final report

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Prepared by: Paul Jensen and Damien Batstone

Advanced Water Management Centre
The University of Queensland

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Meat & Livestock Australia Limited
Locked Bag 991
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Energy and Nutrient analysis on Individual Waste Streams

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1. Executive Summary

The AMSurvey project is intended to identify key contributors to waste stream loads and resources, including thermal, energetic, and chemical. This is 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 three 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.

A review of formal (SCI) literature showed there have been three relevant reviews focusing on red meat processing wastewater characteristics and treatment options published in 1992, 1996, and 2006. The 1995 Johns review is particularly relevant to this project. From the literature it appears that wastewater strength has increased in the last 10 years from a base level of 2000-5000 mgCOD L-1 to >5000 mgCOD L-1, with a water consumption decrease. The MLA/AMPC literature is far more fruitful in terms of relevant publications, including the 2010 environmental performance review, though this is very high level. The most relevant study is the Johns and Lucock Teys Bros survey, which analysed flows and loads comprehensively at the Teys Beenleigh plant. The main concern is variability of streams both within, and between different plants, with strong flows such as the raw materials bin being highly dependent on both operations and site practice. Our survey included consideration of this.

Results from this project show that overall water usage and nutrient loads were within ranges expected from literature, however wastewater strength has increased to ~10,000 mgCOD L-1 and subsequently total organic loads were estimated at 2-4 times greater than the loads expected from literature. Current carbon emission liabilities at two of the processing sites were also high in comparison to the default NGER and CPRS value of 0.35 t CO2 t-1 HSCW. 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 CPRS value (0.29 t CO2 t-1 HSCW). Anaerobic biodegradability and methane potential of all wastewater samples tested was high, with very low indications of inhibition or toxicity, suggesting a very good potential for anaerobic digestion, energy recovery, and carbon liability reduction.

During sampling 5 major sources of wastewater were identified at the 3 meat processing facilities included in this investigation; Cattle Yard Wash, Slaughter Floor, Paunch Handling, Boning Room and Rendering Operations. Paunch Wastewater and Rendering Stick Water were concentrated streams with high volumetric loads and were therefore the most significant sources of COD and total solids. Rendering Stick Water and Slaughter Floor wastewater were the most significant sources of nitrogen, while Paunch was a significant source of phosphorus. 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.

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1. Introduction and Objectives

The Australian Red Meat Wastewater Survey project (AMSurvey) 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).
(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 (30 samples total) 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.

Discussion of Formal (SCI) Literature

The formal literature is extremely weak on stream characterisation and sources. There are approximately 600 relevant articles reported in SCOPUS (slaughterhouse/ abattoir/ effluent/ wastewater), of which 250 are mainly focused on wastewater management and characterisation. Approximately 80% of these are focused on wastewater treatment options, with the remainder focused on environmental impacts (including pathogen distribution). Articles focusing on treatment are useful in terms of bulk stream characterisation, with pig and cattle being generally higher strength (3000-5000 mgCOD L^{-1}) than poultry wastewater (1000-3500 mgCOD L^{-1}) (Batstone et al. 2000; Caixeta et al. 2002; Del Nery et al. 2007; Latif et al. 2011), but are not generally useful in source separation. There are <10 articles focused on characterisation, generally published in less available or lower impact journals, and these do not generally provide information on upstream flows. There is a significant amount of work on potential byproduct digestion or handling (e.g., (Tritt and Schuchardt 1992)), but these are focused on blood, paunch, bone etc. byproducts, rather than analysing wastewater contributors. There was no information provided on biological degradability of individual streams, though extensive work has been done on nitrification removal (Pochana and Keller

1999; Reginatto et al. 2005) and bulk carbon removal through anaerobic digestion (Fountoulakis et al. 2008; Rajakumar et al. 2011). A priority for this project should be publication in peer reviewed journals.

There have been review articles published in 1992 (Tritt and Schuchardt 1992), 1995 (Johns 1995), and 2006 (Mittal 2006), which have been cited, 35, 50, and 26 times respectively. They are all in Bioresource technology, focused on both characterisation and treatment options. One of the best, also highly relevant to the Australian red meat industry was done by Mike Johns (Johns 1995). It is now dated, having been published 17 years ago, but highlights the variation in wastewater strengths, with individual streams varying from medium strength (1000-3000 mgCOD L^{-1}) to high strength (5000-10000 mg COD L^{-1}). Our survey work so far, as well as that done within MLA/AMPC projects has indicated that current Australian plants are at the very top end of that range, due to water consumption reduction, and possible loss of byproduct. Nitrogen levels are generally 5% of COD (i.e.., 100-500 mgN L^{-1}). More recent international review work (Massé and Masse 2000; Mittal 2006) from Canada has indicated higher strength wastewater (>5000 mgCOD L^{-1}) and higher nitrogen levels consistent with this. Solids are relatively high, representing approximately 70% of the COD (Johns 1995; Mittal 2006). A summary table of the information found in terms of waste strength per animal, tonne live weight and per tonne warm dry carcass weight is given in Table 1.

Table 1: Waste sources in different units

	Water (m^3)	COD (kg)	TSS (kg)	O&G (kg)	N (kg)	P (kg)
per head	2.0-8.0	6- 16	3-8	1-5	0.5-1.5	0.05-0.15
per t live	3.3-13.3	10.0-26.7	5.0-13.3	1.7-8.3	0.8-2.5	0.1-0.3
per t HSCW	5.6-22.2	16.7-44.4	8.3-22.2	2.8-13.9	1.4-4.2	0.1-0.4
Concentration (mg/L)	-	2-10	0.5-2	0.1-0.6	0.1-0.6	0.01-0.1

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%.

It is important to compare this with the live cattle weight. Of the average 600 kg live cattle weight, 270 kg is product (~45%), and the rest is sold as by-product or reprocessed internally to produce (e.g.) rendered product, or sold externally (e.g., hide), or shipped as waste (e.g., paunch). This is summarised in Table 2. Approximately 5-10 kg dry (20-50 kg wet), or approximately 5% of the total material flow is lost in the wastewater stream.

Table 2: Product recovery from slaughter cattle

Product	kg per head	% live
Meat	270	45%
Bone	90	15%
Paunch	25	4%
Blood	44	7%
Inedible organs (inc. hooves)	70	12%
Edible organs (inc tongue)	33	6%
Hide	48	8%
Head	15	3%
Total	600	100%

1. (Hedrick et al. 1994; Hui 2001; Terry et al. 1990)
2. Blood volume based on whole blood, not air extracted blood (Hedrick et al. 1994) and therefore includes organ and muscle blood.

Discussion of MLA and AMPC Projects

MLA/AMPC projects environment projects available since 1990 have been reviewed (http://www.redmeatinnovation.com.au/project-reports/report-categories/environment). 19 projects (out of 103) were reviewed, with a breakdown across biological nutrient removal (4), carbon and sustainability (3), heat and water recovery (2), solids handling (3), and wastewater characterisation and treatment options (7).

The major projects assessing overall environmental performance is the Environmental Performance Review, conducted in 1997, 2003, and 2010. The 2010 MLA/AMPC Environmental Performance review was provided by GHD (Maddocks and Trahir 2011). This was a very high level overview of environmental performance (air, land, and water emissions, as well as sustainability measures and social impact), and provided very minimal analysis of upstream impacts, but is useful for this review to assess Australian performance against international benchmarks above.

The review found that Australian raw water consumption averaged 8-10 kL/t HSCW, in line with world practice of 6-20 kL/t HSCW, and this has reduced by approximately 20% in the last 10 years. Water consumption was in line with effluent, occasionally being higher, and occasionally lower. Effluent should be slightly higher (~5%) due to contribution to the water balance by cattle. Lower production than consumption would be due to losses due to steam injection, losses in byproducts, and inaccuracies in metering. Nitrogen emissions were at the lower end of the range in Table 1, while phosphorous emissions were at the high end (for untreated effluents), and we need to evaluate this further. Oil and Grease averaged 12 kg/t HSCW, which seems very high. Previous environmental performance reviews (2003, 1997) have a focus with the current review, and cannot make a substantial contribution to the upstream analysis required in this work.
Amongst the other projects, the focus has generally been on the downstream treatment option rather than upstream characterisation. Of particular interest, the state of BNR research is very high, with relevant and credible options available for biological nitrogen and phosphorous removal, and a high level of transference to the public literature (with consequent peer review of data). However, with one exception, the information is generally too high level to be directly incorporated into this review except for comparative purposes.

The key exception is the Teys bros survey done by Mike Johns and Nicole Lucock (Johns and Lucock 2008), published April 2011. This is an exhaustive survey across 25 streams, identifying flows and key contaminants consistent with what we plan to do (we add metals and biodegradability to the analysis), including temperature. The mass balance approach is also consistent with the approach we plan to conduct. Both the submitted processed report, and the original report by Nicole Lucock are highly informative. The water circuit, and sample points are shown in Figure 1.

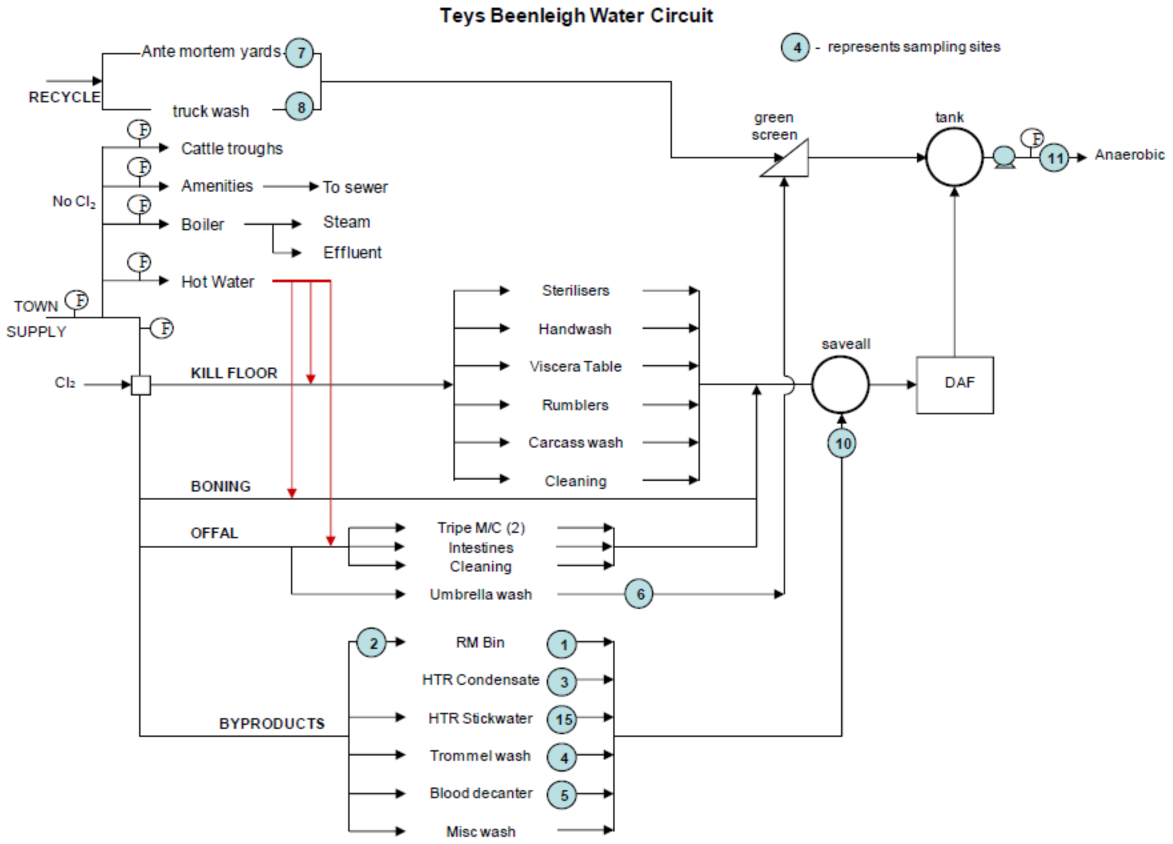

Figure 1: Teys bros water circuit as reported in (Johns and Lucock 2008)

The survey work found that Teys Bros produces 3ML of wastewater per day at 6 gCOD/L, 0.26 gN/L, and 0.04 gP/L, and was at that time, processing 1400 head of cattle per day (2.14 m^3/head). It is therefore in the upper range for all contaminants (compared to Table 1), and in the lower range for water consumption. Key outcomes included the findings that (a) three streams emitted >50% for all contaminants. These were raw materials bin (stream 4), tripe processing, and cleaning flows. The first two were relatively low in flow, but very high in load, while the last was high in flow and load. High-flow, and low load streams including the boning room. The issue that the highest load was a storage bin rather than continuous operations highlights issues around identification of high-load streams where there are variable operations. It will be important through this survey to identify intermittent or particular high-load situations that may only apply to the target plant.

Other student projects as provided by MLA/AMPC were also provided. These were high quality but not directly relevant to this project. Maria Yu's analysis (Yu 2011) focused on identifying options for water reuse from the veal floor at Cassino. This represents 16% of the total flow at the plant, and while it will be assessed in comparison with similar flows in our project, is too tightly focused to be directly incorporated in our final report. Rudra Saha's project at Teys Bros (Saha 2009) was completely focused on pathogen control, which is outside the scope of our project.

2. Methodology

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

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

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. This was effective in the majority of cases, however, 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.

Stream Composition

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 SCOD and NH4-N, 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).

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 2.

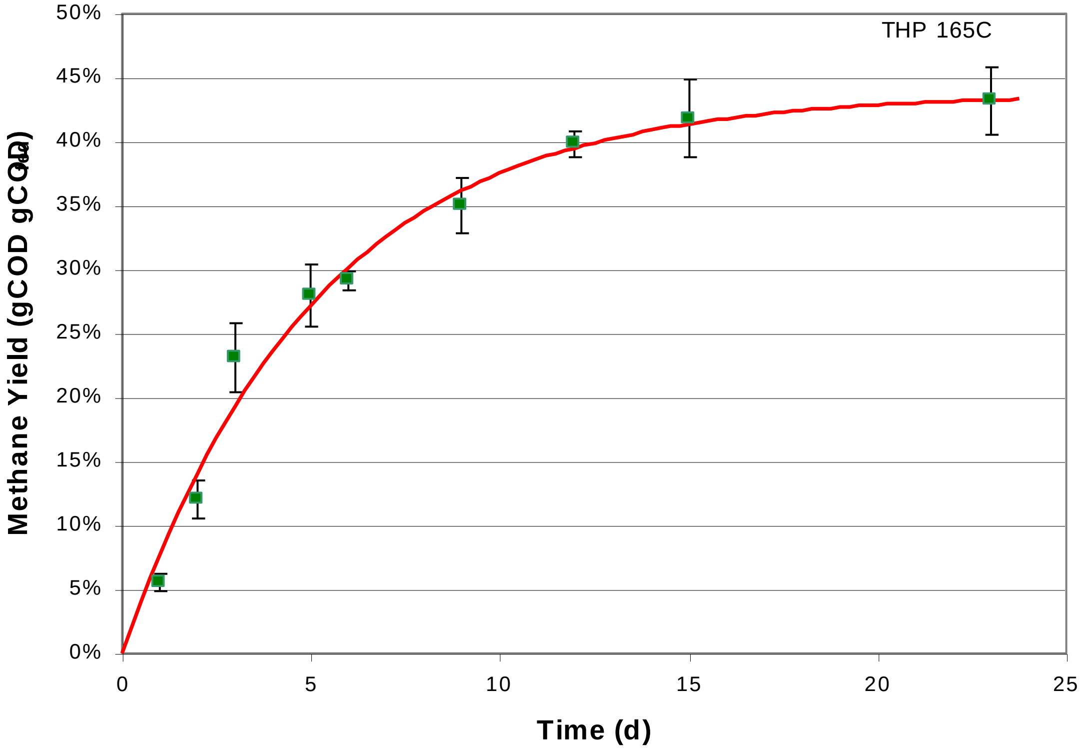

Figure 2: Example output from biological methane potential (BMP) test. Error bars indicate 95% confidence errors from triplicate batches. The line indicates the model used to return key parameters.

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. This project included a total of 34 BMP tests across 3 meat processing facilities.

Mass Balancing and Statistical Analysis

Mass balancing and Statistical Analysis is currently pending additional chemical and biochemical data acquisition. Mass balances will be set based on the process flowsheets shown in the next sections, and blend points analysed for consistency in flows and loads. This will allow identification of suitable branch points for individual treatment. A non-reactive mass balance approach has been used, with COD, N, P, and solids balanced around each process.

3. Results and Analysis.

3.1 Summary of Key Results

3.1.1 Load of Contaminants in Meat Processing Wastewater

Table 3 is a comparison of energy and nutrient loads from each of the 3 sites with load values expected from literature. The total COD load was approximately 2-4 times greater than the load expected from literature at all sites, total solids and oil and grease loads were also significantly greater than literature. Nutrients (N and P) were at the upper range of values expected.

Table 3: Comparison of preliminary 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)	O&G (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

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.

3.1.2 Concentration of Contaminants in Meat Processing Wastewater

Table 4 shows the concentration of combined wastewater streams at each of the 3 sites investigated compared with the concentration ranges expected from literature. Total chemical oxygen demand concentrations from all 3 sites were at the upper range reported by literature. Total solids and Oil and grease concentrations at Sites A and C were significantly higher than the concentrations expected from Literature. Site B was also high in comparison with literature. However, wastewater treatment at Site B incorporates multiple processing units designed to separate oil and grease for recycling to rendering operations. The recovery options are effective resulting in much lower concentrations of total solids and oil and grease at Site B compared to Site A and Site C. Also note that Site B is a mixed species processing site and the HSCW is split approximately 50% beef and 50% sheep.

Table 4: Concentration of wastewater streams compared to literature

Combined Wastewater Effluent Streams						
	TCOD (mg/L)	sCOD (mg/L)	TS (mg/L)[2]	O&G (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

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)

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

Table 5 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 of all three sites are high and comparable to major urban wastewater treatment plants. The CO_2 emissions potential is also very high, given a significant fraction is currently emitted from uncovered lagoons. The parameter used to estimate emissions from a pond is the methane conversion factor (MCF). The IPCC uses an MCF of 0.9 for tropical and temperate uncovered lagoons (IPCC 2006), while the NGER standard for agricultural processes (manures) is 0.8. Both of these are high compared with reality, and a moderately well operated pond will normally achieve an MCF of 0.6. However, this is not relevant for federal accounting purposes, as the NGER standard would be applied in a best case (meat processing waste is more rapidly degradable compared to manures).

The default NGER and CPRS value (based on 13.6 kL per t HSCW, and 6.1 kg COD/kL and 0.8 conversion) is 0.35 t CO_2 t^{-1} HSCW. From this study, current emissions at least for Site A and Site C are significantly higher, likely due to wastewater management strategies, while Site B is lower. In addition to carbon liabilities, there is also the loss of methane, which in most cases (generation of electricity and/or heat) represents $1000-$2000/day of potential revenue for these plants.

Table 5: 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

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.

3.2 Major Sources of Contaminants in Meat Processing Wastewater

3.2.1 Concentration of Contaminants in Meat Processing Wastewater

During the site visits it was observed that the structure and operation of waste and wastewater treatment/recovery processes varied across each processing facility. However, 5 major processing areas were identified as common to each of the processing facilities included in this investigation; Cattle Yard Wash, Slaughter Floor, Offal Processing (e.g. Paunch), Boning Room and Rendering Operations. Individual streams from each of these processing areas were assessed at Site A and Site C, however, all streams could not be separated at Site B.

Process flowsheets (identifying structure of waste handling processes and sample points), and the composition of all streams sampled are included as Appendix A. Examples of wastewater streams from each processing area at Site A and Site C, compared to the combined effluents are shown in Table 6 and Table 7 respectively. At both sites, Paunch wastewater and Rendering Stick Water was identified as the most concentrated streams in terms of COD and total solids. Rendering stick water and Slaughter floor wastewater contained the highest concentration of nitrogen.

Table 6: Comparison of energy and nutrient loads within wastewater at Site A

Major Sources of Wastewater and Contaminants						
	TCOD (mg/L)	sCOD (mg/L)	TS (mg/L)	O&G (mg/L)	N (mg/L)	P (mg/L)
Cattle Yard Wash	3,194	380	3,000	4	89	13
Slaughter Floor[1]	3,756	1,278	3,500	206	2,021	28
Paunch Handling[2]	32,707	2,170	24,800	3,883	281	155
Boning Room	<100	-	-	-	-	-
Rendering Stick Water	40,000	7,840	24,600	5,538	1718	120
Typical Combined Effluent[3]	12,893	1,724	8,396	2,332	245	53

1. Typical composition – however spiked up to 30,000 mg/L TCOD during wash down events
2. Paunch handling at Site A includes Tripe
3. Based on mass balance of total cold effluent and total hot effluent

Table 7: Comparison of energy and nutrient loads within wastewater at Site C

Major Sources of Wastewater and Contaminants						
	TCOD (mg/L)	sCOD (mg/L)	TS (mg/L)	O&G (mg/L)	N (mg/L)	P (mg/L)
Cattle Yard Wash	1,632	680	2,250	<1	175	26
Slaughter Floor	19,257	7,380	7,290	28	2,040	57
Paunch Handling	15,028	2,096	13,370	210	506	256
Boning Room	<100	-	-	-	-	-
Rendering Stick Water	22,103	2,400	13,070	6,017	718	108
Typical Combined Effluent	10,800	890	7,530	3,350	260	30

3.2.2 Contribution of Processing Areas to Daily Load of Contaminants

Table 8 and Table 9 present the best estimates of the load of organic matter and nutrients (kg/day) in of wastewater streams from each of the processing areas at Site A and Site C. At both sites, paunch wastewater and rendering stick water were the most significant sources of COD and total solids. Generally, Rendering Stick Water was the highest source of oil and grease; however Paunch at Site A was also a rich source of oil and grease, mostly due to the tripe/bible wash included in this stream. Rendering Stick Water and Slaughter Floor wastewater were the most significant sources of Nitrogen, while Paunch was a significant source of Phosphorus.

Table 8: Comparison of energy and nutrient loads within wastewater at Site A

Major Sources of Wastewater and Contaminants						
	Water (kL)	COD (kg)	TS (kg)	O&G (kg)	N (kg)	P (kg)
Cattle Yard Wash	882	2,817	2,646	3.5	78	11
Slaughter Floor	450	1,690	1,575	93	909	13
Paunch Handling	330	10,793	8,184	1,281	93	51
Boning Room	-	-	-	-	-	-
Rendering Stick Water	192	7,677	4,723	1,063	330	23
Combined Effluent[1]	2,423	31,331	20,340	5,671	594	143

1. Based on mass balance of total cold effluent and total hot effluent

Table 9: Comparison of energy and nutrient loads within wastewater at Site C

Major Sources of Wastewater and Contaminants						
	Water (kL)	COD (kg)	TS (kg)	O&G (kg)	N (kg)	P (kg)
Cattle Yard Wash	240	392	540	<0.3	42	6
Slaughter Floor	108	2,080	787	3	220	6
Paunch Handling	200	7,495	3,910	42	123	61
Boning Room	90	-	-	-	-	-
Rendering Stick Water	315	6,963	5,646	1,895	226	34
Combined Effluent	2,115	22,810	15,925	7,085	550	74

3.3 Methane Potential, Carbon Liability and Energy Recovery Potential

3.3.1 Biochemical Methane Potential (B_0)

Biological methane potential (B_0) was evaluated for a total of 32 samples from the 3 participant sites. The BMP is an indication of the potential for energy recovery from a material and the solids destruction during treatment (and associated reduction in disposal/reuse costs). Site B was the only site to have a single combined wastewater stream that was accessible. At Site A and Site C the wastewater was separated into "Red wastewater" and "Green wastewater". Specific biochemical methane potential (L $kgVS^{-1}$) for these streams is presented in Figure 3.

At Site C, methane potential of the Red wastewater (>850 L $kgVS^{-1}$) was much higher than the green wastewater (~430 L $kgVS^{-1}$). The difference was not observed at Site A, where the green stream also contained Tripe/Bible wash and was high in oil and grease. Oil and grease (~1000 L $kgVS^{-1}$) has a much higher B_0 than carbohydrates and lignocellulose (~400 L $kgVS^{-1}$) typically found in green wastewater.

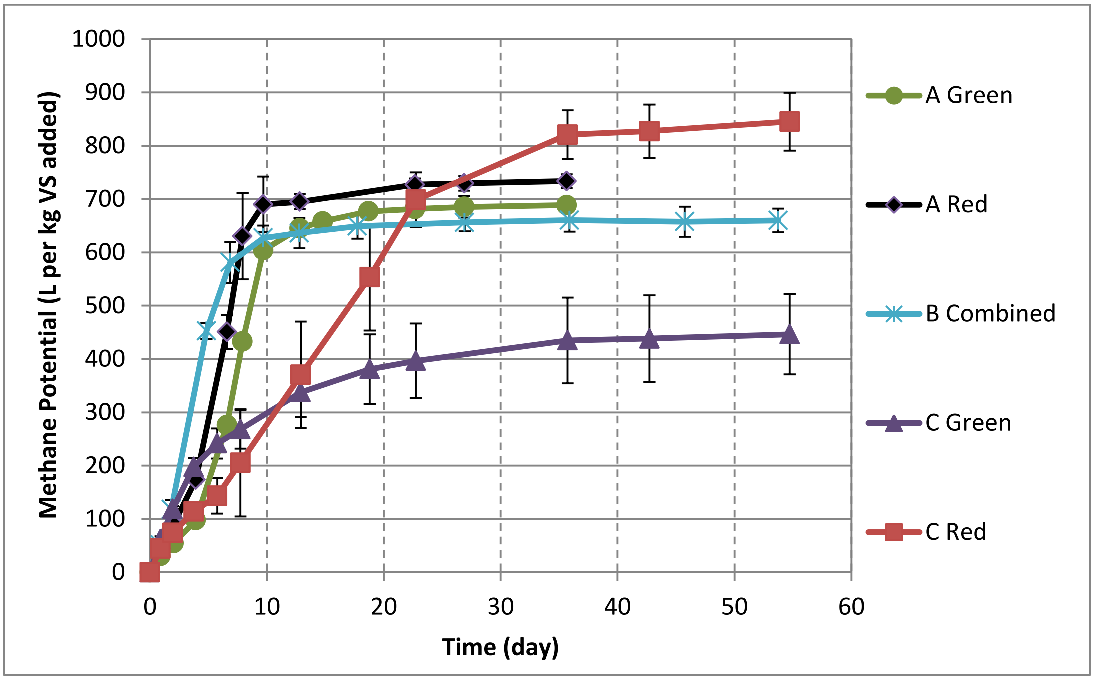

Figure 3. Cumulative methane production (triplicate B_0 tests) for combined wastewater streams at each site

Specific biochemical methane potential (L $kgVS^{-1}$) of samples from the 5 major processing areas at Site C is shown in Figure 4. The B_0 of each wastewater effluent is consistent with the expected composition of these streams.

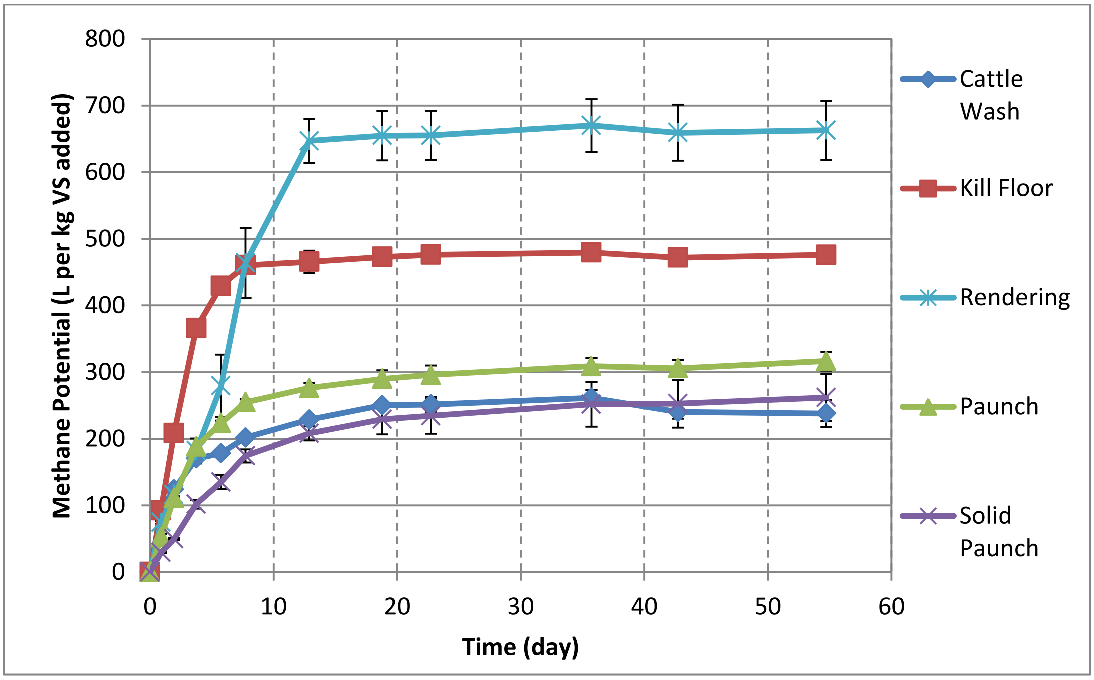

Figure 4. Comparison of specific methane production (triplicate BMP tests) from the 5 major processing areas at Site C.

Biochemical methane potential of Paunch wastewater and Paunch solids was also reported in previous MLA/AMPC projects (A.ENV.0099). B_0 from the Site C paunch samples was similar to that observed from A.ENV.0099; the Site C wastewater sample was ~300 L $kgVS^{-1}$ (compared to 340 L $kgVS^{-1}$) while the Site C paunch solids were ~250 L $kgVS^{-1}$ (compared to ~240 L $kgVS^{-1}$).

3.3.2 Analysis of Methane Potential from all Samples

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 methane potential from Site A, B and C is shown in Table 10, 11, 12 respectively. Degradability of all samples was high, suggesting a very good potential for anaerobic digestion and energy recovery. Cattle Wash and Paunch had a similar methane potential, generally in the range of 200-300 L CH_4 kg^{-1} VS added, this range is consistent with manures and structural lingo-cellulose residues (such as grass and grain residues in paunch). Slaughter Floor wastewater was generally in the range of 500 L CH_4 kg^{-1} VS added, which is consistent with a high protein stream (such as blood). Rendering streams in the range of 600-800 L CH_4 kg^{-1} VS added, and this is consistent with the higher oil and grease content of these streams.

Table 10. Summary of methane potential from each waste stream identified and sampled at Site A

Site A					
Wastewater Entering the Effluent Ponds					
ID	Stream	Hydrolysis rate (day^{-1})	Methane (m^3/t VS)	Methane m^3/kL	Methane m^3/day
SP1	Cattle Wash	0.12	283	0.5	479
SP2	Paunch Liquid	0.32	586	7.4	2,290
SP3	Paunch, Tripe, Green Wash	0.25	542	11.2	3,706
SP4	Kill Floor	0.28	470	1.3	589
SP5	Tripe Wash	0.10	718	13.7	742
SP6	Saveall Effluent	0.16	832	5.8	2,111
SP7	New Render	0.27	652	14.1	2,703
SP8	Total Effluent Cold	0.23	702	6.2	9,357
SP9	Total Effluent Hot	0.34	733	3.0	2,720
Total Wastewater Effluent[1]		N/A	N/A	5.0	12,077
Solids Sent for Composting					
ID	Stream	Hydrolysis rate (day^{-1})	Methane (m^3/t VS)	Methane m^3/t	Methane m^3/day
SP10	Paunch Solids	0.13	325	35.1	662
SP11	Saveall Bin[2]	-	-	-	-
SP12	Kill Floor Bin[2]	-	-	-	-
Total Waste Solids[2]		-	-	-	662
Total Measured Methane Potential Site A[3]					12,739

1. Calculated by mass balance of total effluent cold and total effluent hot
2. Combined these streams contribute approximately 10% of COD load in solids and therefore considered very low impact on daily load
3. Total methane load is equal to sum of wastewater load and solid waste load.

Table 11. Summary of methane potential from each waste stream identified and sampled at Site B

Site B					
	Wastewater Entering the Effluent Ponds				
ID	Stream	Hydrolysis rate (day^{-1})	Methane (m^3/t VS)	Methane m^3/kL	Methane m^3/day
SP 1	Cattle Wash	0.221	199.6	0.5	126
SP 2	Paunch Liquid	0.671	243.7	1.5	631
SP 3	Sheep Paunch	0.264	228.8	10.5	631
SP 4	Sheep Intestinal Wash	0.407	241.2	0.9	108
SP 5	Beef Paunch[1]	0.205	198.2	8.5	-
SP 6	Bone Squeeze	0.793	381.9	12.0	3,424
SP 7	Buffer Tank	0.296	192.2	2.8	1,209
SP 8	Saveall	0.355	547	3.4	7,271
SP 9	DAF Effluent	0.347	657	2.2	6,937
Total Wastewater Effluent		0.347	657	2	6,937
	Solids Sent for Composting				
ID	Stream	Hydrolysis rate (day^{-1})	Methane (m^3/t VS)	Methane m^3/t	Methane m^3/day
SP 10	DAF Sludge	0.263	648.3	80.7	1,247
SP 11	Paunch Screw Solids	0.139	177.8	43.3	476
SP 12	Saveall Contrashear Solids	0.169	249.9	41.5	1,272
SP 13	Gross Fat Separator Sludge	0.438	289.6	40.7	1,248
Total Solids for Compost		N/A	N/A	N/A	4,244
Total Measured Methane Potential Site B[2]					11,181

1. Volume of Beef Paunch could not be estimated; therefore daily load from this stream was not estimated.
2. Total methane load is equal to sum of wastewater load and solid waste load.

Table 12: Comparison of energy and nutrient loads within wastewater at Site A

Site C					
Wastewater Entering the Effluent Ponds					
ID	Stream	Hydrolysis rate	Methane	Methane	Methane
		(day^{-1})	(m^3/t VS)	m^3/kL	m^3/day
SP 1	Cattle Wash	0.318	242	0.4	91
SP 2	Paunch	0.24	303	3	680
SP 3	Green Pit	0.14	430	2	819
SP 4	Kill Room Floor	0.422	476	3	341
SP 5	Screws to Rendering	0.143	783	13	275
SP 6	Tripe Wash	0.157	858	2	953
SP 7	Rendering Belt Wash	0.15	834	4	95
SP 8	Stick Water	0.16	679	8	2502
SP 9	Boning Room	-	-	-	-
SP 10	Red Pit	0.05	951	5	5150
SP 11	Cattle Yards and Clean Overflow	N/A	N/A	N/A	N/A
SP 12	Total Wastewater Effluent				5,969
Solids Sent for Composting					
ID	Stream	Hydrolysis rate	Methane	Methane	Methane
		(day^{-1})	(m^3/t VS)	m^3/t	m^3/day
SP 13	Paunch Solids	0.14	253.5	27	262
SP 14	Red Pit Solids	-	-	-	-
	Total Solids				
Total Methane Potential Site C[1]					5,969

1. Total methane load is equal to sum of green pit and red pit – solids are removed after these sample points.

4. Treatment Recommendations

At this point, we are considering appropriate biological processes rather than alternative treatment technologies such as gasification, charring, or incineration for the paunch. In this review, we are also only considering carbon removal and anaerobic processes, since biological aerobic nitrogen and phosphorous removal are energy negative and destroy the nitrogen. Table 13 presents the best estimates of the potential methane load from each of the processing areas at Site A, Site B and Site C. The methane potential results were largely consistent with the contributions to COD and Total Solids loads. Rendering was identified as the highest contributor to methane potential; and should be a priority when considering treatment and capture options. Specific methane potential (L per kg VS) from Cattle wash similar to Paunch, however, due to dilute nature of this stream, there was very little impact on site methane potential. Similarly, Slaughter Floor wastewater was highly degradable (good rate and yield), but due to the dilute nature and low flow, this processing area contributed to less than 10% of the total site methane potential.

Table 13: Comparison of energy and nutrient loads within wastewater at Site A

Major Sources of Wastewater and Contaminants			
	Site A	Site B	Site C
Cattle Yard Wash	3-5%	1%	1.5-2%
Slaughter Floor	5-7%	-	6-8%
Paunch Handling	30-42%	10%[1]	27-33%
Boning Room	-	-	-
Rendering Operations	22-30%	60%[2]	48-57%

1. Sheep Paunch Only
2. All Red wastewater streams including Rendering and Slaughter floor

Assessing the streams in Table 13, only Rendering, Slaughter Floor, and Paunch should 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, therefore these streams should be able to bypass primary treatment. A suitable polishing step may include aerobic MBR, fixed film or moving bed aerobic bioreactor, or facultative lagoons.

Streams recommended for primary treatment can be placed on our technology selection diagram (Figure 5). This indicates that the liquid stream is not well placed for conventional technology. It contains too much solids and fats for conventional high-rate anaerobic treatment such as the upflow anaerobic sludge blanket reactor (UASB) or internal circulation (IC) reactors. The solids concentration is too low for mixed digestion.

The mixed Rendering/Slaughter Floor stream is potentially ideal for anaerobic membrane processes, as long as the current AMPC/MLA AnMBR project can demonstrate long-term tolerance to fats loading. Another significant benefit in treating this wastewater with this technology is the high degradability of the feed. This would allow for a very low level of solid residue (virtually zero) from digestion. An alternative to the AnMBR is the emerging class of fat-tolerant wastewater options such as the Paques flotation reactor, though this is less tolerant of solids. The long solids retention times (20 days) in an AnMBR would allow for accumulation of acclimatised biomass, which is important to overcome the minor inhibition observed.

Whole Paunch (solids and wastewater) is best treated by conventional solids digestion. This would generate methane and cut current waste solid paunch levels by approximately 45% (where screw presses are used) or 60% (where centrifuges or belt presses are used).

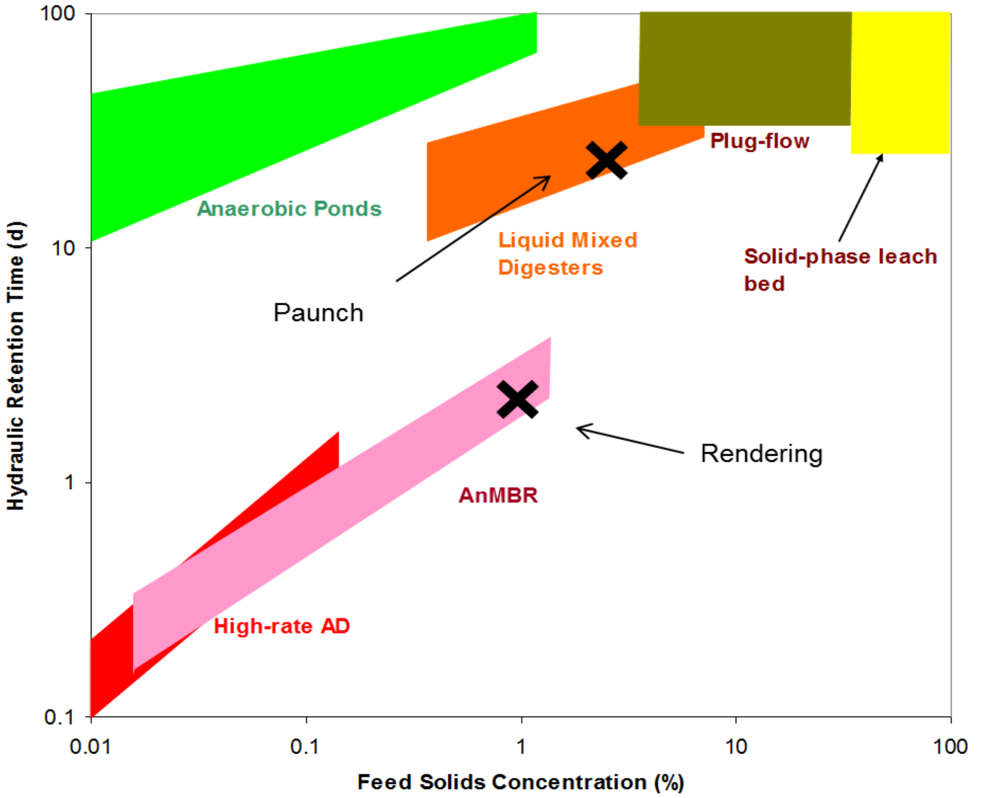

Figure 5. Selection guide for existing and developing anaerobic technologies: High-Rate AD (UASB- Upflow Anaerobic Sludge Blanket, AnMBR – Anaerobic membrane bioreactor)

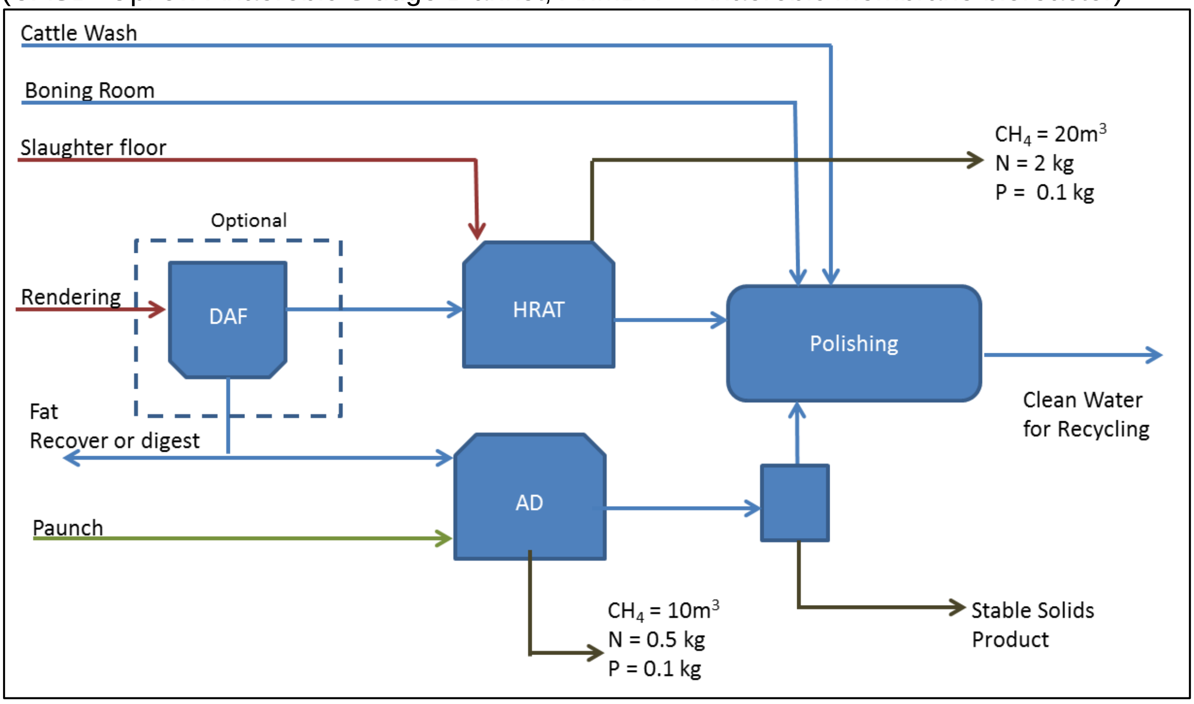

Figure 6: Proposed treatment process and potential recovery of energy and nutrients based on 1 T HSCW (note ~50% recovery of nutrients assumed).

5. Summary

While each plant had a different approach to waste and wastewater handling, there were 5 major processing areas identified at the 3 meat processing facilities included in this investigation; Cattle Yard Wash, Slaughter Floor, Paunch (offal) Handling, Boning Room and Rendering Operations. The following assessments and recommendations were made on how each processing area contributes to the total organic, energy and nutrient loads:

- After comparison with literature (HSCW basis), the total COD load estimated from each site was 2-4 times greater than the load expected from literature, total solids and oil and grease were also high, while water usage and nutrient loads were within expected ranges.
- Current emissions from two of the processing sites investigated in this study were significantly higher than the default NGER and CPRS value of is 0.35 T CO_2 T^{-1} HSCW, this was likely due to wastewater handling strategies. In addition to carbon liabilities, there is also the loss of methane, which in most cases (generation of electricity and/or heat) represents $1000-$2000/day of potential revenue for these plants.
- Paunch Wastewater and Rendering stick water were the most significant sources of COD and total solids. Rendering Stick Water and Slaughter Floor wastewater were the most significant sources of Nitrogen, while Paunch was a significant source of Phosphorus.
- Anaerobic biodegradability and methane potential of all wastewater samples was high, suggesting a very good potential for anaerobic digestion and energy recovery; with little impact of inhibitory compounds.
- It is recommended that Rendering, Slaughter Floor, and Paunch wastewater be treated using an anaerobic process (to remove carbon, and recover nitrogen and phosphorous), since cattle wash and boning room are very high flow and low contaminant. A suitable polishing step may include aerobic MBR, fixed film or moving bed aerobic bioreactor, or facultative lagoons.
- All wastewater streams were highly variable and mass balancing identified some inconsistency when comparing data within a processing site. Organic loads estimated from final effluent streams were approximately 30% higher than loads estimated from the sum of individual streams at two of the processing plants. The higher values were used in assessing carbon liability and energy recovery potential.

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7. Appendix A Flowsheet and Stream Results of Each Participant Site

Processing Site A

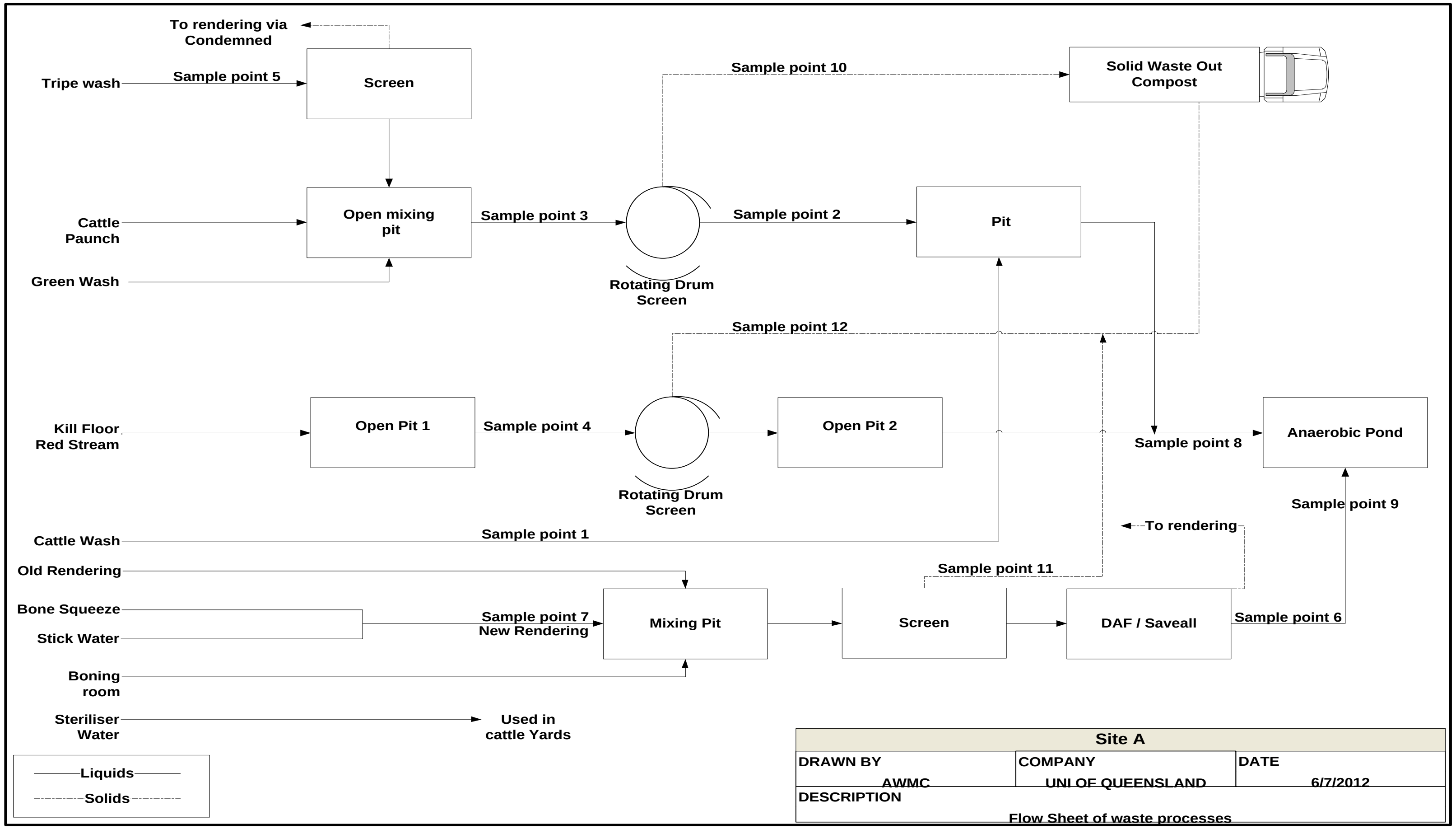

Table 14: Composition of Waste Streams at Site A

Site A												
Wastewater Entering the Effluent Ponds												
ID	Stream	Volume	TCOD	SCOD	TS	O&G	TKN	NH4-N	TKP	PO4-P	Methane	Methane
		kL/d	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mgN/l)	(mgN/l)	(mgP/l)	(mgP/l)	(m^3/t VS)	m^3/kL
SP 1	Cattle Wash	882	3,194	380	3000	4	89	47	13	6	283	0.5
SP 2	Paunch Liquid	311	23,908	2,064	15,800	2,603	517	36	211	160	586	7.4
SP 3	Paunch, Tripe, Green Wash	330	32,707	2,170	24,800	3,883	281	15	155	101	542	11.2
SP 4	Kill Floor	450	3,756	1,278	3,500	206	2,021	17	28	17	470	1.3
SP 5	Tripe Wash	54	30,890	1,210	19,900	11,638	282	9	81	43	718	13.7
SP 6	Saveall Effluent	367	13,295	2,144	8,000	2,900	491	62	46	27	832	5.8
SP 7	New Render	192	40,003	7,840	24,600	5,538	1,718	41	120	73	652	14.1
SP 8	Total Effluent Cold	1,512	16,378	1,798	10,600	3,063	234	67	77	75	702	6.2
SP 9	Total Effluent Hot	911	7,209	1,600	4,800	1,138	264	44	28	17	733	3.0
	Total Effluent[1]	2,423	12,893	1,722	8,396	2,332	245	58	58	53	-	5.0
Solids Sent for Composting												
Stream ID	Stream	Volume	TCOD	SCOD	TS	O&G	TKN	NH4-N	TKP	PO4-P	Methane	Methane
		kg/d	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mgN/l)	(mgN/l)	(mgP/l)	(mgP/l)	(m^3/t VS)	m^3/t
SP 10	Paunch Solids	18,886	163,933	-	128,300	3,440	1,185	-	350	-	325	35.1
SP 11	Saveall Bin	434	251,480	-	191,800	5,133	20,650	-	432	-	-	-
SP 12	Kill Floor Bin	1,268	138,380	-	165,300	4,760	7,350	-	805	-	-	-
	Total Solids	20,588										

Processing Site B

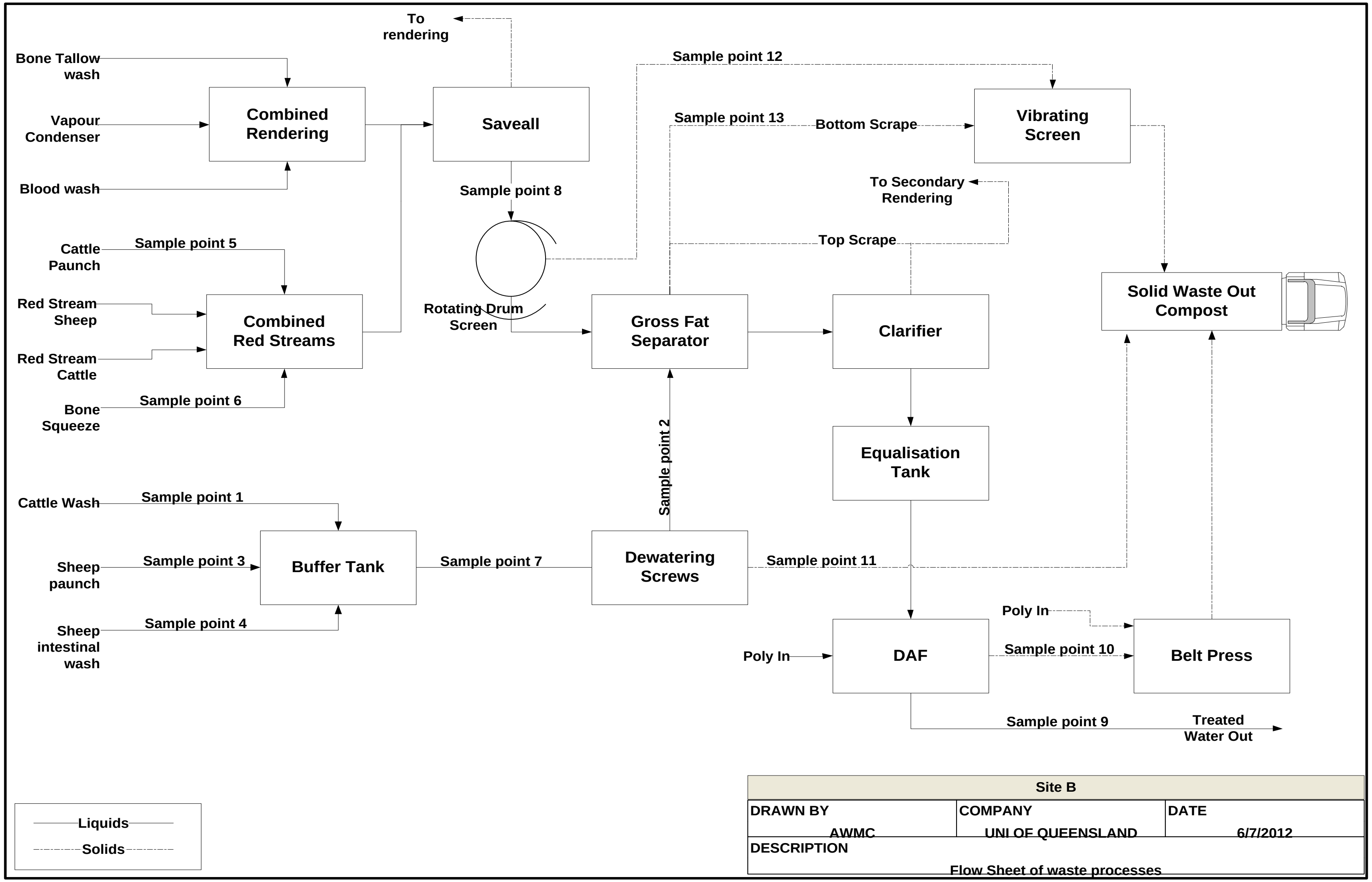

Table 15: Composition of Waste Streams at Site B

Site B											
Wastewater Entering the Effluent Ponds											
ID	Stream	Volume (kL/d)	TCOD (mg/l)	SCOD (mg/l)	TS (mg/l)	O&G (mg/l)	TKN (mgN/l)	NH4-N (mgN/l)	TKP (mgP/l)	PO4-P (mgP/l)	Methane (m^3/t VS)	Methane m^3/kL
SP 1	Cattle Wash	252	3,089	534	3,450	4	220	131	40	20	199.6	0.5
SP 2	Paunch Liquid	421	10,777	2,280	8,100	47	377	190	233	162	243.7	1.5
SP 3	Sheep Paunch	60	52,663	4,890	55,410	226	1,685	181	1,805	922	228.8	10.5
SP 4	Sheep Intestinal Wash	120	5,285	1,900	4,550	30	125	103	35	30	241.2	0.9
SP 5	Beef Paunch	N/A	39,158	2,805	47,880	120	1,390	58	640	251	198.2	8.5
SP 6	Bone Squeeze	285	44,773		33,200	25	4,745	131	11	34	381.9	12.0
SP 7	Buffer Tank	400	13,877	2,124	16,900	29	674	197	314	149	192.2	2.8
SP 8	Saveall	2,138	10,367	2,200	7,000	1,313	304	71	49	33	547	3.4
SP 9	DAF Effluent	3,153	9,587	1,970	4,300	783	232	93	50	38	657	2.2
	Total Effluent	3,153	9,587	1,970	4,300	783	232	93	50	38	657	2.2
Solids Sent for Composting											
ID	Stream	Volume (kg/d)	TCOD (mg/l)	SCOD (mg/l)	TS (mg/l)	O&G (mg/l)	TKN (mgN/l)	NH4-N (mgN/l)	TKP (mgP/l)	PO4-P (mgP/l)	Methane (m^3/t VS)	Methane m^3/t
SP 10	DAF Sludge	18,240	185,753	-	131,500	79,000	2,145	-	259	-	648.3	80.7
SP 11	Paunch Screw Solids	3,443	205,080	-	370,800	60	2,185	-	427	-	177.8	43.3
SP 12	Saveall Contrashear Solids	59,959	158,427	-	174,700	11,533	1,780	-	234	-	249.9	41.5
SP 13	Gross Fat Separator Sludge		170,833	-	210,900	14,467	1,915	-	540	-	289.6	40.7

	Total solids	81,642		-							N/A	N/A

Processing Site C

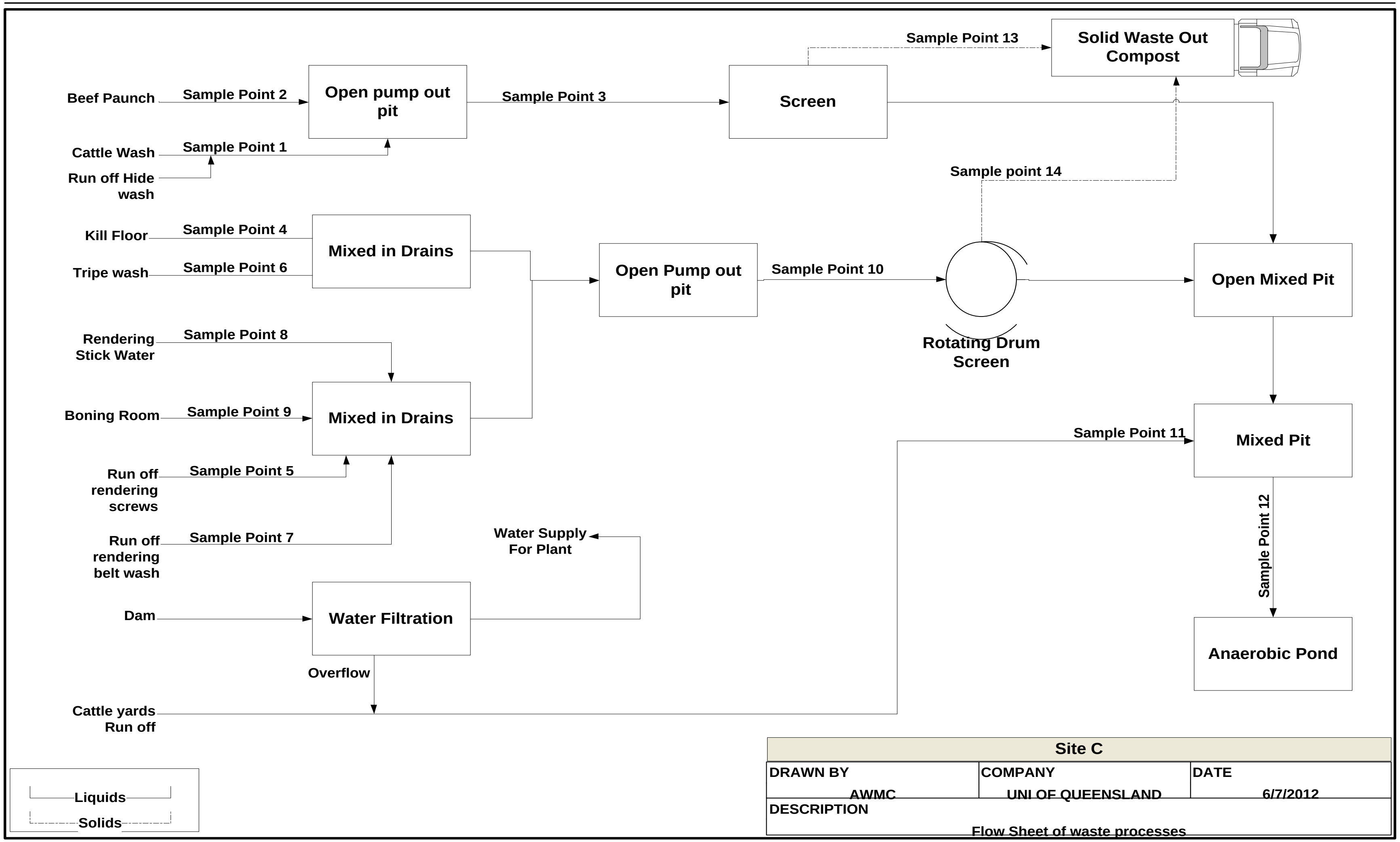

Table 16: Composition of Waste Streams at Site C

Site C												
Wastewater Entering the Effluent Ponds												
ID	Stream	Volume	TCOD	SCOD	TS	O&G	TKN	NH4-N	TKP	PO4-P	Methane	Methane
		kL/d	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mgN/l)	(mgN/l)	(mgP/l)	(mgP/l)	(m^3/t VS)	m^3/kL
SP 1	Cattle Wash	240	1,632	680	2,250	<1	175	82	26	14	0.4	91
SP 2	Paunch	200	15,028	2,096	13,370	210	506	46	256	112	3	680
SP 3	Green Pit	440	5,768	774	5,350	217	276	43	96	41	2	819
SP 4	Kill Room Floor	108	19,257	7,380	7,290	28	2,040	41	57	20	3	341
SP 5	Screws to Rendering	21	24,490	9,900	19,240	1,717	3,050	252	417	145	13	275
SP 6	Tripe Wash	432	10,392	428	2,870	687	51	6	24	13	2	953
SP 7	Rendering Belt Wash	25	6,903	692	4,850	3,430	164	1	19	8	4	95
SP 8	Stick Water	315	22,103	2,400	13,070	6,017	718	21	108	51	8	2502
SP 9	Boning Room	90	-	-	340	,1	-	-	-	-	-	-
SP 10	Red Pit	949	9,683	1,324	6,190	4,400	258	10	24	14	5	5150
SP 11	Cattle Yards, Clean Overflow	171	-	-	190	-	-	-	-	-	N/A	N/A
SP 12	Total Effluent	2,115	10,785	893	7,530	3,350	260	62	30	15	-	5,969
Solids Sent for Composting												
ID	Stream	Volume	TCOD	SCOD	TS	O&G	TKN	NH4-N	TKP	PO4-P	Methane	Methane
		(kg/d)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mgN/l)	(mgN/l)	(mgP/l)	(mgP/l)	(m^3/t VS)	m^3/t
SP 13	Paunch Solids	8,427	82,22	-	111,80	6,267	925	-	222	-		

			0		0							
SP 14	Red Pit Solids	1,782	-	-	403,95 0	116,00 0	-	-		-		
	Total Solids	10,208		-				-		-		