se**	**Zn**
ID		**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**
1	Cattle Wash	8.15	0.00	0.17	0.32	56	0.00	0.00	13	145	27	1.52	0.00	119	0.00	33	0.13	25	0.00	0.81
2	Total render	1.10	0.00	0.31	0.13	105	0.00	0.14	10	54	18	0.12	0.08	61	0.02	78	0.09	25	0.00	2.21
3	Paunch & KF after trommel	0.27	0.00	0.16	0.00	22	0.00	0.12	2	23	14	0.24	0.00	43	0.00	15	0.10	7	0.00	0.31
4	Paunch and KF pit	1.47	0.00	0.16	0.05	38	0.00	0.06	4	49	13	0.27	0.00	86	0.00	40	0.10	13	0.04	0.48
5	Total effluent	0.87	0.00	0.16	0.04	43	0.00	0.10	4	37	15	0.32	0.00	59	0.00	31	0.09	11	0.00	1.32
7	Paunch Solids	72.12	0.00	0.00	0.00	327	0.02	0.14	259	556	49	21.64	0.03	2197	0.16	681	0.00	169	0.01	0.00
8	Cattle blood	5.13	0.00	0.06	0.12	46	0.00	0.13	74	73	16	0.66	0.00	381	0.00	51	0.06	203	0.00	1.22
9	Pig blood	0.00	0.00	0.14	0.00	15	0.00	0.00	7	34	12	0.00	0.00	64	0.00	8	0.05	21	0.00	0.22

5.5 Analysis of Waste Loadings

Table 21 presents the initial estimate of the load of organic matter and nutrients (kg/day) in each of the waste streams analysed. The rendering wastewater is the single biggest contributor to the organic load on the treatment lagoons, but contributes only 10% of the volumetric load, this is consistent with trends observed at other sites in the project.

As previously stated, the paunch solids, cattle blood and pig blood streams bypass the treatment lagoons and are handled using direct land application, as a result less than 50% of the organic load (based on COD) produced at Site F enters the treatment lagoons. This will likely have a major impact on both the energy recovery potential and the carbon liabilities associated with Site F.

Table 21 Estimates for Waste Loading at Site F

ID	Description	Volume kL/d	TCOD kg/d	sCOD kg/d	TS kg/d	VS kg/d	FOG kg/d	TKN kg/d	NH_3 kg/d	TP kg/d	PO_4 kg/d
1	Cattle wash	3.5	15	4	15	10	0	0.8	0.4	0.1	0.0
2	Total render	16.7	367	40	171	161	160	8.6	2.6	1.2	0.6
3	Paunch & KF after screen	99.1	261	70	207	172	15	9.8	4.8	1.5	0.6
4	Paunch & KF pit	34.9	167	29	122	107	20	7.4	4.4	1.3	0.5
5	Total effluent	167.6	1126	192	582	509	379	29.8	12.4	4.5	2.0
7	Paunch solids	2.5[A]	303	n/a	297	258	5	7.0	n/a	2.5	n/a
8	Cattle blood	23.0[B]	990	49	503	478	20	94.1	8.9	1.2	0.8
9	Pig blood	12.7	50	41	38	34	0	4.8	0.3	0.1	0.0

A. Based on 25kg per head and 100 head per day

B. Based on mass balance using combined flow of SP7 and SP8 of 25.5kL/day

5.6 Analysis of Biochemical Methane Potential (B_0)

Methane potentials from ten streams were analysed from Site F during this study. Cumulative methane production curves (L CH_4 per kgVS) representing each processing area and a summary of B_0 values determined from parameter estimation are shown in Figure 13 and Figure 14 respectively.

B_0 results from Site F were largely consistent with other sites investigated in the current project and previously in A.ENV.131. B_0 was highest in the rendering effluent and the combined wastewater streams. Both the rendering wastewater and combined total effluent showed evidence of FOG inhibition however the inhibition was less prominent than at other processing sites investigated.

The B_0 of cattle blood was approximately 520 L CH_4 per kgVS and is consistent with the B_0 of protein rich substrates (A.ENV.155). The Blood steams were also the fastest degrading streams. Similar results were obtained for Slaughter floor wastewater at other processing sites. The B_0 of cattle yard wastewater and Paunch solids was approximately 210 L CH_4 per kgVS and 250 L CH_4 per kgVS respectively. Both the cattle yard and Paunch solids streams were relatively slow to degrade and do not degrade completely.

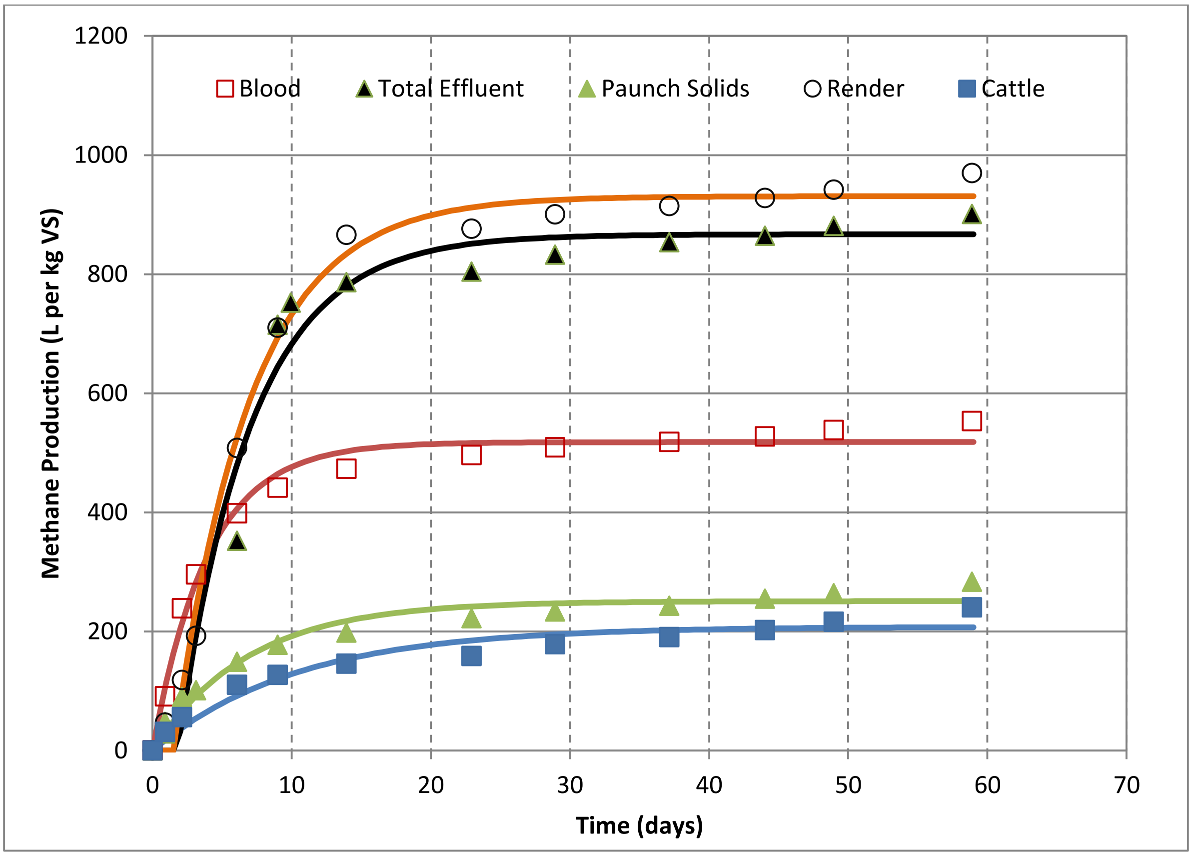

Figure 13 Results from biochemical methane potential (BMP) tests of select sample locations at Site E. Error bars indicate 95% confidence errors from triplicate batches. The line indicates the model used to return key parameters.

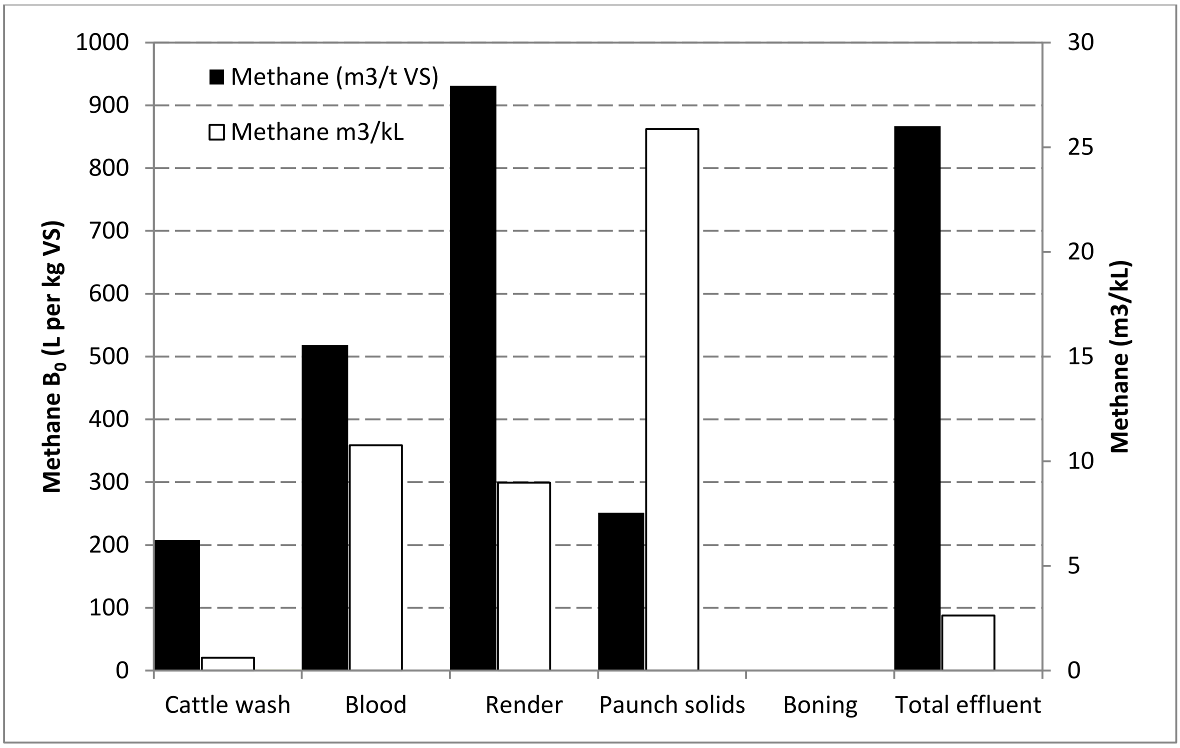

Figure 14 Summary of biochemical methane potential data determined from fitting BMP data to first order model and conducting parameter estimations

The methane production curve for each set of BMP tests was fitted to a first order kinetic model (implemented in AQUASIM 2.1d) to estimate the methane potential (on a VS fed basis) and the hydrolysis rate coefficient (speed of degradation). For each stream, the measured methane potential was then used to estimate methane potential per kL of wastewater and the total potential methane load per day, a summary of the results is presented in Table 22. Site F did not contain a primary treatment step for FOG removal and recovery for comparison with other sites. However, blood and solids streams were handled separately, as a result the wastewater streams treated in the anaerobic lagoon comprised only 60% of the methane potential available at the site.

Table 22 Summary of degradation kinetics, biochemical methane potential and methane loads from Site F

Site F					
ID	**stream**	**Hydrolysis Rate (day^{-1})**	**Methane (m^3/t VS)**	**Methane m^3/kL**	**Methane m^3/day**
1	Cattle wash	0.096	208	0.6	2.1
2	Total render	0.182	931	9.0	149.7
3	Paunch & KF -Screened	0.241	498	0.9	85.6
4	Paunch & KF pit	0.137	905	2.8	97.2
5	Total effluent	0.130	882	2.7	449.1
7	Paunch solids	0.145	251	25.9	64.8
8	Cattle blood	0.252	518	10.8	248.4
9	Pig blood	0.435	413	1.1	14.2
Total estimated methane potential/liability (sum of SP5, SP7, SP8, SP9)					776.5

5.7 Mass Balance and Reliability Analysis

Due to the small size, only 1 mix point was selected to assess the reliability of load calculations at Site F. The mass balance mix point was around the final mixing point collecting all wastewater that was subsequently discharged to the anaerobic lagoon (shown in Figure 15). Results of the mass balances are presented in Table 23.

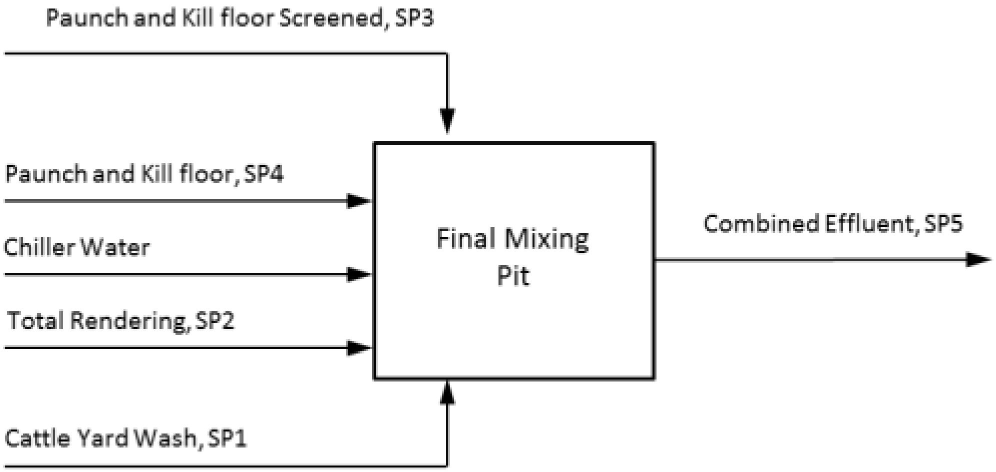

Figure 15 Flowsheet used for mass balance around wastewater mixing pit at Site F.

Mass balance analysis shows some over estimation of solids and organics, particularly FOGs in the mixing pit effluent. Site F received grease trap sludge from an external source early in the sample trip and this was added directly to the mixing pit. The external grease trap sludge may have contributed to the higher FOG content in the mixing pit effluent observed during the sample trip.

The methane potential and carbon liability predicted for Site F will be based on the mixing pit effluent and therefore will include any emissions from accepting external waste streams. This is not expected to have a significant impact on the predictions.

Table 23 Mass balance and load reliability assessment around main wastewater streams

Description	ID	Volume	TCOD	sCOD	TS	VS	FOG	TKN	NH3	TP	PO4
		kL/day	kg/d	kg/d	kg/d	kg/d	kg/d	kg/d	kg/d	kg/d	kg/d
Cattle wash	1	3.5	15	4	15	10	0	0.8	0.41	0.12	0.04
Total render	2	16.7	367	40	171	161	160	8.6	2.56	1.17	0.57
Paunch & KF after trommel	3	99.1	261	70	207	172	15	9.8	4.83	1.49	0.61
Paunch & KF pit	4	34.9	167	29	122	107	20	7.4	4.39	1.29	0.54
Sum of inputs		154.3	810	143	515	451	195	26.5	12.2	4.1	1.8
Total effluent	5	167.6	1126	192	582	509	379	29.8	12.40	4.51	1.97
Error		0.08	0.28	0.26	0.11	0.11	0.48	0.11	0.02	0.10	0.11

6 Comparison with Literature alternative Survey Sites

6.1 Load of Contaminants in Meat Processing Wastewater

Wastewater production and the resulting nutrient and energy loads are shown in Table 24 (expressed per tonne hot standard carcass weight (t HSCW)). Nutrient loads (N and P) were within the upper range of values previously report, however organic loads (COD, TS, FOG) were 2-4 times greater than loads previously reported (*Cowan et al. 1992, Johns 1995, Mittal 2004, Tritt and Schuchardt 1992*).

The primary treatment operations for wastewater in red meat processing plants (e.g. DAF) are designed for removal and recovery of FOGs and solids. The increased organic loads measured in the project (without an increase in nutrient loads) suggest these primary treatment units are not operating effectively; this is discussed in more detail in Section 6.2. Organic loads are a strong indication of methane potential and/or the carbon liability associated with wastewater production, the impact of the increased organic loads from meat processing on emissions will be discussed in more detail in Section 6.4. While the organic loads reported in this project exceed the values in literature, the current NGER and CPRS default calculation (13.6kL waster per t HSCW and 6.1g/L COD) is based on organic loads of 83 kg COD per t HSCW, the sites assessed in this project were generally within this range.

Table 24 Comparison of energy and nutrient loads with literature values per t HSCW

Energy and Nutrient Loads Compared to Literature (per t HSCW)						
	Water (kL)	COD (kg)	TS (kg)	FOG (kg)	N (kg)	P (kg)
Literature [1,2]	5.6 – 22.2	16.7 – 44.4	8.3 – 22.2	2.8 – 13.9	1.4 – 4.2	0.1 - 0.4
Site A[2]	8.1	64-109	70	19.6	2.0-4.8	0.4-0.5
Site B[3]	7.4	71	31.7	5.8	1.7	0.37
Site C[2]	14.7	78-160	110	49	2.4-3.8	0.35-0.43
Site D[4]	~11	55-101	32-59	6-10	2.8-3.6	0.38-0.45
Site E[5]	7.1	78	44	11	1.9	0.3
Site F	7.1	86	49	14	4.7	0.3

1. Based on (*Cowan et al. 1992, Johns 1995, Mittal 2004, Tritt and Schuchardt 1992*)
2. Based on beast weight of 600 kg, and HSCW yield of 60%.
3. Based on weekly HSCW reported by Site B.
4. Based on 266 tHSCW per day at Site D.
5. Based on measured effluent concentration and site metered water use.

6.2 Concentration of Contaminants in Meat Processing Wastewater

Table 25 shows the concentration of combined raw wastewater at each processing site compared with concentration ranges expected from literature. FOG concentrations were high at all sites and varied depending on wastewater structure, particularly the implementation of by-product recovery units. Sites A, D and E recovered FOG using a Dissolved Air Floatation (DAF) unit without the addition of polymer flocculants. Sites C and F contained no units for FOG recovery. Site B recovered or removed FOG using a multiple stage process incorporating a DAF with no flocculants to recover FOG and recycle to rendering, followed by a second DAF with polymer flocculants to improve FOG removal; however sludge from the second DAF was not recycled for rendering due to the polymer addition. Therefore the DAF sludge was an additional solid waste stream at Site B.

Poor recovery or removal of FOG was related to wastewater temperature. At Site A the DAF effluent was 46°C and contained 2,900 mg/L FOG. By comparison DAF effluents at Sites B and D were 35-36°C and contained 800-1,000 mg/L FOG. The melting point of cattle fats varies from 29°C for subcutaneous fat to 46°C for intestinal fat and tallow (*Yilmaz et al. 2010*); the melting point influences the degree of emulsification and FOG particle size in respective DAF units. DAF units are also ineffective at temperatures above 40°C due to poor air solubility at these temperatures (*Tchobanoglous et al. 2003*) (Induced air flotation is an alternative at higher temperatures). The higher FOG in wastewater from Site A is likely due to poor remove of intestinal fat and tallow due to the higher wastewater temperature.

Readily available sources of heat combined with decreased consumption cooling water may be an important factor in the temperature of slaughterhouse wastewater. Hot water (above 70°C) is used extensively during sterilisation processes in a cattle slaughterhouse. Rendering and cooking processes also produce excess steam and hot water. However, raw water consumption by Australian red meat processors (per tHSCW) has reduced by 20% over the past 10 years (*Maddocks and Trahir 2011*). This has likely resulted in an increase in wastewater temperature and hence reduced recovery of FOG. Overall water usage at Site A was 20-30% lower than water usage at Site D, and may represent a reduction in the availability of cooling water that contributed to the higher wastewater temperature and higher concentration of FOG in Site A wastewater (46°C at Site A compared to 36°C at Site D). However, Site B had the lowest overall water consumption in this study (per tHSCW), but incorporated a storage tank (1-2 day residence time) prior to the DAF which allowed wastewater time to cool. This indicates that the impact of reduced cold water consumption may be mitigated by practices that enhance wastewater cooling.

Table 25 Composition of combined slaughterhouse wastewater compared with literature values

Combined Wastewater Effluent Streams						
	TCOD (mg/L)	sCOD (mg/L)	TS (mg/L)[2]	FOG (mg/L)	N (mg/L)	P (mg/L)
Literature Concentration[1]	2,000-10,000	-	500-2,000	100-600	100-600	10-100
Site A	12,893	1,724	8,396	2,332	245	53
Site B	9,587	1,970	4,300	783	232	50
Site C	10,800	890	7,530	3,350	260	30
Site D	12,460	2,220	7,400	1500	438	56
Site E	10,925	1,195	6,118	1,569	272	47
Site F	7,170	1,257	3,806	1,915	182	27

1. Based on (*Cowan et al. 1992, Johns 1995, Mittal 2004, Tritt and Schuchardt 1992*)
2. Literature values are TSS (mg/L), study values are TS (mg/L)

6.3 Analysis of Organic and Nutrients loads from Individual Processing Areas

The source of organic contaminants and key nutrients from each processing area at Sites A, C and D was evaluated based on the composition and flow rate data of each stream; the results are presented in Figure 16. At Sites B, E and F the structure of the waste handling process prevented the collection of data from some individual processing areas, therefore these sites have not been included in this analysis

Rendering and paunch wastewater are clearly concentrated resource streams and this was consistent across all sites in the current study. At Sites A and D rendering and paunch wastewater contributed approximately 70% of the organic, phosphorus and potassium loads in only 20% of the volumetric flow. A similar trend was also observed at Site C, where rendering and paunch wastewater contributed 60% of the organic load and 80% of the phosphorus load in approximately 35% of the volumetric flow. Compared to the final effluent phosphorus (P) was 2 to 4 times more concentrated in the rendering and paunch wastewater respectively. This trend was consistent across all processing sites and strongly supports source separation and dedicated primary treatment of rendering wastewater and/or paunch wastewater for generation of energy and recovery of phosphorus.

Slaughter floor wastewater was a moderately concentrated stream that contributed 60% and 35% of the nitrogen load at Sites A and C respectively, this is a major increase compared to previous reports where the slaughter floor contributed less than 10% of nitrogen (*Johns et al. 1995*). The distribution of nitrogen loads appeared to be due to site specific processes rather than developments in wastewater strategies over the past 17 years. This is supported by Site D where the slaughter floor contributed less than 10% of nitrogen, similar to existing literature (*Johns et al. 1995*). Nitrogen load was concentrated in the slaughter floor wastewater and the rendering wastewater; however the distribution between the two processing areas was highly variable among the sites investigated, therefore would be a case to combine these streams for effective nitrogen treatment and/or recovery.

Offal processing wastewater was a moderate resource stream and was highly variable between sites. At Site A, offal processing wastewater was high-strength, but very low volumetric load and therefore contributed to less than 10% of the organic and nutrient resources. At Site C, offal processing wastewater had the highest volumetric flow and was also relatively high strength contributing over 25% of organic load, but less than 10% of nutrient loads. At Site D offal processing wastewater included a portion of the slaughter floor wastewater contributing to the high volumetric load of this stream, however, the organic and nutrient loads were still relatively low.

Cattle yard wastewater and boning room wastewater are low-strength streams. At Site D, the boning room wastewater is recycled into the cattle yards, and therefore does not contribute to the effluent loads. At Site A, wastewater from the boning room and cattle yards were relatively large flows, but were low strength resulting in minor contributions to the organic, nitrogen and phosphorus loads. However cattle yard wastewater was a moderate source of sodium and potassium. Depending on site operations, the cattle yard and boning room wastewater could by-pass primary treatment reducing the demand on these processing units.

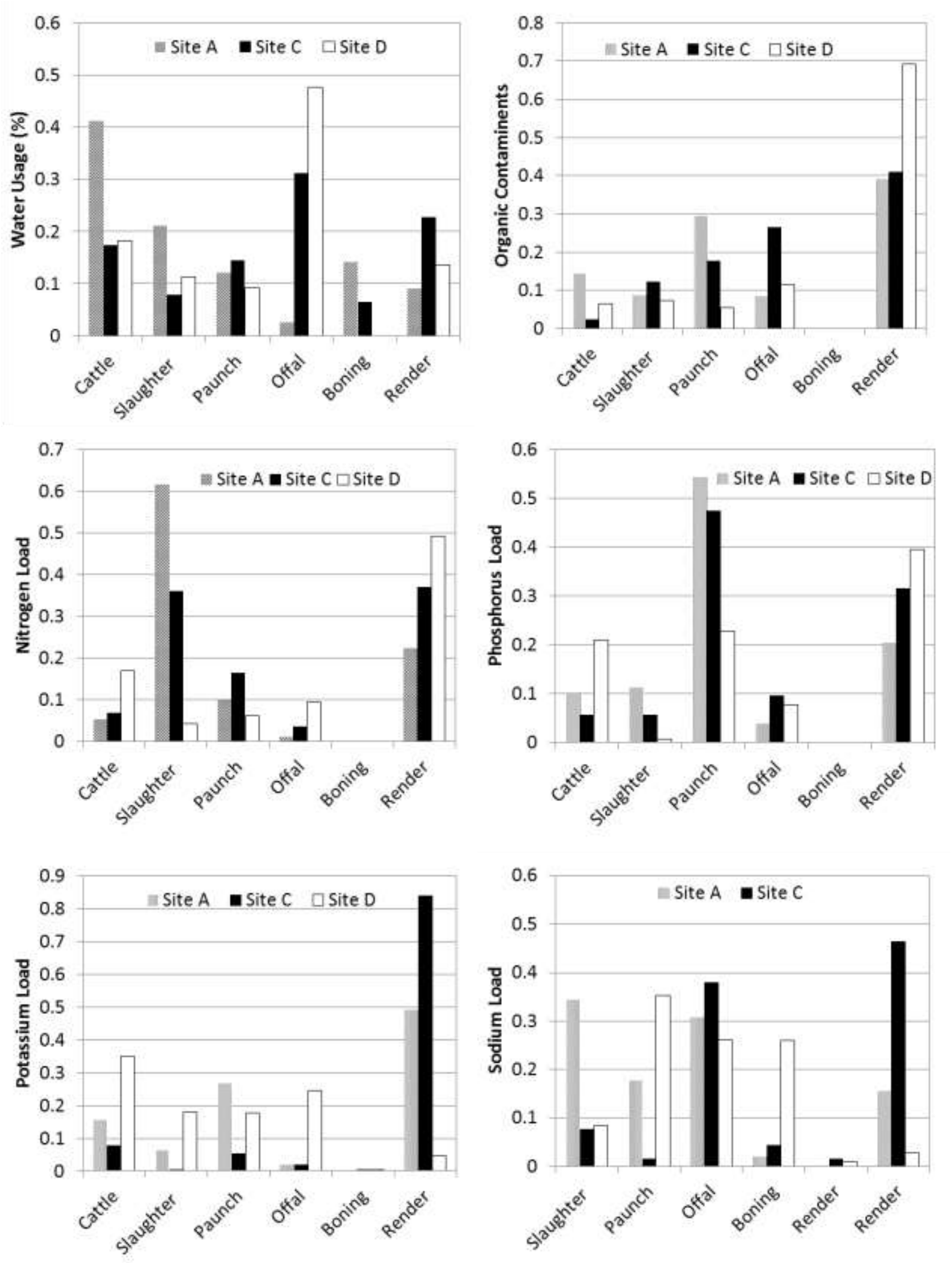

Figure 16 Comparative analysis on water, organic and nutrient loads at each processing site.

6.4 Methane Potential (B_0), Carbon Liability, Energy Generation

Table 26 is a summary of methane potential (B_0), greenhouse gas liabilities and the potential for energy recovery and re-use from red meat processing wastewater. The methane generation potentials from Sites A, C and D are approximately 20-30% greater than the NGERS default calculations (based on 13.6kL waster per t HSCW and 6.1g/L COD). However, methane potential and carbon liabilities at Sites B, E and F were lower than the NGERs default.

At Site E, the wastewater measurements (1ML/d) were significantly lower than the council metered flows (1.6ML/day) during the sample period, manure and urine streams from the cattle yards were also not included in the load calculations, the combination of these factors leads to some significant uncertainty around the estimated carbon liabilities. More data is required to confirm if the emission liabilities at Site E are actually lower than the NGERs default calculation. At Site B, the volume of combined wastewater was closely metered and the composition of this stream was relatively consistent. These factors provide more confidence in the carbon predictions from Site B. Site B had the most advanced and effective primary treatment step, therefore we conclude that the NGERs default calculation is a reasonable, but slightly conservative estimate of plant liabilities; however sites can reduce emissions below this level with appropriate waste handling strategies.

Table 26 Comparison of Energy Potential and GHG Liability

Summary of Methane Generation Potential and GHG liability						
	Methane Potential B_0[1] (m^3/d)	Methane Potential B_0[1] (m^3/t HSCW)	CO_2 Liability[2] (t/d)	CO_2 Liability[2] (t/t HSCW)	Energy Potential (GJ/d)	Electricity Potential (MWh/d)[3]
NGERs	-	25.2	-	0.35	-	-
Site A[4]	12,739	44.2	140	0.49	433	42
Site B[5]	11,181	26.1	122	0.29	380	37
Site C[4]	5,969	41.5	66	0.46	203	20
Site D[6]	11,125	41.8	121	0.45	378	37
Site E[7]	4,890	22.6	53.3	0.25	166	16
Site F	776.5	27.0	8.5	0.29	26.4	2.6

1. Methane volumes based on room temperature and pressure (25°C and 1 atm)
2. Based on 0.8 methane potential B_0
3. Based on 0.35 electrical engine efficiency
4. Based on beast weight of 600 kg, and HSCW yield of 60%.
5. Based on weekly HSCW reported by Site B.
6. Based on 266 tHSCW per day at Site D
7. Based on B_0 of combined effluent and metered water use/discharge at Site E

7 Treatment and Resource Recovery Recommendations

Using July 2013 prices (energy $10/GJ, N $1000/tonne, P $3000/tonne), the energy and nutrient resources in cattle slaughterhouse wastewater are valued at approximately $20 per tHSCW, this corresponds to an average value of $1.2M per year for the sites investigated in this study. Reactor based treatment processes are required maximise recovery of energy (80%) and nutrient (20%) value.

7.1 Anaerobic Treatment Recommendations

The methane potential results indicated that the vast majority of COD and TS were degradable, in particularly in rendering and slaughter floor wastewater. Rendering, slaughter floor, paunch and offal wastewater should be treated using an anaerobic process (to remove carbon, and mobilise nitrogen and phosphorous for recovery). Cattle yard and boning room wastewater are high flow and low-strength, and should bypass primary treatment. A suitable polishing step may include aerobic membrane bioreactors (MBR), fixed film or moving bed aerobic bioreactors, or facultative lagoons.

Based on the results in this project, we recommend separate treatment of red wastewater (combined rendering and slaughter floor) and green wastewater (combined paunch and offal processing). These streams were assessed using an anaerobic technology selection diagram shown in Figure 17 (*Batstone and Jensen 2011*). This indicates that the red wastewater liquid stream is not well placed for conventional technology as the solids concentration and FOG concentration is too high for conventional high-rate anaerobic treatment (upflow anaerobic sludge blanket reactor (UASB) or internal circulation (IC) reactors). The solids concentration in red wastewater is also too low for mixed liquor digestion. However, the red wastewater may be suitable for treatment using developing high rate anaerobic technologies including anaerobic membrane bioreactors (AnMBR) subject to long-term tolerance to FOG loading (*Saddoud and Sayadi 2007*). Another significant benefit in treating this wastewater with development AnMBR technology is the high degradability of the feed and the very low level of solid residue (virtually zero) from digestion. The long solids retention times (20 days) in an AnMBR would allow for accumulation of acclimatised biomass, which is important to overcome the FOG inhibition observed. The short HRT in an AnMBR will allow a much higher space loading than treatment in anaerobic lagoons.

Green wastewater (paunch and offal processing) is best treated by conventional solids digestion. This would generate methane and reduce levels of paunch solid waste by approximately 45% (where screw presses are used) or 60% (where centrifuges or belt presses are used) after digestion and dewatering. Green wastewater (paunch in particular) had a lower anaerobic degradability than red wastewater, and therefore will produce a solid residue that could build up in lagoon based processes. Residual solids accumulate over time reducing effective volume of the lagoon and increasing the frequency of de-sludging events. This issue is negated by separate treatment in a solids digester.

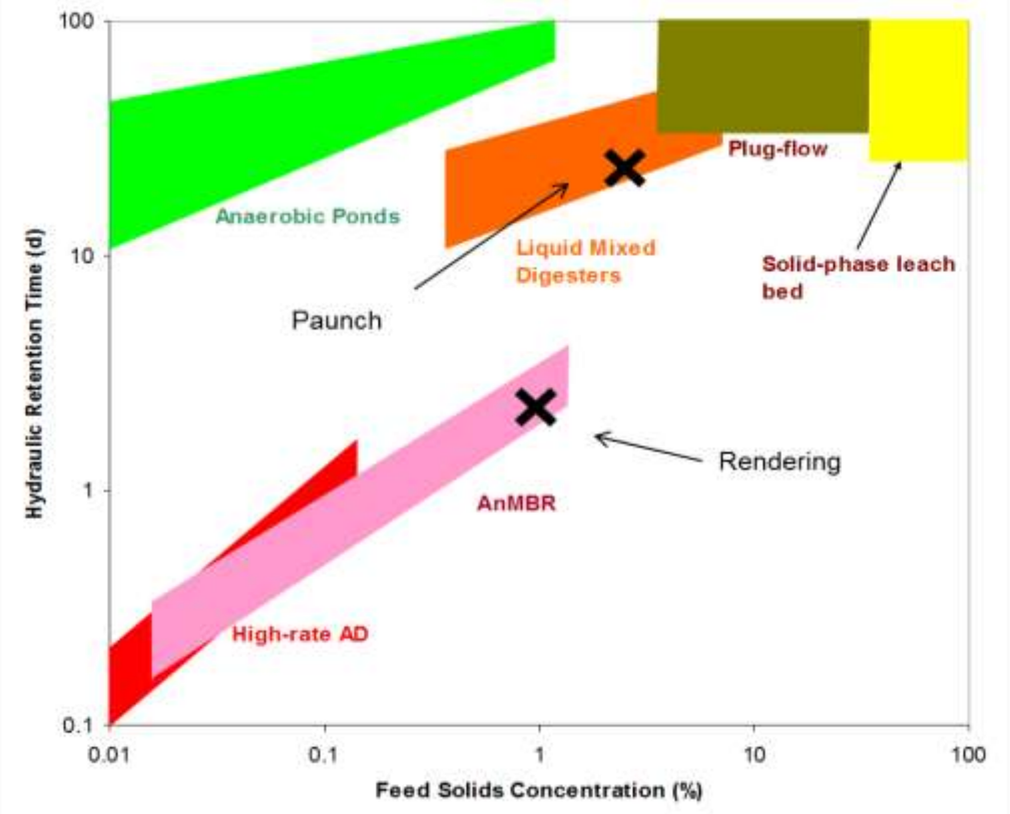

Figure 17 Selection guide for existing and developing anaerobic technologies: High-Rate AD (UASB- Upflow Anaerobic Sludge Blanket, AnMBR – Anaerobic membrane bioreactor)

7.2 Nutrient Recovery Recommendations

Nutrient concentration is a primary factor when evaluating nutrient recovery using crystallization based technologies. In the case of P recovery using struvite crystallization there is an effective P recovery limit of 10 mg/L in the soluble phase (*Yuan et al. 2012*). At Sites A and D, over 30% of the wastewater flow has P concentrations below this recovery limit and therefore recovery of P from these streams (generally cattle yard, boning room and/or slaughter floor) would be difficult. Furthermore streams with dilute P concentrations will also dilute the combined wastewater and may reduce overall P recovery. Therefore, recovery of nutrients, particularly P may be significantly improved using source capture and specialised primary treatment of individual wastewater streams. Generally about 50% of total P in the wastewater streams is soluble and in the form of PO_4, by comparison much less than 50% of N is soluble and in the form of NH_3. Biological treatment to release nutrients is critical prior to recovery from all streams.

7.3 Development of a New Waste Handling Flowsheet

A potential treatment flowsheet based on separate treatment of red waste and green waste is shown in Figure 18. New technologies currently in development in AMPC/MLA projects could be used as part of this treatment strategy. In particular:

- HRAT refers to High Rate Anaerobic Technology such as the Anaerobic Membrane Bioreactor (AnMBR) being developed in A.ENV.133 and A.ENV.149;

- AD refers to a more conventional solids digester, this could also be improved using the temperature phased anaerobic digestion (TPAD) process developed in A.ENV.099 and A.ENV.155;
- Nutrient recovery options (not shown in Figure 18) could be based on the struvite precipitation process being developed and tested in A.ENV.154.

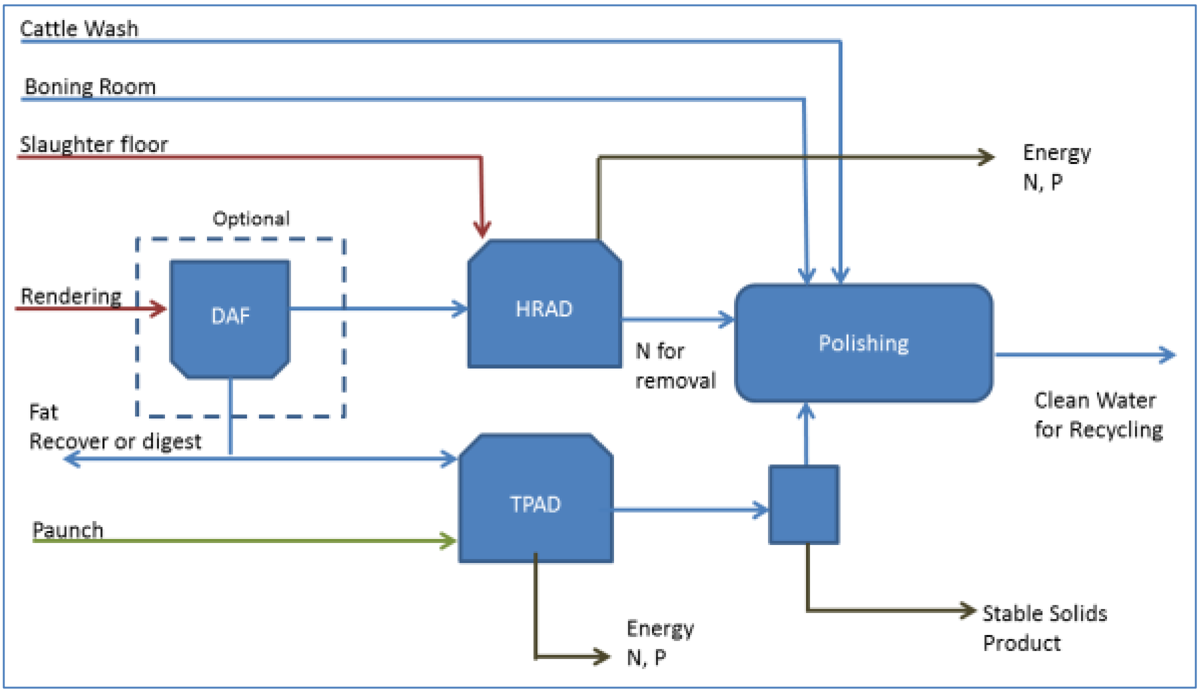

Figure 18 Proposed treatment process for potential recovery of energy and nutrients (note: based on recovery of energy as methane, and recovery of P and N as struvite).

8 Summary

Organic loads in the wastewater analysed from the red meat processing facilities involved in this project were 2-4 times greater than loads previously reported in literature. However, overall water usage has been substantially reduced and nutrient loads have not changed significantly.

Compared to the combined effluent, phosphorus was 2 to 4 times more concentrated in the rendering and paunch wastewater respectively; and significantly diluted in boning room and cattle yard wastewater. In general, 75% of the methane potential, phosphorus and potassium loads were concentrated in only 20% of the volumetric flow.

Anaerobic biodegradability and methane potential of all wastewater samples tested was high, confirming anaerobic digestion is a suitable approach to recover energy and release nutrients. Rendering wastewater is the primary source of organics, phosphorus and nitrogen and is therefore a primary target for source separation and specialised treatment. Co-digestion of rendering and slaughter floor wastewater is recommended to minimise FOG inhibition.

Based on the characteristics of the wastewater, and available technologies, wastewater streams should be separated into red (slaughter floor and rendering), green (paunch and offal), and bypass (boning and cattle yard) streams. There are limited options to treat the red stream, but emerging fat-tolerant options such as anaerobic membrane reactors may be effective. The green stream should be treated in conventional solids digestion, while the bypass stream should be directed to polishing.

9 References

1. Batstone, D. J., and Jensen, P. D. 2011 Anaerobic processes., In *Treatise on Water Science* (Wilderer, P., Rogers, P., Uhlenbrook, S., Frimmel, F., and Hanaki, K., Eds.), pp 615-640, Academic Press, Oxford, U.K.
2. Cowan, J. A. C., MacTavish, F., Brouckaert, C. J., and Jacobs, E. P. 1992 Membrane treatment strategies for red meat abattoir effluents, Water Science and Technology *25*, 137-148.
3. Gopalan, P., Jensen, P. D., and Batstone, D. J. 2013 Biochemical methane potential of beef feedlot manure: Impact of manure age and storage, Journal of Environmental Quality *42*, 1205-1212.
4. Hill, D. T. 1984 Methane productivity of the major animal waste types, Transactions of the American Society of Agricultural Engineers *27*, 530-534.
5. Johns, M. R. 1995 Developments in wastewater treatment in the meat processing industry: A review, Bioresource Technology *54*, 203-216.
6. Johns, M. R., Harrison, M. L., Hutchinson, P. H., and Beswick, P. 1995 Sources of nutrients in wastewater from integrated cattle slaughterhouses, Water Science and Technology *32*, 53-58.
7. Karim, K., Klasson, K. T., Drescher, S. R., Ridenour, W., Borole, A. P., and Al-Dahhan, M. H. 2007 Mesophilic digestion kinetics of manure slurry, Applied Biochemistry and Biotechnology *142*, 231-242.
8. Maddocks, A., and Trahir, S. 2011 Industry Environmental Performance Review 2010 - MLA Version Project A.ENV.0086. , Sydney.
9. Mittal, G. S. 2004 Characterization of the effluent wastewater from abattoirs for land application, Food Reviews International *20*, 229-256.
10. Saddoud, A., and Sayadi, S. 2007 Application of acidogenic fixed-bed reactor prior to anaerobic membrane bioreactor for sustainable slaughterhouse wastewater treatment, Journal of Hazardous Materials *149*, 700-706.
11. Tchobanoglous, G., Burton, F. L., Stensel, H. D., Metcalf, and Eddy. 2003 Wastewater engineering : treatment and reuse, 4th ed. / revised by George Tchobanoglous, Franklin L. Burton, H. David Stensel. ed., McGraw-Hill, Boston :.
12. Tritt, W. P., and Schuchardt, F. 1992 Materials flow and possibilities of treating liquid and solid wastes from slaughterhouses in Germany. A review, Bioresource Technology *41*, 235-245.
13. Yilmaz, M. T., Karakaya, M., and Aktaş, N. 2010 Composition and thermal properties of cattle fats, European Journal of Lipid Science and Technology *112*, 410-416.
14. Yuan, Z., Pratt, S., and Batstone, D. J. 2012 Phosphorus recovery from wastewater through microbial processes, Current Opinion in Biotechnology *23*, 878-883.