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Bedding management and air quality on livestock vessels - A literature review

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Abstract

The Australian livestock export industry has completed an array of projects aimed at improving environmental conditions on livestock vessels. Most of these studies have addressed air quality (mostly ammonia) but bedding management (washing frequency and the use of sawdust) has also been investigated. These studies have been completed over a 15-year time frame with the majority being completed early in that period. These early studies have provided the industry with a good understanding of the issues involved. However, it is timely for the industry to review the more recent literature to identify any recent developments that may have relevance to the industry. One of the more significant changes has been to MARPOL (The International Convention for the Prevention of Pollution from Ships) in regards to effluent disposal. This review places this, and other recent findings, in the context of the overall bedding and environmental management strategies utilised on livestock vessels. These are discussed under appropriate headings throughout the body of the report.

Executive Summary

The review has been undertaken in three sections. The first section examines air quality and recent advances in environmental monitoring. In this section there are three main areas of interest. The first relates to temperature and humidity (dry bulb temperature (DBT), relative humidity (RH) and wet bulb temperature (WBT)). The second relates to pad moisture and the final area relates to emissions (mainly ammonia, carbon dioxide and methane). The importance of airborne particles (dust and airborne remnant microorganisms) is also addressed in this section.

The second section addresses bedding management. There are two main areas of interest in this section. The first is ventilation. Ventilation is inextricably linked to both bedding management and air quality and it is not possible to discuss bedding management and air quality without reference to ventilation. Ventilation is therefore included but only to the extent that it relates to the project. The second area of interest relates to the factors that influence a bedding management strategy. This includes the management of pad moisture, the management of ammonia and the management of the other emissions (identified earlier). The use of sawdust (and/or other bedding materials) is examined, as is the use of bedding additives. It examines the factors that influence washing frequency and explores the possible use of feed additives and/or dietary manipulation to manage both pad moisture and emissions. The importance of flooring is examined in some detail.

The third section addresses the issue of reporting. The review looks at how advances in environmental monitoring technology could support existing reporting and monitoring functions.

The review notes that DBT, RH and WBT continue to be the most important environmental indicators on livestock vessels. New technology suggests that real time monitoring with computer capture is now both possible and practical. It is envisaged that these techniques could automate much of the data collection and provide alerts in terms of real time monitoring and in terms of the prediction of deck conditions based on anticipated weather (if linked to a stowage plan). Just how these techniques may be employed represents an industry knowledge gap and is an area identified for future research. The main issues associated with temperature and humidity are summarised in Table 1.

Pad moisture is another important measurement (but rarely measured) parameter on livestock vessels. The literature search uncovered very little published work with any direct application. Further research is required to quantify both the levels and patterns of pad moisture under a range of scenarios (in both the sheep and cattle pad) to provide a better understanding of the linkages involved. The main issues associated with pad moisture are summarised in Table 2.

There is a large body of both recent and past research that addresses ammonia (NH_3). This provides the basis for a strong understanding of the effects of NH_3, critical levels and the factors that influence NH_3 emission.

The most comprehensive study was undertaken by Acciolly in 2004. The maximum safe level of NH_3 exposure, as proposed by the Australian standards (ASEL) is 25ppm (as a time weighted value). This is supported by the industry research. This is the same level recommended by SafeWork Australia. More recent research, has suggested much lower levels for both animal and human health in 'other' intensive livestock industries.

It is noted that the industry has yet to monitor NH_3 levels on a continuous (time weighted) basis and has conducted very little formal monitoring since 2003. At that time, NH_3 was measured on a single point daily basis using hand held equipment. Monitoring equipment is now more sophisticated. Continuous measuring techniques exist but the equipment requires mains power and is relatively expensive.

Methods to mitigate NH_3 production and release are well described in the literature. This includes the use of citric acid in bedding, gypsum as a feed additive and more generally limiting protein levels in the feed. These measures can be used to counter problems as they arise. The main issues associated with NH_3 are summarised in Table 3.

Carbon Dioxide (CO_2) has been measured extensively during the industry ventilation studies and subsequent research. Levels generally were low (less than 600ppm) and CO_2 was used primarily to detect less ventilated areas within the livestock holds on livestock vessels. Levels above 1500ppm were indicative of poor ventilation. The main issues associated with CO_2 are summarised in Table 4.

Methane (CH_4) is a colourless gas that is being increasingly studied in relation to the greenhouse emission contribution of livestock operations. It is not thought to contribute to animal health problems on livestock vessels. The main issues associated with CH_4 gas are summarised in Table 5.

Hydrogen Sulphide (H_2S) is a highly poisonous gas and levels above 10 ppm are of concern. It is not evident that H_2S can be found in any significant quantities on livestock vessels, but because of their importance in relation to OH&S matters. The main issues associated with H_2S gas are summarised in Table 6.

Carbon monoxide (CO) can be lethal in very small quantities, so its presence in vessels is unacceptable. Because it is colourless and odourless it has no inherent warning properties. It is not normally associated with diesel or heavy oil powered engines. It could become an issue if any of the new vessels opt to gas power their engines. In this situation, adverse wind conditions could lead to the ingestion of engine exhaust into supply vents. The main issues related to carbon monoxide are detailed in Table 7.

The importance of airborne particles (dust) is feature of the more recent literature. Apart from the direct detrimental health effects of the airborne particles, these pollutants also act as a carrier for both noxious gases and remnant microorganisms. Cell wall components of dead and decaying bacteria (endotoxins have the potential to trigger an immune response in the lung even though they are no longer living.

Bedding management on livestock vessels is a specialised field. The literature search struggled to find work with any direct application to the onboard situation. Headings were drawn from industry documents (e.g. Stockman's manual), to provide a logical framework from which to address the factors involved. The extent to which the discussion is supported by available science is noted.

The report first addresses the factors that influence the quantity and consistency of manure on livestock vessels. It notes the differences between the sheep and cattle pad. These differences (and the significant differences in voyage duration) influence the bedding management strategy, and the practices associated with these differences (e.g. long haul versus short haul cattle voyages). The report notes how it is difficult (if not impossible) to be prescriptive about bedding management and that management strategies are modified and amended in response to the interplay of a large number of factors. It is strongly influenced by the way in which events unfold during the course of a voyage. The principles involved however, appear to be well understood by industry personnel (industry pers. comm.).

The factors that influence the bedding management program fall under a number of headings. Ship factors include flooring, air delivery and ventilation design, configuration, ship design and size and trim. Livestock factors include breed type, coat length, bodyweight, pregnancy status, age and the presence or absence of riding behaviour. Other factors also exist (fodder type and feeding, stocking density, actual and anticipated weather conditions and voyage duration and eventual destination). The report also describes the more recent changes to the MARPOL regulations and discusses the possible implications. These apply to the discharge of effluent (rate of discharge and the proximity to land).

The report includes a small section on how to manage slurry (should it occur) and has a major heading that discusses how flooring influences bedding management. A new flooring system is proposed that embraces the principle of continuous removal. The report notes that the proposed system is a long way from application but it represents a 'blue sky' option for the industry to consider.

The report notes that sawdust is the preferred bedding material. However, the quality of bedding material varies greatly and there are no formal quality assessment criteria (e.g. absorbency and/or ability to buffer abrasive flooring). This is an area identified for future research.

One of the most significant findings of the review was the identification of new technologies that provide real time monitoring with computer capture. This now has practical application and could be seriously considered by the industry. It is envisaged that this would automate much of the data collection and provide alerts both in terms of real time monitoring and in predicting deck conditions based on anticipated weather. This technology has application to both emissions and environmental conditions.

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1 Introduction

The Australian livestock export industry has completed an array of projects aimed at improving environmental conditions on livestock vessels. Most of these studies have addressed air quality (mostly NH_3) but bedding management (washing frequency and the use of sawdust) has also been investigated. The industry has also undertaken pivotal studies into both ventilation and heat stress. These studies have been completed over a 15-year period and have provided the industry with a good understanding of the issues involved.

More recently, there has been significant changes to MARPOL (The International Convention for the Prevention of Pollution from Ships) in regards to effluent disposal. This, and heightened concerns about the environment generally, has prompted a renewed focus on bedding management and air quality on livestock vessels. This has led to further regulation by the Australian Maritime Safety Authority (AMSA) through Marine Orders 96, and the industry through the auspices of the Australian Standards for the Export of Livestock (ASEL). There are also concerns, not only about the environmental conditions that affect animals, but also the occupational health and safety of workers.

Whilst the industry is of the opinion that both air quality and bedding is managed to an acceptable level, there is always room for improvement and periodic reviews are in the interests of the industry. It is timely, therefore that a review should be undertaken to identify any recent innovation that might have the potential to improve the onboard environment.

The importance of keeping the findings and recommendations of the review within a practical and commercial framework is acknowledged. However, the researchers were given latitude to take a ‘blue sky’ approach to sections of the literature review. Consequently, some of the findings of the review may seem beyond the current capacity of industry to implement.

It is possible that over time, as the industry evolves and/or as the technologies are further developed, some of the ‘blue sky’ findings may have commercial application. They are presented with this view in mind. It is hoped that the report strikes an appropriate balance between the ‘blue sky’ type findings and those that may have immediate benefit within the commercial constraints of the industry as it currently stands.

The review has been undertaken in three sections. The first section examines air quality and recent advances in environmental monitoring. In this section there are three main areas of interest. The first relates to temperature and humidity (dry bulb, relative humidity and wet bulb temperature). The second relates to pad moisture and the final area is that of emissions (mainly ammonia, carbon dioxide and methane). The importance of airborne particles (dust and airborne remnant microorganisms) is also addressed in this section.

The second section addresses bedding management. There are two main areas of interest in this section. The first is ventilation. It should be stressed that the industry has studied both ventilation and heat stress in great depth and that both these areas are of sufficient importance to warrant investigation in their own right. However, ventilation is inextricably linked to both bedding management and air quality. It is not possible to discuss bedding management and air quality without some reference to ventilation. Ventilation is therefore included but only to the extent that it relates to the project.

The second area of interest relates to the factors that influence a bedding management strategy. This includes the management of pad moisture, the management of NH_3 and the management of the other emissions (identified earlier). It discusses the interplay between emission rate, ventilation and resultant environmental levels. It looks at the use of sawdust (and/or other bedding materials) and the use of bedding additives. It examines the factors that influence washing frequency and explores the possible use of feed additives and/or dietary manipulation to manage both pad moisture and emissions. The importance of flooring is examined in some detail.

The third area addresses the issue of reporting. The review looks at how advances in environmental monitoring technology could support existing reporting and monitoring functions. The review acknowledges a hierarchy of reporting functions. The first is the reporting of monitoring information to onboard personnel. This information can be used to influence onboard decision-making and achieve the best possible outcomes on the voyage in question. The same information can be reported to the exporter (and possibly the ship owner) in a way that may influence the next or subsequent voyages (e.g. more sawdust/reduced stocking density). Information can also be collected that can be used to assist industry decision-making and/or support research and development. At another level the information can assist in meeting the mandatory reporting requirements of the Government and supports both Industry and Government in determining regulation.

A review of the industry best practice guidelines that apply to air quality and bedding management was also undertaken as part of the project. It was noted that there is no formal industry stand-alone document that outlines best practice air quality and bedding management guidelines. The most relevant document is the industry Stockman's manual that contains a substantial section on bedding management. Some best practice recommendations were made by Banney in the report entitled 'Management of bedding during the livestock export process' (Banney *et al.* 2009). The ASEL standards have sections that relate to both air quality and bedding management. AMSA regulations have sections that relate to bedding management. These were reviewed for the purposes of the study. Areas where 'best practice' could or should be updated were identified.

A final chapter makes recommendations about possible future research based on the findings of the literature review. Each of these recommendations is provided with a background (based on the findings of the review) and followed by a description of what may be involved, the justification or benefit of undertaking further research as well as any possible risks. They are presented in no particular order of priority.

2 Project Objectives

The stated objectives of the project were to:

1. Complete a broad literature review.
2. Complete a review of Best Practice Guidelines.
3. Update Best Practice Guidelines (if required).
4. Make recommendations for future research (if required).

N.B. Objectives 3 and 4 were preceded by a GO/NO GO decision by MLA based on the findings of the literature review.

3 Methodology

The project was conducted as a desktop study using routine literature search methodology. Various search engines were utilised. The section on air quality and environmental monitoring is addressed using a series of appropriate headings and the extensive use of tables. The key information is presented with a view to 'what' (under the heading of characteristics), 'why' (under the heading of effects), 'how' and 'when' (under the heading of detection and measurement), followed by a relevant discussion of risk factors, mitigation or management techniques and suggested optimal/acceptable levels and general comments.

The section on bedding management follows a more traditional format with simple headings that address each of the areas of importance. Each heading is followed by a discussion of all the key aspects. It should be noted that bedding management on livestock vessels is a specialised field and that the literature review identified very few studies with immediate relevance. Headings were therefore also drawn other industry documents (e.g. Stockman's manual), to provide a logical framework from which to address the factors involved. The extent to which the discussion is supported by available science is noted under each heading.

4 Air Quality and Environmental Monitoring

Gases are constantly produced within livestock buildings, and this includes livestock vessels (Banhazi *et al.* 2009d; Banhazi *et al.* 2009e). The quality of the environment is significantly influenced by the concentration of these gases (Groot Koerkamp *et al.* 1998; Accioly *et al.* 2004; Zhang *et al.* 2005; Bjerg *et al.* 2013c).

In livestock buildings, ammonia (NH_3), carbon dioxide (CO_2), carbon monoxide (CO), hydrogen sulphide (H_2S) and methane (CH_4) are the main concerns (Donham and Popendorf 1985; Gerber *et al.* 1991; Sharpe *et al.* 2002). (Tables 3 - 8).

More recently there has been renewed interest in the importance of airborne particles (dust) and airborne microorganisms (Tables 9 - 12). Dry bulb temperature, relative humidity and wet bulb temperature are still, however, the most important indicators of environmental quality (Banhazi *et al.* 2009c) (Table 1). Pad moisture is another important consideration (Table 2) (McCarthy 2008 unpublished).

4.1 Relative humidity, dry bulb and wet bulb temperature

Dry bulb temperature (DBT), relative humidity (RH), and wet bulb temperatures (WBT) are the most important environmental indicators on livestock vessels (MAMIC Pty Ltd 2000a; MAMIC 2002; MAMIC/Maunsell Pty Ltd 2004). These parameters indicate the suitability of the thermal environment for different classes of livestock.

The DBT is recorded with a thermometer that is dry when the reading is taken. WBT is measured when a damp wick is placed over the thermometer bulb. Typically, the WBT will always be less than the dry bulb temperature. However, when the air is very humid, the WBT and DBT could be quite similar (MAMIC 2002). Absolute humidity is the measure of the moisture content of the air. Relative humidity is the ratio of the moisture content to the maximum moisture content possible at that dry bulb temperature. Onboard personnel, using strategically placed thermometers and/or hand held equipment record these parameters routinely.

These parameters (particularly the wet bulb temperature) are integral to the industry heat stress risk assessment model (HSRA). This model determines a heat stress threshold (HST) for each category of livestock based on breed type, body weight, coat length, body condition and acclimatisation. An anticipated wet bulb rise (based on breed type and the ventilation rate) is applied and added to the anticipated weather conditions for the voyage in question, at that particular time of the year. Stocking density is then adjusted to ensure that the final anticipated wet bulb figure does not exceed the heat stress threshold (and/or exceed an anticipated mortality probability) (MAMIC/Maunsell Pty Ltd 2003).

Pilot work investigating the use of data logging to record temperature and humidity readings on livestock vessels (McCarthy 2003a) showed that although data loggers had proved useful in experimental situations, they were not considered to be suitable for routine use. The rationale for this was that they had no real time read out and that the downloading and collation of data was time consuming and error prone. There were concerns that this would lead to data being incorrectly interpreted.

New technology suggests that real time monitoring with computer capture is now both possible and practical. It is envisaged that these techniques could automate much of the data collection and provide alerts in terms of real time monitoring and in terms of the prediction of deck conditions based on anticipated weather (if linked to a stowage plan). Just how these techniques may be employed represents an industry knowledge gap and is an area identified for future research.

Finally, there is some recognition that livestock building designs and management might need to be changed in the future, to cope with the negative effects of expected climate change and still provide an optimal environment for the different classes of livestock (Kuczynski *et al.* 2011). This may have relevance to the livestock export industry.

Table 1: Description of temperature and humidity parameters

Important aspects	**Description**	**References**
Characteristics	Dry bulb temperature (DBT), relative humidity (RH) and wet bulb temperature (WBT) are the fundamental indicators of environmental quality on livestock vessel	(Brown-Brandl *et al.* 2005a; Eigenberg *et al.* 2005)
Detection	Mercury-based thermometers that are fixed in strategic positions throughout the vessel or hand held instruments that accompany ship staff	(Eigenberg *et al.* 2007)
Measurement	• DBT, RH, WBT are routinely measured on a daily basis at strategic positions throughout livestock vessels • Mercury based wet and dry bulb thermometers. • Digital thermometers. • Sling psychrometer. • Digital thermo hygrometers.	(Lacey *et al.* 2000; Saha *et al.* 2013)
Effects	• WBT is the key indicator of whether heat stress is likely to occur in any give category of livestock. • A WBT above the heat stress threshold (HST) for that particular category of livestock is likely to cause heat stress.	(MAMIC/Maunsell Pty Ltd 2003; Eigenberg *et al.* 2005; Salak-Johnson and McGlone 2006)
Sources of problems	External environmental conditions and ventilation issues.	(Brown-Brandl *et al.* 2003; Brown-Brandl *et al.* 2005b)
Risk factor	Slurry, wet bedding, over stocking, sub-optimal ventilation rates and/or sub-optimal ventilation design.	(Yanagi Jr *et al.* 2002; Brown-Brandl *et al.* 2005b)
Reduction or improvement	Improved ventilation and bedding management and reduced stocking rate The wetting of animals to alleviate heat stress has also been evaluated.	(Hemsworth *et al.* 1995; Gaughan *et al.* 2003 & 2005)
Acceptable levels	Varies with environmental conditions, stocking rate and ventilation rates etc. Acceptable levels are linked to heat stress thresholds (HST) inherent within the industry heat stress risk assessment model (HSRA).	(Achutan *et al.* 2001; MAMIC/Maunsell Pty Ltd 2003)
Previous publications	A number of MLA/LIVECORP publications addressing specific problems.	(MAMIC Pty Ltd 2000b; MAMIC 2002; MAMIC/Maunsell Pty Ltd 2004)
General comments	New technology allows for continuous real time monitoring and computer capture of DBT, RH and WBT. DBT, RH and WBT are interrelated.	(Pereira and Naas 2008)

4.2 Pad moisture

Pad moisture is another important measurement (but rarely measured) parameter on livestock vessels. It influences air quality and is a major determinant of the animal's environment. Pad moisture reflects the water absorbing capacity of the pad (consisting of bedding material and the manure production from the animals). The literature search, however, found very little published work with any direct application.

Manure is added to the pad continuously and the manure pad builds in terms of both weight and volume. This is key to the manure removal and stability calculations that are routinely undertaken on the vessel. It is important to recognise that much of the manure weight is actually held as water.

Unpublished work (McCarthy 2008, unpublished) established a strong and repeatable linkage between a visual bedding score (and/or pugging score) and moisture in the sheep pad on a livestock vessel. The pad moisture was measured using a soil moisture probe and these measurements were calibrated (confirmed) by oven drying the manure samples. The moisture probe proved to be accurate across the lower range of moisture levels but lacked accuracy as the moisture level increased.

The same work demonstrated a moisture profile within the sheep pad. It showed that although moisture tended to gravitate toward the bottom of the pad, layers were established that reflected the environmental conditions over the course of the voyage. If conditions were cool and dry, a dry layer would be established above which a moist layer would sit if subsequent hotter and more humid conditions were experienced. If these conditions persisted the pad would moisten to the point that moisture mixed within the pad to produce a more even moisture profile.

Further research is required to quantify both the levels and patterns of pad moisture under a range of scenarios (in both the sheep and cattle pad) to provide a better understanding of the linkages involved. This represents an identified knowledge gap and an area for future research.

The same study mentioned above sought to model the overall water balance occurring within the hold (i.e. not simply the water balance associated with the cooling of the animals). The calculations showed how the capacity for ventilation to lift moisture from the pad is quickly overwhelmed during periods of high temperature and humidity whereby animals are drinking and urinating excessively. The calculations also demonstrated that the water balance required is not about removing all the water added to the pad but more about maintaining a manure consistency that ensures animal comfort. This is particularly evident in the case in sheep where the pad is maintained for the entire voyage (except under very extreme conditions of heat and humidity). It is less important in the case of cattle whereby the pad can be removed by strategic washing events. This is discussed in more detail under the heading bedding management (see later).

Again, the literature search was not able to identify any published work with direct relevance to the unique onboard situation. Additional research is required to better understand the overall water balance equation throughout the course of a voyage in the face of a range of environmental challenges. This represents an identified knowledge gap and an area for future research.

Table 2: Description of pad moisture related issues

Important aspects	**Description**	**References**
Characteristics	If the relative humidity is high, then there is little or no capacity for the air moving through the hold to lift the moisture from the pad. This may lead to the rapid deterioration of pad quality.	McCarthy (pers. comm.)
Detection	Pad moisture levels can be measured by hand held soil moisture probes, but oven drying of bedding material is considered the most reliable (but labour intensive) way of measuring pad moisture.	
Measurement	Visual assessment based on a bedding (and/or pugging) score, that has been correlated to a specific moisture level is considered to be the most likely practical application.	(McCarthy unpublished 2008)
Effects	Sheep can became discoloured and cattle may develop dags and/or develop matted coats.	(McCarthy unpublished 2008)
Sources	High pad moisture levels generally coincide with hot weather where animals are drinking excessively (polydipsia) and consequently urinating excessively (polyuria).	
Risk factors	Hot, humid weather and sub-optimal ventilation.	
Improvements	Improved drainage. Improved ventilation levels. Improved air speed over the pad.	
Acceptable levels	As low as possible so as to maintain the comfort of the animals but not so dry as to contribute dust. N.B. There is no formal work that identifies the moisture levels associated with a good quality pad.	(McCarthy unpublished 2008)
Previous levels	There has been no formal study aimed at measuring moisture in either the sheep or cattle pads. Unpublished work completed by McCarthy (2008) established a linkage between pad moisture levels and a bedding score in sheep.	(McCarthy unpublished 2008)
General comments	There is considerable scope to use a bedding score to bolster reporting as a component of the daily reporting function for both sheep and cattle (see Reporting).	

4.3 Ammonia

There is a large body of both recent and past research that addresses NH_3. This provides the basis for a strong understanding of the effects of NH_3, critical levels and the factors that influence NH_3 emission (see below).

From an industry point of view, the most comprehensive study undertaken to evaluate the effects of NH_3 was undertaken in 2004 (Accioly *et al.* 2004). Cattle were placed in specially designed simulation rooms and atmospheric NH_3 concentrations were monitored throughout the experiments. The bronchio-alveolar lavage (BAL) performed on the experimental animals demonstrated that there was a significant increase in total white cell and mono-nucleated cell counts ($P<0.05$) in animals that stayed in rooms with elevated NH_3 concentrations (42.3 ± 2.8 ppm). However, lower levels of NH_3 concentrations (22.0 ± 1.6 ppm) had no detectable effects on the experimental animals (Accioly *et al.* 2004).

The industry maximum safe level of NH_3 exposure, is drawn from the Australian Animal Welfare Standards for the Export of Livestock (Review of ASEL - Iesag) and is also stated in the Australian Standards for the Export of Livestock (ASEL). The limit is 25ppm (as a time weighted value). This is supported by the industry research (Costa *et al.* 2003)). This is the same level recommended by SafeWork Australia (http://www.safeworkaustralia.gov.au/ sites/SWA/about/ Publications/Documents/639/Workplace_Exposure_Standards_for_ Airborne_Contaminants.pdf) in humans. Other research (Donham 1991), has suggested much lower levels for both animal and human health in 'other' intensive livestock industries, but this considers the combined effects of dust and NH_3 together. This suggests that the NH_3 debate is still very much open. It is important to note that there is an inconsistency in the way in which NH_3 levels are described and/or interpreted. Whilst certain levels are reported to affect production, this is distinct from levels that are considered to cause animal health problems and different again to levels that are thought to be critical to animal welfare. Levels can also be expressed as time-weighted levels and/or as maximum (single point) critical levels. The literature is not always explicit in this regard.

Methods to mitigate NH_3 production and release are well described in the literature. This includes the use of citric acid in bedding, gypsum as a feed additive and more generally limiting protein levels in the feed (Tudor *et al.* 2003). These measures can be used to counter problems as they arise (Rong *et al.* 2014). NH_3 emission rates are related to floor type and manure-handling method (Zhang *et al.* 2005; Pereira *et al.* 2011; Philippe *et al.* 2011)

The effects on human health are equally as important and critical levels are likely to be driven equally from the point of view of occupational health and safety. People exposed to airborne pollutants (including NH_3) (Pedersen *et al.* 2001; Wenger *et al.* 2005) have demonstrated increases in morning phlegm production, coughing, scratchy throat, burning eyes, wheezing, shortness of breath, chronic bronchitis, and decline in lung function when compared with individuals who are not agricultural workers (Schwartz *et al.* 1995; Mackiewicz 1998; Asmar *et al.* 2001; Laitinen *et al.* 2001; Radon *et al.* 2001).

Table 3: Description of ammonia related issues

Important aspects	**Description**	**References**
Characteristics	Colourless gas with distinctive pungent odour.	(Banhazi *et al.* 2007; Banhazi and Hillyard 2009; Banhazi *et al.* 2009a)
Detection	NH_3 gas has a fairly typical smell, but detection should not be relied on by human senses alone.	(Bjerg *et al.* 2013a; Bjerg *et al.* 2013b; Bjerg *et al.* 2013c)
Effects	• Strong irritant of mucosal tissue. • Causes inflammation of the respiratory tract. • Predisposes the lung to respiratory disease by lowering the natural defence toward infection. • May also reduce growth rate. • Concentrations of NH_3 above 35 ppm (in cattle) have been shown to result in inflammatory changes in the wall of the respiratory tract and the reduced bacterial clearance from the lungs. • May interact with respirable dust, microbial particles and endotoxins. • NH_3 is lighter than air and tends to rise towards the ceiling – potentially contributing to the corrosion of ceiling materials.	(Drummond *et al.* 1980; Gustin *et al.* 1994; Urbain *et al.* 1994; Urbain *et al.* 1996a; Urbain *et al.* 1996b; Urbain *et al.* 1996c; Urbain *et al.* 1998; Accioly *et al.* 2004; Lee *et al.* 2005; Murphy *et al.* 2012; Banhazi 2013c)
Measurement	Traditionally NH_3 has been measured as a single point daily using hand held equipment. Continuous measuring techniques (that can be mounted in strategic places throughout the vessel) exist but they require mains power and are relatively expensive (see Gas measurement methods).	(Banhazi 2009b; Banhazi 2012)
Sources	NH_3 is produced as a result of chemical/microbiological breakdown of waste material (urine and faecal material). Emissions are usually episodic.	(Groot Koerkamp *et al.* 1998)
Risk factor	• Increased pH, inadequate air movement and high temperatures. • Reduced hygiene and waste removal frequency. • Sub-optimal ventilation rates. • High protein levels within feed. • Roughage with low digestibility.	(Groenestein *et al.* 2007; Banhazi *et al.* 2008d; Bjerg *et al.* 2013c; Rong *et al.* 2014)
Reduction	• Regular effluent removal and cleaning. • Dietary manipulation to lower protein levels. • Citric or acetic acid as a bedding additive • Improved ventilation. • The use of feed additives (e.g. gypsum). • Slurry activators can be used to reduce the pH of the slurry. • Cooling of slurry can be used to reduce evaporation.	(van 't Klooster *et al.* 1993; Shi *et al.* 2001; Hyde *et al.* 2003; Zhang *et al.* 2005; Groenestein *et al.* 2006; Gilhespy *et al.* 2009; Bjerg *et al.* 2013c)

Acceptable levels	Industry studies (Costa *et al.* 2003) suggest that NH_3 levels above 25ppm as a time weighted measure, are harmful to animals and should be avoided. This is consistent with SafeWork Australia recommendations for exposure in humans. (http://www.safeworkaustralia.gov.au/) workplace exposure standards for airborne contaminants (22nd December 2011). The stated short-term exposure limit is 35ppm. Other studies suggest slightly lower levels. (Donham 1991; Pines *et al.* 2005; Greer 2007; Phillips *et al.* 2010, 2012).	(Costa *et al.* 2003; Pines *et al.* 2005; Phillips *et al.* 2010, 2012; Pines and Phillips 2013)
Previously measured levels	Typical levels on vessels were 15ppm with readings sometimes above 50ppm. On board work, and work under simulated conditions suggests that NH_3 levels rarely exceed 20ppm (McCarthy 2003b, 2003a; Pines and Phillips 2011; Pines *et al.* 2013; Pines and Phillips 2013), particularly on the newer better-ventilated vessels.	(Attwood et al., 1987)

In regards to human health, a number of studies have suggested that NH_3 combined with components of the microorganisms (such as endotoxins) carried by dust particles can trigger acute health effects in individuals working in livestock buildings (Clark *et al.* 1983; Schwartz *et al.* 1995; Zhiping *et al.* 1996). Work-related respiratory symptoms, such as chest tightness and nasal and eye irritation, were reported by 23 of the 29 workers (approx. 80%) in an European study (Crook *et al.* 1991). It appears that repeated exposure to both gases and particles while working in animal buildings can cause respiratory complications, such as oedema and collagen deposition in the lung tissues (Asmar *et al.* 2001). Studies have confirmed that exposure to airborne pollutants in livestock environments alters lung function and cytokine levels in the blood (Palmberg *et al.* 2002; Von Essen and Romberger 2003). These findings emphasise the importance of NH_3 levels in regards to occupational health and safety.

A number of studies have demonstrated the effects of sub-optimal air quality (NH_3) on production efficiency in a variety of livestock species (Donham 1991; Urbain *et al.* 1994). Again, it is difficult to isolate the negative effects of one single airborne pollutant, as the observed health or productivity improvement tends to be associated with the reduction of a number of different airborne pollutants. Additionally a number of authors have asserted that the negative impacts of sub-optimal air quality are associated with the combined effects of a number of airborne pollutants acting in concert to impact on the respiratory system in both humans and animals (Donham 1991; Donham *et al.* 2000; Banhazi 2013c).

It has been demonstrated that animals, including pigs reared in clean environments (with better air quality) grow faster than pigs living in commercial farm buildings with sub-optimal air quality. In one study, a 6% growth rate improvement was associated with a 17% reduction in the count of viable bacteria, a 51% reduction in respirable particles, and a 69% reduction in NH_3 concentration (Banhazi 2013c). Some authors have reported growth rate reductions in pigs exposed experimentally to various levels of NH_3. Pigs exposed for 4 weeks (immediately after weaning at the age of 27 or 28 days) to 0, 50, 100, or 150 ppm NH_3 and a filtered air mixture showed growth rate reductions of 0%, 12%, 30%, and 29%, respectively (Drummond *et al.* 1980). However, recent results from the UK have demonstrated no effect of NH_3 on production efficiency at concentrations of 37 ppm (Wathes *et al.* 2004). Both pigs and poultry have been observed to have a natural aversion to NH_3 (Jones *et al.* 1998; Jones *et al.* 2000; Kristensen *et al.* 2000; Wathes *et al.* 2002).

It is worth noting that the industry has yet to monitor NH_3 levels on a continuous (time weighted) basis and has conducted very little formal monitoring since 2003. At that time, NH_3 was measured on a single point daily basis using hand held equipment (MAMIC Pty Ltd 2000a; MAMIC/Maunsell Pty Ltd 2004). Monitoring equipment is now more sophisticated. Continuous measuring techniques exist but the equipment requires mains power and is relatively expensive.

Further research that determines NH_3 levels over time (using the equipment described later) would be informative. It would also demonstrate (and or confirm) the episodic nature of NH_3 emissions and the links to the factors evolved. This, combined with a better understanding of pad moisture (and the pad generally) would facilitate a better understanding of the cause and effect in the on-board situation.

Furthermore, if the industry wishes to use a time-weighted average as its benchmark, it should be able to demonstrate the effect of NH_3 not simply on the basis of a single point level but also in terms of duration of exposure.

4.4 Carbon dioxide

CO_2 is monitored mainly as an indicator of ventilation efficiency (Barber et al., 1993). Very high CO_2 levels indicate either the shed is overpopulated or the ventilation system is inadequate for the population size. Concentrations of CO_2 is of interest to livestock managers, as it is widely used to estimate ventilation rates within livestock buildings (Banhazi *et al.* 2011b).

CO_2 was measured extensively during the industry ventilation studies and subsequent research (MAMIC Pty Ltd 2000b; MAMIC/Maunsell Pty Ltd 2004). Levels generally were low (less than 600ppm) and CO_2 was used primarily to detect less ventilated areas within the livestock holds on livestock vessels. Levels above 1500ppm were indicative of poor ventilation. Table 4 summarises the main issues related to CO_2 concentrations.

Table 4: Description of carbon dioxide related issues

Important aspects	Description	References
Characteristics	Heavier than air and therefore tends to accumulate at animal level.	(Pedersen *et al.* 1998; Banhazi *et al.* 2011d)
Detection	Can be detected in a variety of ways (Parrish and Fehsenfeld 2000; Monn 2001; Phillips *et al.* 2001). Measurement system will be described later in this report, but infrared sensors are usually effectively used for CO_2 detection.	(Jeppsson 2002; Banhazi 2009b; Banhazi *et al.* 2011d; Kiwan *et al.* 2013)
Effects	Can cause tiredness and lethargy that ultimately can result in reduced feed intake. Increased prevalence of respiratory disease has been associated with levels above 1500 ppm.	(Donham 1989; Donham *et al.* 1989; NOHSC 1995)
Sources	Produced mainly by the animals as the natural product of respiration. Smaller amount is produced as a by-product of bacterial breakdown of waste material.	(Ni *et al.* 1999).
Risk factors	• High stocking rates. • Reduced ventilation. • Heightened animal activity. • Short-circuiting, recirculation.	(Jeppsson 2000)
Reduction	Reduced stocking density and improved ventilation levels.	(Seedorf *et al.* 1998a)
Acceptable levels	In livestock building, levels of less than 1500-2000 ppm are suggestive of adequate ventilation with a level of 3000 ppm (TWA) being the acceptable maximum. N.B. This relates to ventilation rather than occupational health and safety. SafeWork Australia states a maximum time weighted value of 5,000ppm and 30,000ppm in reference to occupational health and safety. (http://www.safeworkaustralia.gov.au/)	(Donham 1991; Donham 1995; Donham *et al.* 1995; Donham *et al.* 2000)
Previously published levels	600ppm in piggery buildings. Similar levels (600ppm) were recorded in the industry ventilation study.	(Pedersen *et al.* 1998; Banhazi *et al.* 2011d) (MAMIC Pty Ltd 2000b; MAMIC/Maunsell Pty Ltd 2004).
General comments	Ambient air naturally contains 300 - 400 ppm of CO2 gas. Carbon dioxide (together with methane and nitrous oxide) emitted from agricultural buildings is considered to be part of 'Greenhouse gas' (GHG) emission load of the animal operation.	(Sommer and Moller 2000)(NOHSC, 1995)
GHG emission	This gas is also of concern in relation to global warming.	(Phillips *et al.* 1998)

4.5 Methane

Methane (CH_4) is a colourless gas that is increasingly studied in relation to greenhouse emission contribution of livestock operations. It is not thought to contribute to animal health problems on livestock vessels. Low concentrations are not harmful. The main issues associated with methane gas are summarised in Table 5.

Table 5: Description of methane related issues

Important aspects	Description	References
Characteristics	Colourless, odourless gas.	(Flessa *et al.* 2002; Beauchemin *et al.* 2010)
Detection	Requires specialised monitoring equipment.	(Ngwabie *et al.* 2009; Hassouna *et al.* 2013; Rong *et al.* 2014)
Effects	Does not pose a threat to either animal or human health on-board of livestock vessels, but could significantly contribute to the overall GHG emission of live animal transport operations. https://www.ccohs.ca	(Beauchemin *et al.* 2010)
Sources	Manure and digestive system of animals.	(Misselbrook *et al.* 2001; Aarnink and Verstegen 2007)
Risk factors	Reduced ventilation rates for high indoor concentrations, inappropriate manure management systems.	(Sommer and Moller 2000; Sandars *et al.* 2003)
Reduction	Improved ventilation system and manure management procedures.	(Philippe *et al.* 2007; Philippe and Nicks 2015)
Acceptable levels	Not generally considered a problem for health reasons, but it is important to keep low indoor concentrations for safety and environmental reasons. SafeWork Australia makes no reference to Methane but recommends levels below 0.1 ppm on a time-weighted basis for both tetrabromomethane and tetrachloromethane. (http://www.safeworkaustralia.gov.au/)	(Webb *et al.* 2001)
Previous levels	Benchmarking of methane levels on livestock vessels yet to be undertaken.	(Flessa *et al.* 2002; Ngwabie *et al.* 2009; Beauchemin *et al.* 2010)
Comments	Renewed interest in methane reduction due to the carbon science.	(Sandars *et al.* 2003)

4.6 Hydrogen sulphide

Hydrogen Sulphide (H_2S) is a highly poisonous gas and levels above 5 ppm are of concern. Most industries aim for zero tolerance. There is no evidence that H_2S is found in any significant quantities on livestock vessels, but because of its importance in relation to OH&S matters; this gas is reviewed below (Table 6).

Table 6: Description of hydrogen sulphide related issues

Important aspects	Description	References
Characteristics	Dangerous, colourless, flammable gas with an offensive odour resembling rotten eggs. No previous indications that it is a problem on livestock vessels.	(Ni *et al.* 2002a)
Detection	Gas tubes can be used effectively but more precise measurement systems are also available	(Parbst *et al.* 2000; Ni *et al.* 2002a)
Effects	• Concentrations of 20ppm cause reduced feed intake and increased stress in livestock. • In humans, levels between 10 and 20 ppm caused eye and upper respiratory tract irritation. • Concentrations between 50 and 100 ppm cause vomiting, nausea and diarrhoea. • Concentrations greater than 100 ppm can cause unconsciousness and death.	(Gerber et al, 1991) (Donham, 1995)
Sources	Slurry is the major source.	(Ni *et al.* 2002b)
Risk factors	Agitated slurry in a confined area.	(Ni *et al.* 2002a)
Reduction	Regular removal of manure will eliminate opportunities for the production of this gas.	(Assaad Abdelmseeh *et al.* 2008)
Acceptable levels	Earlier work suggests levels below 5ppm but levels of less than 10 ppm as a time weighted average (TWA) and 15ppm as short-term exposure limit (STEL) are recommended by SafeWork Australia. (http://www.safeworkaustralia.gov.au/)	(NOHSC, 1995).
Previous levels	Limited information within the industry studies.	(Ni *et al.* 2000; Ni *et al.* 2002b) (MAMIC, 2000)

Hydrogen sulphide would not appear to be a problem on livestock vessels. However, workers have described symptoms of fatigue and shortness of breath after working in some of the more confined livestock areas within livestock vessels (industry pers. comm.). It is possible that hydrogen sulphide is a contributing factor. Because of the dangerous nature of this gas it is suggested that industry remain pro-active and continue to monitor levels and assess workers for possible effects from the point of view of health and safety.

4.7 Carbon monoxide

Carbon monoxide (CO) can be lethal in very small quantities, so its presence in vessels is unacceptable. Because it is colourless and odourless it has no inherent warning properties. It is not normally associated with diesel or heavy oil powered engines. It could become an issue if any of the new vessels opt to gas power their engines. In this situation, adverse wind conditions could lead to the ingestion of engine exhaust into supply vents. The main issues related to carbon monoxide are detailed in Table 7.

Table 7: Description of carbon monoxide related issues

Important aspects	**Description**	**References**
Characteristics	Highly poisonous colourless and odourless gas.	(Donham and Popendorf 1985)
Detection	Detection systems are available, but simple gas tubes can be used effectively.	(Wilhelm *et al.* 2001; Fung and Wong 2002)
Effects	• Binds to the haemoglobin reducing the oxygen carrying capacity of the blood. • At higher concentration death can quickly occur, before the victim realises, what is happening. • Continuous exposure to low levels can cause impaired judgement, visual perception in humans and can affect the central nervous system.	(Fung and Wong 2002)
Sources	Incomplete combustion of fuels such as wood, gas, coal and kerosene.	(Gerber et al, 1991)
Risk factors	Sub-optimally performing gas burners or exhaust gases drifting into the decks through ingestion into supply vents.	(Donham and Popendorf 1985)
Reduction	Adequate ventilation and using well maintained gas burners.	(Donham and Popendorf 1985)
Acceptable levels	SafeWork Australia states a TWA upper level of 30ppm. (http://www.safeworkaustralia.gov.au/) Given the highly toxic nature of this gas industry should aim for zero levels.	(Wilhelm *et al.* 2001)
Previous levels	Carbon monoxide has as not been measured in the livestock export situation. 9ppm (in ‘other’ intensive livestock industries).	(Donham and Popendorf 1985)

4.8 Gas measurement methods

4.8.1 Practical measurement methods for use on livestock vessels

Studies often utilise **gas-sampling tubes** for the measurement of gas concentrations (Williams 1995; Hinz and Linke 1998; Jones *et al.* 2000; Chang *et al.* 2001; Górecki and Namiešnik 2002; Guy *et al.* 2002; Misselbrook *et al.* 2002; Nicholson *et al.* 2002). These glass tubes contain a sorbent that reacts with the specific gas being sampled (Górecki and Namiešnik 2002). This technique relies on the diffusion of gas drawn through the glass tube and on the reaction with the sorbent to determine gas concentrations. In order to determine the gas concentrations, the two ends of the glass tube are typically broken off and ambient air is drawn through the sampling tubes using a sampling pump. These tube samplers are valuable for taking short-term spot measurements in animal housing to detect localised gas concentrations.

There are also **passive samplers** available for long term (4-8 hours) sampling. These are worn as a badge and gases are allowed to diffuse without the need for pumps to draw the ambient air. Various other badge type passive samplers are also available. This method is inexpensive. It does not require costly machinery but it does not give any more information than a time weighted average (TWA) or an instantaneous spot measure. This technique would be suitable for back-up measurements or to gain supplementary data.

Non-dispersive infrared (NDIR) gas analysis involves exposing the gas sample to a beam of infrared light. The gas will then absorb light of a certain wavelength. The strength of the signal is then compared to that of a reference signal, which has not been exposed to the gas sample. The difference between the two is then used to calculate the gas concentration (Phillips *et al.* 2001). A range of gases can be measured using NDIR, and this method is especially suitable and considered to be very accurate for the measurement of CO_2 concentrations (Ouellette *et al.* 1999; Jeppsson 2002). This technique is also reasonably priced (Banhazi 2009b) and for this reason this technique is favoured over others for the measurement of CO_2 concentration. Sensors of this type can also be attached to data-loggers to collect significant amounts of continuous information that can be stored and analysed later.

Sometimes **electrochemical** cells are used to monitor gases containing an electrolyte and a series of electrodes (Phillips *et al.* 2001). Gas is usually drawn through a membrane into the electrolyte of the cell. While in the cell the gas creates an electric potential which is measured and is used to determine the concentration of the gas. Different electrochemical techniques exist and are quite popular for the determination of gas concentration, particularly NH_3 (Hinz and Linke 1998; Ouellette *et al.* 1999; Banhazi 2009b). This technique is reasonably common and gas sensors of this type are relatively inexpensive and are moderately accurate.

4.8.2 Other measurement options

A wide variety of **spectroscopic techniques** exists (Ragunathan *et al.* 1999) but most are unsuitable for onboard measurements due to their lack of portability. In addition, these measurement systems are typically very expensive (Mennen *et al.* 1996; Phillips *et al.* 2001). Thus, this method is unlikely to be a suitable system for studies conducted on livestock vessels. Chemiluminescence detector can accurately measure NH_3 concentrations and these sensors are often used in scientific studies (Groot Koerkamp *et al.* 1998; Phillips *et al.* 2001) requiring precision measurements (Phillips *et al.* 1998; Sommer *et al.* 2001). Chemiluminescence detectors are accurate, but are unfortunately very expensive (Phillips *et al.* 2001),thus highly unlikely to be used for on-board studies. **Wet chemistry** methods are also available for the determination of gas concentrations, but these methods could not be used as part of a computerised and sensor based monitoring system. Wet chemistry techniques do require the collection and storage of the gas sample as well as a suitably equipped laboratory to process the samples.

4.8.3 Summary of gas measurement techniques

In conclusion, there are a wide variety of methods available for the measurement of gas concentrations in the air. Different specific techniques are better suited to different gases and different operational requirements. The electrochemical sensors for NH_3 and NDIR for CO_2 are suitable as they are relatively accurate, easily managed, provide near real-time continuous measurements and are relatively inexpensive. Passive sampling tubes are also valuable tools, as they are inexpensive and easily managed.

From an operational point of view, it is necessary to have a method for determining gas levels that is easily maintained and operated in the field. A balance needs to be achieved between the cost, the utility and the level of accuracy desired. The use of an electrochemical sensor to detect NH_3 and an IR sensor to detect CO_2, connected to a data logger would provide accurate and responsive sensing and the ability to collect a large amount of data over a long time period (Banhazi *et al.* 2012).

Table 8: Equipment that can be used for environmental gas measurements and detection

Equipment	Reference	Comments
Dräger tubes	http://www.gas-detectors.com.au/images/file/Detector_Tubes_081209.pdf	Practical spot measurement
Infrared sensors	http://www.vaisala.com/en/products/carbondioxide/Pages/default.aspx	Reliable measurements systems
Electrochemical sensors	http://www.draeger.com/sites/assets/PublishingImages/Products/cin_x-zone_5000/US/gas-detection-br-9041145-us.pdf http://www.draeger.com/sites/en_aunz/Pages/Chemical-Industry/Draeger-Polytron-7000.aspx	Available measurements systems
Portable detectors	http://www.gastech.com.au/products/gas-detectors-portable/multi-gas	Variety of hand held instruments
Experimental instruments	(Banhazi 2009a; Banhazi 2009b; Clements *et al.* 2011)	Semi commercial instrument

Secondary to this technology could be the use of passive sampling tubes as they are relatively inexpensive and give a virtually instantaneous reading. Table 8 lists some of the equipment that can be used for environmental measurements in livestock buildings and vessels.

4.9 Airborne particles

Airborne particles (or dust) are important pollutants found in many livestock buildings (Pedersen *et al.* 2000; Banhazi *et al.* 2008e; Banhazi *et al.* 2011c; Banhazi 2013b). Although, virtually no information is available on the concentrations of airborne particles measured in livestock vessels, it is assumed that airborne particles can pose a problem in livestock vessels as well. Airborne dust is measured as PM (micrometres) or µm (mg/m^3 of air) and is classified in several ways, according to particle size (Table 10).

Apart from the direct detrimental health effects of the airborne particles, these pollutants also act as a carrier for many of the noxious gases as well as remnant microorganisms (Takai *et al.* 2002; Banhazi *et al.* 2009d; Banhazi *et al.* 2009e). Cell wall components of dead and decaying bacteria (endotoxins and 1,3 beta-glucans) can be absorbed onto the dust particles and carried into the lungs (Takai *et al.* 2002; Banhazi *et al.* 2009d; Banhazi *et al.* 2009e). Dust also plays an important part in odour management (Williams 1989; Liao *et al.* 2000; McCarthy 2003a; Lee and Zhang 2008). The issues related to airborne particles are presented in Table 9.

Table 9: Description of dust/airborne particle related issues

Important aspects	**Description**	**References**
Characteristics	Airborne dust is measured and classified according to particle size and has different health impacts.	(Banhazi *et al.* 2009e)
Detection	Standard measurement instrumentations using gravimetric methods but photo-optic systems are readily available.	(Seedorf and Banhazi 2006; Banhazi *et al.* 2008d)
Effects	• Engage the immune system, initiating physiological changes in the animal, which lead to reduced growth and increased level of respiratory diseases. • Can be responsible for failure of electrical equipment such as fans. • Compromises the respiratory health of humans.	(Whathes *et al.* 1983; Rylander 1985; Carpenter 1986b, 1986a; Donham *et al.* 1989; Robertson 1992; Donham and Thorne 1994; Donham *et al.* 1995; O'Shaughnessy *et al.* 2009)
Sources	Diverse mixture of different organic and inorganic material including; bacteria and bacteria cell wall components, mites, skin	(Curtis *et al.* 1975; Carpenter 1986b; Accioly *et al.* 2004; Banhazi *et al.*

	flakes, undigested nutrients, feed particles, dried urine and dung, mites and fungal spores from feed.	2009d; Banhazi *et al.* 2009e)
Risk factors	Work activities, such as feeding, sweeping, moving animals. Low humidity as well as very high levels of ventilation and seasonal variations.	(Takai *et al.* 1998; Radon *et al.* 1999; Pedersen *et al.* 2000; Banhazi *et al.* 2008e)
Reduction	Washing pens, floors, walls and ceilings. Adding oil to the diet. Spraying area with oil and water mixture Fogging, showering and misting sheds. Modifying ventilation systems.	(van 't Klooster *et al.* 1993; Takai *et al.* 1995; Gustafsson 1999; Ellen *et al.* 2000; Takai and Pedersen 2000; Banhazi *et al.* 2011c)
Acceptable levels	The maximum acceptable level in intensive livestock buildings for respirable dust is 0.23 mg/m^3 and 2.4 mg/m^3 for total dust.	(Donham 1991; Donham *et al.* 1995)
Previous levels	No information is available on livestock vessels.	

4.10 Measurement of airborne particles

Dust can be measured by a variety of methods, such as photo-optical (light-scattering), gravimetric, Tapered Element, nephelometer and beta meter (Monn 2001). Different methods are better suited to different sampling regimes. For example, in human dust exposure assessment, it is desirable to target the specific dust size directly involved in biological mechanisms (Görner *et al.* 2001). Thus different techniques will be more applicable in some areas than others (Jacobs 1994; Pedersen *et al.* 2001)

4.10.1 Practical measurement methods for use on livestock vessels

Gravimetric analysis involves the collection of a sample of dust from the air. This is collected on a filter paper of known weight. The difference between the final and initial weights gives a total weight of dust measured over a known time period. This can be used to determine an average exposure. Gravimetric analysis can be used to record a variety of particle sizes (Jacobs 1994), and thus target the particle size most related to the desired outcomes of the study. For example, **cyclone samplers** selectively measure the respirable fraction of dust and are essentially the industry standard for the measurement of this dust fraction (Nieuwenhuijsen *et al.* 1999; Gao *et al.* 2000; Chang *et al.* 2001; Lumes and Spee 2001).

Table 9: Methods of measuring different airborne particle fractions and potential animal health impacts.

	Total dust fraction	Inhalable dust fraction	Thoracal dust (PM_{10}) fraction	Respirable fraction	Very fine fraction ($PM_{2.5}$)
Cut-off size	> 100 μm	100 μm	10 μm	4 μm	**2.5 μm**
Short definition	All particles suspended in air	Mass fraction of total airborne particles which is inhaled through the nose and mouth	Fraction of inhaled particles which penetrate beyond the larynx	Mass fraction of inhaled particles which penetrate to the bronchiole and alveolar parts of the lungs	**Penetrate the gas exchange parts of the airways and the vascular system**
Detection method	Open face filter connected to a sampling pump or a real time dust monitor	IOM or "seven-hole" samplers connected to a sampling pump	Real time dust monitor with a PM_{10} inlet; gravimetric sampling with impaction or cyclone pre-separator	Gravimetric sampling with a cyclone pre-separator or a real time dust monitor with a cyclone pre-separator	**Real time dust monitor with a $PM_{2.5}$ inlet; gravimetric sampling with impaction or cyclone pre-separator**
Health issue	**Allergies, sinusitis, irritation of mucous membranes of eyes and nose**	**Allergies, bronchitis and irritation of mucous membranes of eyes and nose**	**Asthma, bronchitis**	**Adverse impact on respiratory and /or cardio-vascular system including allergies and asthma**	**Adverse impact on respiratory and/or cardio-vascular system including asthma**

*Sources: (Seedorf *et al.* 1998b; Takai *et al.* 1998; Tucker 2000; Pedersen *et al.* 2001; Donham and Thelin 2006; Hofschreuder *et al.* 2007)

Cyclone samplers sort the dust particles by size using a "vortex" effect (Pant *et al.* 2002). These are designed so there is a constant flow of air being drawn into the sampler, a vortex is formed by air passing through the conical shape of the filter housing. This vortex sorts the different sized particles, selecting the smaller respirable fraction.

The **IOM (Institute of Occupation Medicine) and Seven Hole Sampler (SHS)** samplers collect the "Inhalable" fraction of dust and are frequently used in the assessment of dust concentration (Niven *et al.* 1998; Kenny *et al.* 1999; Nieuwenhuijsen *et al.* 1999; Ouellette *et al.* 1999; Soutar *et al.* 1999; Kenny and Ogden 2000; Fishwick *et al.* 2001; Kenny *et al.* 2001; Liden and Bergman 2001; Pedersen *et al.* 2001). The technique draws sampled air across the filter media at a rate of 2L/min-1. In field trials these two samplers were found to give virtually the same results when placed in a side-by-side comparative trial (Vaughan *et al.* 1990).

Optical particle counters have only developed since the early 20th century (Kerker 1997), and rely upon the theory of light scattering by individual particles (Spurny 1998). Optical counters have evolved from using incandescent globes as the light source to using lasers. Optical particle counters have also evolved to include the ability to determine a particle size distribution (Spurny 1998). Increasingly these instruments are becoming widely available and accurate enough to warrant on-farm use (Seedorf and Banhazi 2006; Banhazi 2013d). Thus, these instruments might be suitable for on-board measurements on livestock vessels (Sioutas *et al.* 2000; Hand *et al.* 2002).

4.10.2 Other measurement options

Determining the particulate matter concentrations with a **Tapered Element Oscillating Microbalance** (TEOM) involves measuring the change in the rate of oscillation of a tapered element (Walton and Vincent 1998; Cyrys *et al.* 2001). The TEOM is considered to be an internationally recognised method for the measurement of PM_{10} (micrometres) dust (Artaxo *et al.* 1999; Soutar *et al.* 1999; Sloss and Smith 2000) and is used as a standard for comparison with other methods (Muraleedharan and Radojevic 2000; Baldauf *et al.* 2001). These devices are very expensive and require regular maintenance, which would make this method unsuitable for measuring dust levels on livestock vessels. **Light detection and ranging (LIDAR)** can be accurately used to track the PM_{10} dust fraction (Holmen *et al.* 1998; Holmen *et al.* 2001a, 2001b). The requirement for the broad scale application of LIDAR is likely to preclude its use from livestock vessels.

4.10.3 Summary airborne particle measurement techniques

Dust levels can be measured in a variety of ways. For comparative studies, the use of continuous monitoring equipment, such as light scattering devices is an attractive option (Seedorf and Banhazi 2006). These devices utilise photo-optical techniques and are able to demonstrate relative differences between treatments. The relative accuracy of these devices has also been improving at an exponential rate so these dust monitoring devices are suitable for inclusion in on-board monitoring systems. If highly accurate dust measurements are required that are also comparable with international standards; the use of IOM or SHS samplers for inhalable dust and cyclone samplers for respirable dust are considered to be most appropriate. However, these measurement methods still rely on laboratory equipment (Precision micro-balance) that is complex to operate. Thus the incorporation of a continuous dust measurement method into onboard monitoring systems should be considered in the future (Banhazi and Hillyard 2009; Banhazi 2009b).

The best method will always be a compromise between different, sometimes opposing considerations. The level of accuracy, practicality and reliability should be balanced with the cost of the chosen device. Table 11 lists some commercially available instruments.

Accurate measurement of gas and dust concentrations at animal confinement facilities, including livestock vessels is essential for ensuring a high level of animal welfare and worker safety are achieved. The risk associated with exposure to airborne pollutants for humans and livestock has recently been reviewed (Banhazi *et al.* 2009d; Banhazi *et al.* 2009e).

Impaired lung function in farm workers (Donham and Cumro 1999a; Ormstad 2000; Pedersen *et al.* 2001) and reduced production efficiency as well as increased susceptibility for respiratory diseases in livestock (Hartung and Seedorf 1999; Pedersen *et al.* 2001) have been reported by a number of authors as a result of exposure to high levels of airborne pollutants found in livestock buildings.

Table 10: Equipment that can be used for environmental dust measurements and detection

Equipment	Reference	Comments
Osiris	http://www.turnkey-instruments.com/environment.php?id=8	Photo-optical instrument
DustTrak™	http://www.tsi.com/dust-monitors/	Photo-optical instrument
Gravimetric measurements	http://www.acu-vib.com.au/gilian-air-sampling-pumps.htm?gclid=CLiQxqOqhMYCFVJvvAodFDsAPQ	Industry standard instruments
Dust filter holders	http://airsamplingsolutions.com/index.php/airsampling/other-sampling-heads/ http://airsamplingsolutions.com/index.php/airsampling/respirable-dust-fraction-sampling-heads/ http://www.3-a.co.uk/product-details.asp?Auto_ID=138	Industry standard instruments
Microbalances	http://sartorius.balances.com/sartorius/sartorius-micro-balances.html	Gravimetric measurement of dust filters
Experimental instruments	(Banhazi 2005b, 2005a; Banhazi and Berckmans 2008)	Semi commercial instrument

Dust is also acknowledged as being involved in the transmission of disease agents between buildings and potentially between farms (Stärk 1999). Excessive exposure to NH_3 has had a detrimental effect on animal health (Hayter and Besch 1974; Van Wicklen *et al.* 2001; Guy *et al.* 2002). The combination of dust and NH_3 exposure greatly increases the risk of developing human health problems (Curtis *et al.* 1975; Robertson 1992; Robertson 1993; Donham and Cumro 1999b; Sigsgaard *et al.* 1999). It is therefore necessary to accurately measure the concentrations of important airborne pollutants, such as dust and noxious gases to ensure a safe and healthy working environment. A variety of methods are available to measure each of these environmental variables (Banhazi and Hillyard 2009).

Dust can be an underrated air pollutant, particularly on board livestock vessels where the focus is generally on keeping the pad as dry as possible. It is suggested that dust should be monitored from a research perspective on sufficient voyages to determine typical levels under a range of scenarios.

4.11 Airborne microorganisms

Although airborne microorganisms have been measured it is only recently that it has been demonstrated that even though microorganisms may be dead, their cell wall components may trigger harmful immune reaction in host animals. The population of airborne microorganisms is made up of different bacteria and fungi. The majority of bacteria in animal buildings are gram-positive bacteria and are non-pathogenic, while the rest are dead or decaying (Seedorf *et al.* 1998b; Banhazi *et al.* 2004). However, as mentioned, the cell wall components of dead (remnant) bacteria are just as capable of engaging the immune system of pigs and humans as viable bacteria (Fogelmark et al., 1994; Gustin et al., 1994)(Seedorf *et al.* 1998b).

Table 11: Description of viable airborne particle and endotoxin related issues

Important aspects	**Description**	**References**
Characteristics	Majority of bacteria in animal buildings are gram-positive bacteria and are non-pathogenic.	(Urbain *et al.* 1999)
Detection	Viable microorganisms are usually measured by using the six stage Anderson bacterial impactor and a standard air pump.	(Phillips *et al.* 1998; Seedorf 2004)
Effects	Increased prevalence and severity of respiratory diseases. Activate an immune response in the epithelial cells and alveolar macrophages. Modifies the cell population present in the respiratory tract. Reduced food and water intake elevates body temperature, heart rate and respiration rate.	(Murphy *et al.* 2012) (Almond et al., 1996) (Fogelmark et al., 1994) (Kelly et al, 1987; Klasing et al, 1987; Klasing and Barnes, 1988) (Robinson, 1994) (Fogelmark et al, 1994) (Almond et al, 1997).
Sources	Inefficient effluent removal and lack of general hygiene, feed, bedding material may also contribute to elevated levels.	(Gordon, 1963)
Risk factors	High stocking density. Low temperature and high humidity. Dust.	(Butera et al, 1991).
Reduction	Reduced stocking rate and population size. Improved ventilation (without dust). Improved general hygiene and efficient effluent disposal.	
Acceptable levels	Total airborne bacteria should be less than 100 000 CFUs per cubic metre. Streptococci species should be less than 20 000 CFUs per cubic metre. Fungal particles should be less than 10 000 CFUs per cubic metre. Endotoxin level is recommended to be less than 0.08 ng per cubic metre of air for humans.	(Butera et al., 1991) (Cormier et al., 1990) (Curtis et al., 1975b) (Gordon, 1963) (Martin et al., 1996) (Thorne et al., 1992). (Bäckström and Jolie 1996)
Previous levels	Endotoxins levels from 10 to 60 times recommended levels have been recorded in livestock buildings.	(Bäckström and Jolie, 1996).

At present, three different types of cell wall components are regarded as important. Endotoxins, 1,3 beta-glucan and peptidoglycan are the cell wall components of gram negative bacteria, gram positive bacteria and fungi, respectively.

Airborne microorganisms are removed by coagulation, sedimentation, and impaction and by exhaust ventilation. It is important to understand that microorganisms are not removed by death, because, (as mentioned before) their cell wall components are just as capable of engaging the immune system, as live bacteria. Issues related to airborne bacteria as presented in Table 12.

Airborne microorganisms can also be a primary source of disease. Conditions such as pinkeye are highly contagious and the combination of dust and the onboard ventilation systems can contribute to the spread of disease (Stockman's Manual). This is slightly outside the scope of this project but is an important consideration.

4.12 Measurement of airborne microorganisms

Although other methods are also described in the literature (Baekbo and Wolstrup, 1988; Alvarez et al., 1994; Clarke and Madelin, 1987), viable microorganisms are usually measured by using the six stage Anderson bacterial impactor and a standard air pump. The sampler is loaded with plates filled with special media onto which the organisms are trapped (See Figure 1). Total bacteria, gram-positive bacteria and fungal species are sampled using (Clarke and Madelin, 1987) horse blood agar, HBA+CNA and fungal (Sabouraud) plates, respectively. The plates are incubated for 48 hours and the colony forming units are counted manually. The concentration of bacteria is measured in colony forming units (CFU) per cubic metre. Colony forming units is a measure of clumps of bacteria, rather than an individual bacterium, and this measure does not include dead or non-viable bacteria.

Figure 1: Anderson sampler used routinely for airborne bacteria measurements

The cell wall components such as endotoxin, beta-1, 3-glucan and peptidoglycan can be estimated using wet chemistry methods. Airborne bacteria are trapped onto Millipore dust filters and then these filters are mixed with different chemical agents. At the end of a complex chemical process their levels are expressed as ng (nanogram) per cubic metre of air (Currie et al., 1997).

The importance of airborne bacteria (and/or cell wall components) has not been previously recognised by the livestock export industry. The way in which infectious disease may be spread within the livestock holds has been considered and it is recognised that the patterns of air movement may influence the population at risk. Discrete holds will obviously limit the extent to which an airborne infectious disease may spread to other animals. However, the way in which dust borne bacteria may trigger an immune response even in the absence of clinical disease is a slightly new concept. This is a significant review finding. There has been no sampling undertaken to determine the levels of airborne bacteria on board livestock vessels and this represents both a knowledge gap and an area for future research.

4.13 Spatial and time monitoring of airborne pollutants

In order to maximise the relevance of any measurements taken on livestock vessels, it would be useful to identify the optimal sampling locations on livestock vessels and perhaps the optimal timing of any sampling as well. However, at present there is no reliable information available on optimal sampling sites on livestock vessels.

In contrast, the most practical and representative sampling locations for air quality and environmental measurements inside intensive livestock buildings have been identified (Banhazi 2013a) and this information might be used to maximise sampling efficiency in livestock vessels.

Interesting patterns in the concentration of CO_2, dust and NH_3 were observed over time and space within livestock buildings. CO_2, airspeed and dust concentration demonstrated an obvious circadian pattern. The difference in the concentrations of NH_3 and CO_2 were not statistically significant at alternative sampling locations inside each building (Banhazi 2013). However, the gravimetric measurements indicated that the concentrations of inhalable particles were not uniform throughout the buildings and proved to be higher above the dry areas such as walkways.

NH_3 and respirable particle concentrations were significantly higher in summer when compared to winter conditions (Phillips *et al.* 1998; Banhazi 2009b). These results were combined to identify the most appropriate sampling times and sampling places for reliable evaluation of air quality in intensive livestock buildings. This study also highlighted areas where potential Occupational Health and Safety (OH&S) problems can occur.

These results demonstrate the value of developing continuous monitoring techniques for all airborne pollutants. The suggested standard sampling locations and times for piggery buildings are summarised in Table 13.

Table 12: Suggested sampling locations and time periods for different airborne pollutants within naturally ventilated Australian piggery buildings.

Pollutants	Likely high concentration locations (spatial)	Likely high concentration periods (diurnal)	Likely high concentration periods (seasonal)
NH_3	Anywhere	Daytime	Summer
Carbon dioxide	Anywhere	Night time	Winter
Inhalable particles	Over aisle	Daytime	Winter
Respirable particles	Anywhere (Over aisle)	Daytime	Summer

* Source Banhazi, (2013)

There is no ‘stand out’ choice of monitoring equipment. The siting of monitoring equipment onboard livestock vessels and the timing of sampling is also untested in the shipping environment. This represents a knowledge gap for the industry to address. The livestock export industry should determine its own sampling profile based on the patterns determined from continuous monitoring.

5 Bedding Management

Bedding management is an important component of maintaining a high level of health and welfare in most livestock buildings. For example, good bedding management and resulting environmental quality are essential components of maintaining the feet health of poultry (Ekstrand *et al.* 1997; Martrenchar *et al.* 2002). Good quality bedding is also important for maintaining high welfare standards and hygiene in piggeries (Morgan *et al.* 1998; Barnett *et al.* 2001) and cattle buildings (Gilhespy *et al.* 2009).

The quality of bedding also significantly impacts on air quality, especially on the concentration of airborne particles in a variety of livestock buildings (Banhazi *et al.* 2008b; Banhazi *et al.* 2008d; Banhazi *et al.* 2009d). In turn, it is well established that sub-optimal air quality will have negative effects on the health, welfare and production efficiency of livestock (Wathes *et al.* 2004; Lee *et al.* 2005; Murphy *et al.* 2012; Banhazi 2013c). Thus appropriate management of bedding is an essential component of good building management for almost all livestock species kept indoors.

Likewise, bedding management is a critical component of maintaining optimal environmental conditions during the transportation of animals on livestock vessels. It should be noted, however, that bedding management onboard livestock vessels is a specialised field and that the literature review identified only one study with immediate relevance (Banney *et al.* 2009). Headings have been drawn from these studies and other industry documents (e.g. Stockman's manual) to provide a logical framework from which to address the factors involved. The researchers have also undertaken some level of industry consultation to enable an informed discussion over and above the scope of the literature review. The extent to which the discussion is supported by science is noted under each heading.

5.1 Manure production and consistency

Manure is described as the combination of both the urine and faeces produced by animals (Banney *et al.* 2009). Livestock can produce significant amounts of manure over the course of a voyage. Obviously the amount of manure produced is directly proportional to a number of factors. The amount of manure produced is directly related to the length of the journeys and to the number of livestock involved, but it is also influenced by both feed and water consumption. The amount of urine produced will be influenced by both water consumption and the amount of moisture evaporated from the skin surface due to the animal cooling process. This is obviously influenced by the prevailing weather conditions.

Feed intake directly influences manure production and can range between 2-3.6% of body weight depending on livestock type (pers. comm. industry consultation). MARPOL (and subsequently onboard personnel) use a fixed figure of 35% as a guide for the amount of manure produced as a proportion of feed intake (see Appendix 12.5). A basic average of manure and urine production figures is presented in Table 23.

These values are consistent with the literature but it is noted that the amount of manure (and its consistency) may also be influenced by the digestibility and nature of the feed type

(Møller *et al.* 2014; Van Weelden *et al.* 2016). In many instances bedding (and/or the pad) will consist of manure only. For example, sheep pads tend to perform much better when compared to cattle pads because of the reduced liquid produced by sheep as a percentage of their bodyweight. Sheep faeces are dry pellets and sheep also produce smaller quantities of urine per animal (Table 15).

Table 13: Daily production of manure

	Animal Live weight (kg)	Total Manure (kg)	Dry Matter[a] (kg)	Organic Dry Matter[b] (kg)	Urine (L)
Cattle	300	17.4	2.6	2.2	5.4
	450	26.1	3.8	3.2	8.1
Sheep	30	1.2	0.33	0.28	0.45
	45	1.8	0.5	0.41	0.68
Goats	25	1.0	0.32	0.23	0.37
	40	1.6	0.52	0.37	0.6

Source: Banney et al (2009)

a) Dry matter is everything remaining after all water is removed.

b) Organic dry matter is dry matter less the ash content (minerals).

5.2 Bedding materials

Sawdust as bedding is used extensively on long haul voyages with cattle, but it is usually spread at the outset of the voyage and not used again until shortly before arrival. The interim period (after the first wash) relies on manure only as bedding (industry pers. comm.).

One of the main functions of bedding on livestock vessels is to absorb liquid produced by animals via defecation and urination. Table 15. shows that animals can produce significant amounts of waste in a liquid form. This is often beyond the capacity of ventilation system to evaporate (Zhang and Barber 1995; Soldatos *et al.* 2005). As a result, bedding materials such as sawdust are used frequently on vessels transporting cattle. In fact, the use of sawdust is a regulatory requirement on long haul voyages involving cattle.

The water holding capacity of sawdust is significant and can vary from 1.5 to 2.5 per unit weight basis (Banney *et al.* 2009). In other words, 1kg of sawdust can potentially absorb 1.5-2.5 kg of liquid (Table 16 & 17). This high water holding capacity is an important feature of good bedding material.

Desiccated manure (although not featured in the above mentioned tables) has 10 fold the absorptive capacity of sawdust (Jeppsson 1999a). This explains the hygroscopic nature of manure and its ability to hold water. This is an important area to consider for future research despite the possible sanitation issues. Desiccated manure could contain cell wall material that would contribute to problems with airborne microorganisms. This would only be the case if it became a dust problem. The absorptive properties of bedding materials are shown in the following tables.

Table 14: Absorbency of different bedding materials

Material	Form	Absorbency Factor[a]		
		Kains et al (1998)[b]	Voyles et al (year) [b]	S.D.S.U. (year) [bc] *[1]
Wheat straw	Baled	2.1		
	Chopped	2.1		2.1
Barley straw	Baled	2.0		
	Chopped	2.0		
Oat straw	Baled	2.5	2.86 (not specified if baled or chopped)	
	Chopped	2.4		2.4
Hay (unspecified type)	Baled	3.0		
	Chopped	3.0		3.0
Sawdust	Hardwood	1.5		1.5
	Softwood[1]	2.5		2.5
Shavings	Hardwood[2]	1.5		
	Softwood	2.0		2.0
Cornstalks		2.5	2.7	2.5
Sand		0.3		
Peat moss		10.0		
Shredded paper			2.08	
Triticale straw			1.97	
Shredded lumber			1.15	
Peanut shells				2.5
Cottonseed hulls				2.5

Source: Banney et al (2009)

a: Absorbency Factor = (weight after soaking – original weight) ÷ original weight

b: Weight of water held per unit weight of dry material; assumes initial moisture content of bedding is less than 10%

c: College of Agriculture & Biological Sciences / South Dakota State University / USDA – Extension Extra 1007, Updated April 2002

[1] Softwood is wood coming from coniferous trees.
[2] Hardwood is wood coming from broad-leaved dicotyledonous trees.

Table 15: Bulk density, absorption and requirements for various types of bedding material

Bedding material	Bulk density	Water absorption	Requirements*
Sawdust (pine)	225 kg/m³	2.5 kg/kg	4.1 kg/d/t LWT
Shavings (pine)	150 kg/m³	2.0 kg/kg	3.1 kg/d/t LWT
Straw (barley)	40 kg/m³	2.2 kg/kg	11 kg/d/t LWT

Source: Banney et al (2009) from Crafter, I., White, F., Carey, B. and Shephard, R. (2006) Review of soft flooring options for saleyards – southern beef zone. *Project Report AHW.158*, Meat and Livestock Australia, Sydney - *The heading requirements refers to the equivalent quantity of product to achieve the same amount of absorption. Note the suitability of pine shavings as opposed to pine sawdust.

Bedding materials have to perform a number of distinct functions and the use of bedding is influenced by the interplay of a number of factors. The main functions of bedding materials are to:

- Keep animals dry and clean by absorbing liquid waste.
- Maintain generally healthy environment and specifically good foot health.
- Prevent “scuffing” whereby foot abrasions from feet being in contact with rough flooring can become a source of infection.
- Provide comfort and ensure good traction between the flooring and the feet of animals.
- Contribute minimal extra heat via in-situ composting.

All livestock species, including cattle and sheep will more readily lay on comfortable and dry bedding material as opposed to soiled surfaces (Banhazi *et al.* 2009b). By and large, domesticated animals instinctively avoid soiled areas, unless they have problems with maintaining their body temperature within the thermo-neutral zone.

There are a number of benefits resulting from maintaining clean and dry bedding in livestock vessels. A reduced level of contact between the animals and their manure will reduce disease risk and exposure (Madec *et al.* 1998; Venglovsky *et al.* 2006; Madec 2013). This is especially true in relation to leg and locomotive diseases such as abscesses, infected cuts, hoof infections and other lameness (Hemsworth *et al.* 1995; Barnett *et al.* 2001; Cargill *et al.* 2001). Clean bedding will also reduce the formation of dags on cattle hides or discolouration of sheep wool and therefore will result in better-presented animals at disembarking. Clean animals have a better ability to shed heat and cool themselves. Bedding materials also need to be sufficiently course to prevent “scuffing” but fine enough to provide animal comfort. They also require an absorptive capacity sufficient to fulfil the previously described functions.

Additionally the in-situ composting of the bedding needs to be considered as during in-situ composting significant amounts of heat can be produced (Sommer and Moller 2000). In compost piles temperatures can reach in excess of 50 C^o (Turner 2002; Pittaway *et al.* 2014). Obviously under the prevailing conditions on livestock vessels such additional heat production is undesirable.

In addition, bedding materials used on livestock vessels should be:

- Cost effective.
- Readily available and reliably supplied.
- Safe to use, so the bedding should be non-irritant and non-toxic.
- Easily stored and handled so their storage and handling on vessels can be relatively easily managed.
- Easily discarded during or after the voyage so the bedding material should be environmentally friendly and biodegradable.

5.2.1 The use of sawdust

Sawdust is a useful management tool and has real application where it is relatively easy to source. However, getting sawdust to the more remote ports across the north of Australia is both costly and logistically difficult. Whilst welfare is obviously foremost, at some point there must be a balance between cost and benefit.

There are two sorts of sawdust currently utilised within the industry. Pine shavings are the preferred bedding due to the absorptive properties and the way in which it provides an effective barrier between abrasive flooring and the animal. The product has been dried and has exceptional absorptive powers. The other product is a 'red' sawdust powder. This is thought to have far less absorptive capacity (industry pers. comm.).

Sawdust is measured in either metric tonnage or volumetric cubic metres. Volumetric measurement differs from metric tonnage based on weight. Some sawdust is compressed prior to packaging. Prices should be compared accordingly. Current ASEL requirements are for a minimum of 7 metric tonnes (or 25 cum) per 1000 square metre of pen space for all cattle on long haul voyages (see Appendix). There is no requirement for sawdust on short haul voyages or long haul voyages that depart from Brisbane or any ports north of the 26th parallel and destined for South East Asia or Japan (ASEL).

It is difficult to quantify the benefits of sawdust. The benefits are subjective and based mainly on observation. Possible quantifiable benefits include:

- Less noise at loading.
- Reduced NH_3 levels at loading.
- Fewer leg injuries and infections.
- A greater proportion of time spent lying down.
- Extending the time between washes.
- Lower humidity levels after washing.
- Better grip to deal with riding behaviour.

More anecdotal benefits include:

- Animals being generally more comfortable in their environment.
- Reduced time to settle into surroundings.
- Stronger animals at the point of discharge.
- More options when combating hot conditions and heat stress.

Fine sawdust as a bedding material may become a significant source of respirable and inhalable dust. In turn, the high dust concentrations can cause respiratory problems for animals and workers attending the livestock (Banhazi *et al.* 2008c). Impregnating bedding materials, including saw dust a small amount of natural oil is an acceptable way of reducing dust concentrations in livestock buildings that have bedded systems (Banhazi *et al.* 2011a). Sawdust could also be impregnated with acid (e.g. acetic acid) to assist in keeping NH_3 levels to a minimum. This could be trialled as part of future industry research.

5.2.2 Alternative bedding materials

A number of different bedding materials that have been used in various livestock industries (Table 24), could potentially be considered for use on livestock vessels (Thompson 1995). Some of the bedding materials might offer various advantages over other bedding systems. For example, concentrations of airborne particles might be reduced by using certain bedding materials, such as straw pellets (Fleming *et al.* 2008). Other studies have shown NH_3 volatilization might be reduced by up to 57% by using a mixture of peat and chopped straw when compared to a system using long straw bedding for cattle (Jeppsson 1999a).

However, the same study found that temperature also strongly influenced NH_3 emission rates (Jeppsson 1999a) and such a positive correlation between air temperature and NH_3 emission rates in livestock buildings was also identified by other researchers (Groot Koerkamp *et al.* 1998; Banhazi *et al.* 2008a; Banhazi *et al.* 2008d). Thus on a practical level, one has to consider other factors, such as air temperature that might interact with the potential benefits associated with using alternative bedding materials.

Other bedding materials that might be suitable for use on various livestock farms might not be suitable for use on livestock vessels for a variety of reasons, including problems with price, availability or handling (Ward *et al.* 2001; Seedorf *et al.* 2007; Lips *et al.* 2009). However, the industry should constantly look out for alternative bedding materials. Pine shavings have become expensive (as high as $1,500 per metric tonne – industry pers. comm.). Sawdust is therefore a significant cost that influences the profitability of livestock shipments. In turn the quality, quantify and type of bedding material used during these voyages will determine the likelihood of successful implementation of best practice bedding management (Banney *et al.* 2009).

The evaluation of the alternative bedding materials first requires an objective and meaningful quality evaluation. This would allow the products to be compared against each of the possible benefits listed above (with cost being an obvious inclusion). In this regard, absorptiveness may be relatively easy to measure whereas a product's suitability to prevent foot abrasions may be much harder to quantify. Onboard trialling (or trialling under simulated conditions on land) may be required to complete the appraisal of different products.

As mentioned previously, the literature review demonstrated that there is not a large body of work on bedding that relates directly to the live export situation. However, on the basis of the review and anecdotal evidence obtained by the researchers, five products have been identified that could be evaluated and compared. Firstly, there is the red sawdust and the pine shavings described earlier, but secondly there are some other products that could have application. Straw has been used by the industry and some vessels are specifically set up to handle it (pers. comm.). The other product of interest is desiccated manure. Provided that sanitary and quarantine considerations can be met, desiccated manure has great application as a bedding product (see Table 18).

The final product of interest is the woodchip. These have been found to be most useful in bedding scenarios because of their ability to achieve drainage within manure pads. Moisture seeps along the surface of the woodchip. This overcomes the hygroscopic nature of the pad and allows moisture to drain. It is unlikely that woodchip would have any real application to current management systems but they may if the industry were to adopt any continuous removal (slat type) system. A slatted type bedding system is described as a possible alternative later in the report. Woodchips still provide some level of comfort and slip resistance. However, this size of woodchip may affect shipboard pumps. The five products mentioned are compared in Table 18. These tables are based on previously published reports (Banney *et al.* 2009) and to a lesser extent previous studies (Deininger *et al.* 2000).

Table 18: Currently used and potential bedding materials that might be used on livestock vessels

BEDDING MATERIALS	BENEFITS	DISADVANTAGES	COMMENTS
Red sawdust	Easily removed.	Sawdust of fine particle size may add to dust problems. Poor absorptive qualities	Considered an inferior product.
Pine shavings (kiln dried)	Can be dry on top and wet underneath. Good protection against scuffing and feet and leg abrasions. Excellent absorptive qualities.	Tends to be expensive.	Commonly used in the horse industry. The most commonly used bedding within the livestock export industry.
Large woodchips	Provides good structure for drainage.	Moisture content should be less than 30% to maximise absorbency. Could play havoc with pumps.	Storage needed to keep woodchip dry. Wood type and size is important.
Cereal and other resilient straw	Most commonly used bedding in many livestock housing situations. Excellent physical structure and drainage characteristics.	Straw is not easily removed from decks and can play havoc with pumps. All straws can catch fire,	Straw from longer varieties is likely to be more effective than straw from short varieties. These straws are often a neglected as a cheap source of bedding.
Dried or desiccated manure solids	Good water holding capacity.	Can have high bacterial cell wall counts (and possibly other pathogens) with associated biosecurity issues.	Used on dairy farms in the USA and has potential.

5.3 Managing manure

Manure is the combination of faecal material and urine and is composed of total solids and water. Manure management in many instances will also involve the management of any bedding material and/or bedding additives that have been spread or added to the bedding surfaces. Bedding management is a key component of good livestock management on farms. The main aims of manure management on farms are to (1) reduce the environmental effects of the raw manure produced on the surrounding areas around the farm and to (2) process the manure on farms so it becomes stable and biologically available for plants after it has been applied to the land (Pittaway *et al.* 2014).

Manure management on vessels has different aims. Firstly, on sheep vessels, the manure pad is maintained for the entire voyage and then washed out after the livestock have been discharged. Similarly, most short-haul cattle voyages are sufficiently short in duration to allow the cattle to be delivered before it is necessary to wash down. It is usually only on long haul cattle voyages that a washing program is required. On these voyages, the manure produced on vessels is not stored and/or processed but released directly into the oceans. The rate of discharge is restricted and there are restrictions in regards to proximity to land (see Appendix 12.1).

The review has also explored ways in which liquid waste could be separated and removed on a continuous basis. A possible system using slats is described later in the report (see 7.6.6). This system would keep the pad dryer and therefore result in health and welfare improvements for the animals and potentially for the staff as well. In addition, a dryer manure pad would last longer, reducing the need for frequent washing and re-bedding. Alternatively, the use of organic bedding (sawdust) might be completely eliminated if the slatted areas are managed in such a way to provide a comfortable resting area for the animals.

In the interim, current management practice involves the removal of manure as a washing event (industry pers. comm. and Stockman's Manual). Whereby this event takes place after the livestock have been removed, there is very little finesse required (just a good deal of hard work (industry pers. comm.). However, on long haul cattle voyages, where wash downs must be completed whist the livestock are still in situ, the process requires some careful planning. The factors that influence a washing program (or plan) are discussed under the next heading.

5.4 Factors affecting washing frequency and the use of sawdust

As mentioned previously, whereas aspects of bedding management, such as NH_3, have been studied in some detail there is limited documentation of best practice procedures in regards to washing frequency and the use of bedding. There has been only one research project that directly addresses bedding management in the live export industry (Banney *et al.* 2009). Consequently, this section is largely anecdotal and open to some conjecture. Unless clearly stated, it should be assumed that this section has been compiled based collective industry knowledge sourced via the recommendations of the industry Stockman's manual and/or industry consultation.

Washing frequency and the use of sawdust is central to the effective transport of animals on livestock vessels on long haul voyages involving cattle. This section therefore relates specifically to cattle on long haul voyages only.

It is difficult to be prescriptive about bedding management due to the interplay of a large number of factors. It is also strongly influenced by the way in which events unfold during the course of a voyage. The principles involved however, seem to be well understood by industry personnel (industry pers. comm.).

Depending on the livestock category involved, a lack of sawdust can be compensated for by more frequent washing. In fact, under many circumstances, more frequent washing may be a better strategy to combat heat stress and provide acceptable conditions on board. However, the washing event requires additional work for the crew and the logistics of spreading sawdust after every wash could meet some resistance from the crew on board, particularly if the benefits were not obvious. Washing repeatedly (say every two days) can be a good strategy (Stockman's handbook). The crew on most vessels are very willing, but this needs to be respected if management wishes to draw on this goodwill when it is urgently needed.

There are a number of factors affecting washing frequency and the use of bedding. They fall into three categories:

- ship factors such as flooring, ventilation design, ship configuration, size and design and trim.
- livestock factors such as breed type, coat length, bodyweight, pregnancy, age and riding behaviour.
- miscellaneous factors such as fodder type and feeding, stocking density, actual and anticipated weather conditions, voyage duration voyage destination.

These are discussed under each heading below.

A further heading addresses the challenges of dealing with slurry.

5.4.1 Ship factors

The most obvious ship factors are flooring type and ventilation but each ship is different with its own peculiar set of features and limitations. This is one of the reasons why it is difficult to be prescriptive about bedding management. The following factors are considered important. Note again that this discussion is largely anecdotal.

5.4.1.1 Flooring

Brand new flooring can be abrasive and associated with feet and lower joint infections. Flooring is generally better once it has been "worn in". Cement/concrete flooring can be slippery at loading but is also an acceptable flooring. Flooring is not always consistently even throughout the vessel. Some areas may have additional grating for grip or be prone to extra wear. These areas are candidates for additional sawdust. The suitability of flooring therefore influences the bedding management strategy. For example, ‘new’ flooring would require more liberal use of saw dust than ‘worn in’ due to the potential for abrasions.

5.4.1.2 Air delivery and ventilation design

Ventilation is a major factor in the management of bedding. The air moving through a hold has two tasks, as discussed previously. One is to remove heat from the animals (and the hold) and the second is to remove moisture from the pad.

The ability to lift moisture is influenced by the pen air turnover (P.A.T.) and the way in which the air is delivered. A high P.A.T. provides a greater capacity to lift moisture from the hold. The more evenly the air is delivered, and the extent to which it passes across the pad also dictates the extent to which air can lift moisture from the pad. Therefore, the use of bedding is more justified in areas that have lower PAT.

The need to wash pens is usually dictated by the ‘worst’ pens in the hold. Configurations that deliver air to each pen will generally have the most ‘even’ pad. The evenness of air delivery therefore has a bearing only how quickly a wash is required. In most vessels the worst pens will be adjacent to the exhaust vents.

Vessels that adopt a ‘long run’ configuration of the deck hold (to chase high average air speed) and are ventilated by supplying air from one end of the hold and exhausting it at the other will demonstrate the most disparity between pens within the hold.

Fully ventilated open decks have the capacity to allow additional air to flow across decks. This allows bedding to be maintained for a longer period due to the extra airflow afforded under good conditions. Open decks without full ventilation may struggle when the vessel orientation leads to a following breeze and ‘nil wind’ conditions. The pad may deteriorate quickly in this situation.

5.4.1.3 Configuration, ship design and size

Vessel design varies considerably. In general, smaller vessels are easier to wash than larger vessels. Theoretically, there is no reason, why a larger vessel should not be washed just as easily if the staffing and pump and power generation capacity is proportionally greater. In practice bigger vessels are logistically more difficult and require a higher level of management skill. ‘Bottlenecks’ develop whereby routine activities seem to become compromised if washing programs become too ambitious on large vessels. The task of spreading sawdust after a wash always seems greater on the larger ships, particularly if bottlenecks exist at hatches or in the use of lifts or cranes.

Some vessels are hampered by less than ideal design whereby drainage is compromised by scuppers (drainage holes) that are too small or positioned in the wrong places. Ribbing or ventilation shafts can obstruct drainage, leaving areas that must be swept dry. These areas often benefit from the spreading of sawdust. As a general rule, however, sawdust should not be used to “soak up moisture”, but should be used in a more pro-active manner.

Vessels that are broken into discrete holds are generally easier to wash. It is often desirable to be able to wash decks independently although most vessels find this challenging. The exception is the distinction between open and closed decks whereby the decks are usually separated by a watertight main deck. Open decks are less risky to wash since they do not rely on pumps to remove the water.

Some vessels have decks that utilize grating to allow the passive removal of air from lower decks. This may compromise the washing options if there is water ingress between decks. Flat decks (with a slight camber) are usually easier to wash than decks with either a raised or lowered pen area. Some vessels utilise kick plates to direct water flow and assist in the washing. In some instances, kick plates actually hinder the washing process.

Therefore, in general, the use of bedding is more justified in poorly designed, larger vessels with poor drainage when compared to well-designed smaller vessels.

5.4.1.4 Trim

The ability of a vessel to provide a trim is a much under-estimated feature. A strong trim (say a 1 metre difference from forward to aft) will facilitate a faster and more effective wash. In many vessels fodder tanks are situated forward and consumption is required to get the "nose up" sufficiently to have adequate trim for a wash. In other cases, trims can be theoretically provided but water making or storage limitations will compromise the trim.

Stress factor calculations are also an important consideration (particularly in fully loaded vessels) whereby the emptying of tanks mid-ship can trigger excessive stress factor calculations. This may also limit the availability of trim.

The time taken to complete a wash can be an issue if cattle are made to stand in water for an extended period. This will soften feet and make them more prone to foot infection. A fast effective wash is therefore more readily undertaken on a vessel that can provide a trim anytime as opposed to a vessel where the trim is compromised.

5.4.2 Livestock factors

Livestock category is probably the most important factor when considering a bedding management/washing program. Some categories of livestock require the extensive use of sawdust to maintain their health and well-being. Other cattle are quite robust and handle conditions much better. The most important determinant is agility.

There is interplay between heat tolerance and the extent to which animals soil their own pad. Animals that approach their heat tolerance thresholds will drink excessively through a physiological mechanism known as polydipsia/polyuria. In these circumstances the animals will drink and urinate more. This leads to a rapid deterioration of the pad. Young, agile cattle have far fewer problems and are unlikely to require any special bedding requirements. Note again that the following discussion is largely anecdotal.

5.4.2.1 Breed type

Bos indicus cattle are more agile than *Bos taurus* cattle.

Bos inducus cattle have a greater heat tolerance and therefore drink and urinate less. They are less likely to exhibit polydipsia/polyuria (Barnes *et al.* 2004).

Bos indicus cattle will be taller at similar weights and this gives them more scope to mill and move within the pens.

Bos taurus cattle are less agile and more likely to incur grazes or foot abrasions (scuffs) that lead to foot and /or leg infections. These cattle are more likely to exhibit polydipsia/polyuria (Barnes *et al.* 2004). This can be a problem in very hot and humid conditions whereby the pad deteriorates very quickly after washing.

Friesian cattle are more prone to foot and leg injuries and are less heat tolerant than most other cattle. The use of sawdust is essential when transporting these cattle.

5.4.2.2 Coat length

Cattle with long coats can become quite discoloured and matted. The physical appearance of these cattle and their surroundings at this time can be quite confronting. When considered in the context of an overall washing program the situation is probably acceptable, however, the industry should acknowledge that this represents a perceived welfare risk even though there may not be any real risk to the animal's health and well-being. Cattle with long coats are less heat tolerant and more likely to exhibit polydipsia/polyuria. The use of sawdust can help to mitigate this situation but there are times when sawdust is simply overwhelmed and its use becomes impractical.

5.4.2.3 Bodyweight

Within each breed, heavier cattle require more care. In most instances cattle with a higher bodyweight will be older and carry more body condition, but both factors will make animals less agile and more prone to leg and feet injuries and subsequent infection.

An exception to this rule is animals in poor condition that lack strength. These animals also find it difficult to get up and down. Sawdust is a useful adjunct to effectively manage these cattle. Age is less of a factor except that older cows of similar weights to younger cows are generally more difficult to transport (see later).

5.4.2.4 Pregnancy

Pregnant animals require additional care. The weight of the foetus contributes to a lack of agility and increases likelihood of leg injuries and infections. There can be a tendency to over feed these animals in a bid to meet a perceived greater nutritional requirement. In fact, the nutritional demands of the calf at this early stage of pregnancy (less than 6 months) are quite minimal and it is unnecessary to feed these animals aggressively.

Addressing the animal's ability to easily move from standing to sternal or lateral recumbence (and back) is a more important consideration. Restricting feed intake can lessen the weight of intestinal contents and make it easier for these animals to get up and down. In some cases, hay can be used to restrict feed intake. This satiates the animals with less intake of weight (since the hay is not as dense).

Engorged animals are clumsy and prone to grazes or injury when moving from standing to sternal or lateral recumbence. The use of sawdust can assist greatly in minimizing the risk of injury and /or infection in this category of livestock.

5.4.2.5 Age

As mentioned earlier, older, fatter cows are a difficult cargo to transport on both short and long haul voyages. The use of sawdust is recommended for this category of livestock, particularly for older cows on ‘short haul’ voyages sourced from southern ports destined for South East Asia.

5.4.2.6 Riding behaviour

A major cause of lameness on board is riding behaviour. This is seen in bulls as part of the pattern of social dominance but it is also seen in unjoined heifers that exhibit standing heat. Riding can also be evident when feed is restricted and trough space is limited. Animals will ride each other in their efforts to get to a trough. Sawdust provides a better footing for these cattle and also reduces the risk of infection due to scuffing of the feet. Under ideal circumstances sawdust should be considered for both these categories of livestock.

5.4.3 Other factors

5.4.3.1 Fodder type and feeding

The type of fodder utilized during the voyage affects bedding and the bedding management program. As mentioned, the use of bulky, low-density (but good quality) hay can restrict animal’s overall intake (by weight) and avoid animals becoming engorged and cumbersome. This is particularly the case in young dairy cattle that have the capacity to eat in excess of 3.4% of their bodyweight (industry pers. comm.).

Restricting animal’s intake so that they feel full yet reduce the weight of their rumen contents will have a major effect on the expected number of leg wounds (grazes) and feet injuries (sole abrasions) (industry pers. comm.). The use of high-density pellets and an ad lib feeding program can lead to an increase in leg problems and lead to a greater reliance on sawdust to manage the problem.

Another aspect that has not been investigated is the way in which feed type affects the consistency of the dung. The additional moisture that is added to the pad during hot weather is not simply due to urination. Faecal consistency is also affected by feed type (Møller *et al.* 2014; Van Weelden *et al.* 2016). It is conceivable that some feed types may assist to maintain faecal consistency during periods of hot and humid conditions. Therefore, the frequency of washing may be greater for cattle fed on high-density pellets than animals fed on good quality hay for example. More work is required to quantify how feed type affects manure consistency and its subsequent management. This represents an identified knowledge gap and an area for future research.

5.4.3.2 Stocking density

Stocking density is a key determinant when planning a washing program. High densities will lead to an earlier deterioration of the pad due to additional urine and faeces and the pugging effect of cattle. Stocking density also influences the wet bulb rise and this may trigger heat stress, and the associated polydipsia and polyuria, in a great number of cattle.

The opposite is also true. The bedding in pens stocked at very light stocking densities (with abundant air) can often be maintained for long periods. Occasionally this is practiced on long haul voyages (as a matter of convenience) where a small consignment of cattle travel with what is predominantly a sheep consignment. These cattle arrive with a pad that is far superior to that obtained with sawdust after a final wash. This would be a commercially unviable option in most cases but it does demonstrate the importance of stocking density.

One of the difficulties in planning a washing program is that the decision to wash is usually dictated by the worst pens on a deck. This may trigger the need to wash an entire hold. The strategic use of sawdust (either applied after washing or some other time) can sometimes be used to hold the bedding in these areas and prolong the time to the first wash (or the interval between washes). It also encourages the deck plan and subsequent stowage to be as even as possible with regards to both stocking density and the livestock factors described above

Therefore, on ships, in pens where equivalent animals are kept at high stocking density, more frequent washing is required than in pens with low stocking density. This of course acknowledges that there are industry restrictions on stocking density both through ASEL and the industry heat stress risk assessment model.

5.4.3.3 Actual and anticipated weather conditions

Temperature and humidity have a direct influence over the nature and development of a pad. Temperature is important because it largely dictates how much an animal drinks (and consequently urinate). Humidity is important because it dictates the extent to which the air passing through the hold can lift moisture from the animal (evaporative cooling via the skin and respiratory tract) and from the pad. For the animal, this provides the cooling effect through the latent heat of evaporation.

There is some evidence that the evaporation of water from the pad surface (or the floor) has a cooling effect. Note that washing has been shown to have a cooling effect and washing decks across the equator and other hot and humid areas is encouraged (Gaughan *et al.* 2003 & 2005). Note that the evaporation of moisture from the pad is considered to be wet bulb neutral. It may have a cooling effect but it makes no change to the wet bulb temperature and is not thought to influence the wet bulb rise.

The pad will accumulate water in keeping with the water balance. That is the balance between the water added as urine/faecal material and the water removed by evaporation. Fully saturated air cannot increase its moisture content (in the form of water vapour) and in this situation an animal must rely solely on convective cooling to maintain its body temperature below the critical level. Equally, fully saturated air has no capacity to lift moisture from the pad. The opposite is also true, whereby if the temperature of the air is the same as the body temperature (38.6°C), all of the cooling must be achieved through the evaporative process. Therefore, depending on how the air is delivered and the humidity involved, there may be some residual capacity to lift moisture from the pad.

Wet bulb temperature alone is not a good indicator of water intake and/or urine output. Neither is it a very good indicator of evaporative cooling from the animal and/or the lifting of moisture from the pad. It is however a very good indicator of heat stress tolerance. In the maritime situation, higher wet bulb temperatures are usually associated with high humidity. This may change when the weather is influenced by a nearby land mass and may often be different in port. The washing program will be planned around the anticipated weather conditions. Clearly it is impractical to spread sawdust if another wash is planned for the next day or the day after.

Sawdust will usually only be used mid voyage if it helps to "catch" the pad. This will generally only be possible under cooler and/or dry conditions. To this extent, the justification for the use of sawdust may actually be less if adverse hot and humid conditions are anticipated. The use of sawdust, mid voyage, is generally more useful when the weather is anticipated to be cooler.

Sawdust is almost always used after the last wash, prior to arrival. This presents animals in the best possible way to the importer (and/or authorities) at the point of discharge. It also allows animals to "gather themselves" prior to discharge.

In summary washing will be undertaken more frequently under hot and humid conditions compared to cooler, less humid conditions.

5.4.3.4 MARPOL restrictions

The regulations for the prevention of the pollution of oceans and seas (by sewage) are contained in Annex IV of MARPOL. This includes the effluent from livestock vessels. Essentially the MARPOL regulation restricts the discharge of untreated effluent to a distance of more that 12 nautical miles from the nearest land.

It also restricts the rate of discharge based on the ships speed, breadth and draft. The other factor being the amount of manure involved. This is calculated as a %age (35%) of the overall fodder consumption but an assumed moisture content is not specified. The actual wording is as follows:

> *"The discharge of sewage into the sea is prohibited, except when the ship has in operation an approved sewage treatment plant or when the ship is discharging comminuted and disinfected sewage using an approved system at a distance of more than three nautical miles from the nearest land. Sewage which is not comminuted or disinfected may be discharged at a distance of more than 12 nautical miles from the nearest land, and the rate of discharge of untreated sewage shall be approved by the Administration (see resolution MEPC.157(55))"* (see Appendix 12.1).

> and *"The MEPC also adopted a standard for the maximum rate of discharge of untreated sewage from holding tanks at a distance of more than 12 nautical miles from the nearest land (see resolution MEPC.157(55))"* (see Appendix 12.2).

AMSA have no jurisdiction over ships in international or other nationality's waters, however, ships that operate within Australian waters must have the capacity to comply with the MARPOL regulation. The AMSA regulation is shown in Marine Orders 96 (see Appendix 12.3). These restrictions on the rate of discharge do not normally impose on normal operations. They are sometimes triggered if the initial wash is delayed (to say Day 12) by additional sawdust being spread on vessels with better than average ventilation. They may also restrict some of the larger vessels wishing to wash down in a single day.

The reason for the restrictions, as stated by MARPOL is that the discharge of raw sewage can create a health hazard and/or lead to oxygen depletion and can be a problem for countries with a major tourism industry. However, it is generally considered that on the high seas, the oceans are capable of assimilating and dealing with raw sewage through natural bacterial action. Therefore, the regulations in Annex IV of MARPOL prohibit the discharge of sewage into the sea within a specified distance from the nearest land, unless otherwise provided. Governments are required to ensure the provision of adequate reception facilities at ports and terminals for the reception of sewage, without causing delay to ships.

The Annex requires ships to be equipped with either an approved sewage treatment plant or an approved sewage comminuting and disinfecting system or a sewage holding tank. New ships were expected to comply with this regulation immediately (i.e. on the date of entry into force of Annex IV, namely since 27 September 2008). Existing ships were required to comply with the provisions of the revised Annex IV five years after the entry into force. Consequently, all livestock vessels are now required to have a sewage tank that allows the vessel to comply with both the rate of discharge and/or distance from shore restrictions

Of further note is MARPOL's use of special areas. MARPOL defines certain sea areas as 'special areas' in which, for technical reasons relating to their oceanographical and ecological condition and/or to their sea traffic, the adoption of special mandatory methods for the prevention of sea pollution is required (IMO – Special areas under MARPOL). The nominated special areas are the Mediterranean Sea, Baltic Sea, Black Sea, Red Sea, Persian Gulf, Gulf of Aden and the Antarctic area. More recently MARPOL have added significant restrictions to shipping in the polar region (Resolution MEPC 265(68), 2015).

At present, the only special area established under Annex IV (relating to sewage discharge) is the Baltic Sea, however it is increasingly apparent that environmental pressures may lead to more special areas being established under this heading.

5.4.3.5 Voyage duration and eventual destination

The industry views short haul and long haul voyages quite differently. Bedding management on long haul voyages is well rehearsed and well understood. There is less documentation on how bedding could or should be managed on short haul voyages. This represents a substantial knowledge gap and an area for industry consideration.

Short haul voyages vary in their duration from 3-4 days to over a week. Voyages that extend to 7-8 days face unique problems since they are pushing the limits of the pad. Note that the approved stocking densities are slightly higher on short haul voyages. Short haul voyages that extend past 7-8 days will usually require a washing event to maintain the pad in a suitable state, although the close proximity to land may preclude this as an option. Similarly, bedding management on voyages with multi-port discharges can also be problematical due to insufficient time due to the short distances between discharge ports. Again, this can restrict the ability to wash. Spreading cattle after each discharge can be an effective counter to a moist pad where it is logistically possible. The lower densities resulting from spreading allow the pad to hold and generally provide more comfortable conditions for the livestock involved.

Anecdotally, there are claims that short haul vessels are sometimes reluctant to wash prior to arrival and have a mind-set to just “get there and get them off” (industry pers. comm.). There is no evidence to support this, however a long haul voyage tends to have a greater focus on settling the animals and avoiding any compromise to amenity. This suggests that some of the principles of the long haul are not necessarily being applied to the longer short haul voyages. This applies in particular to the long/short haul voyages undertaken by bigger ships that are typified by multiple port loadings and multiple port discharges. The cattle that are loaded first are often the last cattle to be discharged and issues with bedding have been reported. The guidelines on how to address bedding management on long haul voyages are quite explicit however, the guidelines on how to address bedding on the longer ‘short haul’ voyages are less explicit and require some refinement. This is an area for future research and development.

Another important factor to consider when planning a washing program is the eventual destination. There are peculiarities about most destinations. In the Middle East there are washing restrictions within the Persian Gulf that influence a washing program. When negotiating the Red Sea there may be times when proximity to land is a problem and washing must be curtailed. If Jeddah is the final destination it is prudent to leave the final wash to the very last minute. If the destination is Aqaba or Eilat, it can be a good strategy to wash well before arrival to allow the anticipated hot and dry conditions to set the pad and allow cattle to clean their coats before arrival. If the destination is Zhenjiang (in China) then the voyage would finish with a 2 day journey up the Yangtze River with obvious restrictions on washing activity, however, China generally (and particularly in the winter) can be very cold which allows the pad to set nicely. In this case it may also be a good strategy to wash well before arriving.

Again, these examples highlight the difficulty in being prescriptive about washing programs. There may be a preference to lower decks last if they are the last to be unloaded, or maybe a preference for open decks to be last if sawdust is more easily distributed and other arrival activities place pressure on available labour. In most (and possibly all) cases, plans need to be modified depending on the way in which the voyage unfolds

5.5 Dealing with slurry

There are situations when the pad deteriorates very quickly after washing. This is a problem in very hot and humid conditions, and most commonly with less heat tolerant cattle that are drinking and urinating excessively. Sometimes this results in deck conditions that are nothing more than slurry. Slurry is a feature of many livestock housing situations and it would be unreasonable to think that the live export situation was somehow spared from having to face up to the challenges involved.

As mentioned previously, sawdust in this situation is simply overwhelmed and is seemingly a waste of time and effort. Research is required to quantify both the amount and length of stay that sawdust can provide under these circumstances. An alternative strategy is to wash the decks as frequently as possible and/or contemplate design alternatives

With suitable cattle, decks can be washed every day, however, long coated *Bos taurus* can become fatigued by daily washing. There are other practicalities to consider. It is possible to wash daily on small ships (indeed it is an established practice on a small ship travelling to Japan on a regular basis) (industry pers. comm.) but almost impossible on the very large vessels since it is a time consuming event and compromises other activities such as feeding and cleaning waters. There are also limitations in terms of pumps, generator power and the rate of effluent discharge (see Appendix 12.3 -12.5). The interplay between washing frequency and the use of sawdust under these conditions requires considerable finesse and would benefit from further investigation.

The alternative is to opt for the continuous removal of manure and especially urine via a slatted flooring system. This is explored in more detail under the heading of 'possible new flooring arrangements'.

5.6 Flooring

Flooring is an important component of all livestock housing and of course it is a very important structural component of livestock vessels as well. Again, much of this discussion is anecdotal, since there is very little literature that relates directly to the onboard situation. It is important to use quality materials for the construction of livestock flooring in livestock vessels, as the environment is usually quite corrosive. The use of sea water for cleaning, the high humidity environment and the relatively high stocking densities all put stress on flooring materials. Flooring needs to have a number of characteristics (that are sometimes conflicting) in order to fulfil its functions (Flaba *et al.* 2002; Flaba *et al.* 2014). These characteristics are:

- Structurally sound, cost effective and affordable.
- Slip resistance and adequate hardness.
- Appropriate traction without being too abrasive.
- Adequate drainage and comfortable surface.

5.6.1 Structure

First of all, flooring must be strong enough to physically able to support the weight of the animals and additional equipment and/or pen components. In addition the flooring material has to be cost effective and affordable so companies managing the livestock vessel can run a profitable operation (Flaba *et al.* 2014).

All materials used in the construction of floors should be non-toxic and be able to resist chemical (i.e. manure, sea water, cleaning and disinfectant chemicals) and physical impacts, such as the effects of pressure washers and animal impacts. In addition, floor materials should be able to resist environmental impacts, such as the negative impacts of extreme temperatures and solar radiation.

Ideally, the flooring must also provide an impermeable barrier, which is especially important feature of flooring on multi levels vessel environments.

5.6.2 Slip resistance and hardness

The slip resistance is a characteristic of the flooring that enables the animals' feet/claw to be in contact with surface of the flooring without frequent slippage (Flaba *et al.* 2014). Slippery flooring can cause injuries and can compromise natural animal behaviour, while slip resistant flooring enables animals to have stable movement. However, if the flooring is too rough/abrasive it can lead to claw and leg disorders. Rubber (mats) floor covering might be used to enhance slip resistance and improve animal comfort. The condition of flooring on newer vessels is usually good, often offering a good mix of grip/traction versus comfort.

The hardness of floor materials may be unavoidable if they are to perform functions such as load bearing, resistance to corrosion and damage, while being practical and economic to use (Flaba *et al.* 2014). However, animals prefer to stand and walk on softer surfaces. Covering slats and solid hard floors with materials that provide a soft contact surface, such as resilient rubber mats or coatings, can improve the animals' natural behaviour and welfare, and may result in animals being better presented at disembarkation.

5.6.3 Traction and abrasiveness

All floors made of conventional materials will be abrasive to some extent. Indeed, for most hoofed animals, floors need to be abrasive to a degree to keep the claw in good condition. On the other hand, floors that are too abrasive can lead to abrasion scuffing and injuries. Brand new flooring can be abrasive and associated with feet and lower joint infections. Flooring is generally better once it has been 'worn in'. The standard flooring used within the industry is a flooring called 'bullet' which glues a layer of light grit onto the flooring surface over which is then painted over.

5.6.4 Cleanliness, health and ammonia emission

Efficient drainage is a very important feature of all flooring used in livestock buildings. Without adequate drainage, hygiene levels will quickly deteriorate and the resulting wet floor surfaces are a health and welfare hazard for all livestock species. Clean flooring improves the general cleanliness, resulting in better health and welfare outcomes. Effective liquid drainage is also a way of reducing NH_3 emissions.

Traditionally in other intensive livestock industries, slatted floor areas are used to keep flooring clean. Concrete slats, above a slurry pit or channel, are the most common type of suspended floor design.

5.6.5 Flooring Types

In Table 19, the various flooring types are shown and their potential advantages and disadvantages are also listed.

Table 19: Different floor types

FLOOR TYPES	Advantages	Disadvantages	Comments
"Bullet" flooring	Proven flooring with good slip resistance.	Can be abrasive when new.	Standard industry flooring. Considered best practice. Easy to clean.
Solid concrete	Relatively cheap and widely used.	Can be slippery when covered with manure.	Quality might not be consistent throughout the vessel.
Mastic asphalt	Impermeable flooring that is slip resistant.	Can be expensive.	Usually cast onto a solid concrete floor
Rubber	Good slip resistance.	Can be very expensive.	Resilient rubber can be used as surface material in the form of mats or as a coating. May have application in hospital pens on livestock vessels.
Additional grating	Provides additional slip resistance where required.	Requires additional sawdust to avoid leg problems.	Used at the base of ramps and other areas where animals are loaded.
Slatted	Good drainage. Improved hygiene conditions and better animal health and welfare outcomes.	Could be moderately expensive. Could be difficult to clean, particularly to quarantine standards.	The spacing between the slats will influence the drainage capacity and comfort level of the slatted areas.

5.6.6 Possible new flooring arrangements

While the current bedding and manure management practices serve the industry quite well, it is always prudent to look for new and innovative solutions that might serve the needs of the industry and animals transported even more effectively.

Therefore, this review has explored ways in which liquid waste could be separated and removed on a continuous basis. This would keep the pad dryer and therefore result in health and welfare improvements for the animals and potentially for the staff as well. In addition, a dryer manure pad would hold longer, reducing the need for frequent washing and re-bedding.

Referring to other industries it would seem that there are a few options available to remove at least the urine component of the animal waste. These options include the establishment of various types of slatted flooring systems that are frequently used in livestock buildings. These manure removal systems would need to be modified substantially to fully serve the needs of animals on livestock vessels.

The practical options for the establishment of some form of slatted systems will be discussed under the sub-headings “flooring” (Section 8.5). Alternatively, the use of organic bedding can be completely eliminated if the slatted areas are managed in such a way to provide a comfortable resting area for the animals

The key change proposed is to establish similar slatted flooring systems on livestock vessels that are frequently used in livestock buildings to remove the liquid and solid components of the animal waste.

5.6.6.1 Implementation options

The first option would be to install the slats directly on the deck floors and under the slats install water jets, which would clean the manure continuously and thus, keep the under-slat area clean and free of blockages.

The reviewers note the many issues involved, particularly the sanitation requirements of AMSA/DAFF prior to loading. Not all these are resolved in the suggested design. It is, however, the only real way forward if the industry wishes to move away from the existing flooring systems.

In Figure 2, the envisaged slat design is presented. The slats would be self-supporting and the ‘legs’ of the slats would enable these slats to be directly placed on top of floors. These legs would create distinct ‘manure channels’ (in between the legs) similar to the channels that are created in a building housing livestock in other industries.

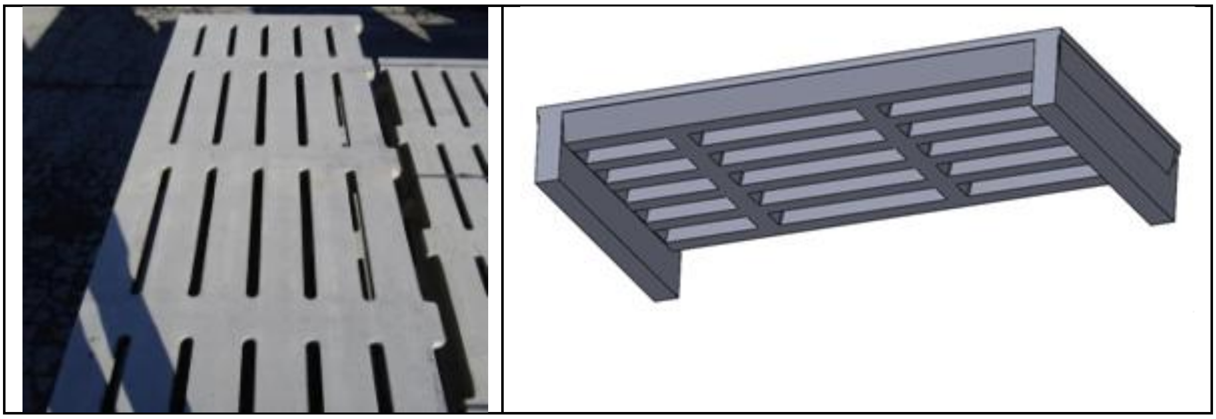

Figure 2: Innovative slat design with self-supporting 'legs' that can be placed directly on deck floors

These manure channels ensure that the water turbidity and speed will remain sufficiently high to flush the solid manure component of the waste from the compartments. Using the same concept, these self-supporting slats would create the ideal conditions for efficient manure removal. However, it might be possible that, depending on trim, some parts of the under-slat area (especially around corners and/or on uneven concrete floors) might accumulate manure, stick to the flow and potentially create blockages. These are intangibles at this stage. Of course improved design of the beams and extra resin coating of the existing flooring might reduce the likelihood of manure accumulations.

An alternative solution is to install additional fibreglass sheets under the slats creating a waterproof under-slat area that would be easy to clean. It is envisaged that these fibreglass sheets might be installed between the beams and the slats (Figure 4).

The installation of these fibreglass sheets would be relatively easy, quick and cost effective. The envisaged design of the under-slat sheet installation and the design of the slats can be seen in Figures 3a and 3b.

Under this flooring design, beams would be installed on the deck floors (instead of the self-supporting 'legs' suggested for the previous design) and of course the distribution of the beams would be dictated by the existing layout of the deck areas being used. The length of slats can vary to accommodate the ideal distance between beams rows that in turn would be dictated by the on-board environment. The beams could be made of reinforced concrete, but other alternative materials, such as treated hardwood might also be considered. The envisaged layout of the slatted area can be seen in Figure 4 from above and from the side.

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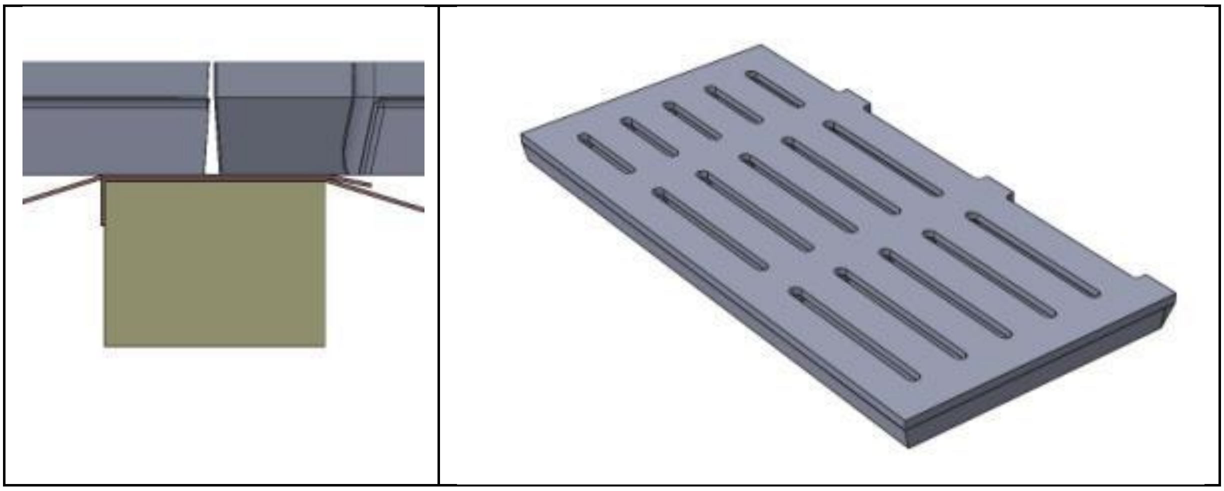

Figures 3a and 3b: Arrangements proposed for creating an under slat, water proof area for efficient manure management.

After the beams are installed and aligned (would be relatively easy to install the beams directly on the deck floors), the fibreglass sheets would be installed on the beams. The fibreglass sheets might be pre-cut and prepared beforehand and installed on the vessels relatively quickly. However, in this case, there would be joints between different fibreglass sheets and thus water and manure could potentially leak between the joints. Usage of silicone in between the joints would reduce or potentially completely eliminate leakage.

To avoid this occurring; the fibreglass sheets might be produced in-situ on the vessels. The procedure described below could potentially be implemented on the vessels. This part of the design is critical to the onboard situation. Once installed these stop the water movement associated with unbaffled water channels. Note that even the smallest ship movement can produce quite exaggerated movements of water. This is the reason that baffles are constructed in both fuel and water tanks onboard vessels.

Firstly, the fibreglass sheets (delivered in rolls that could be several 100 m long) would be extended and laid out covering the whole deck floor. Then the sheets would be impregnated with polyester resin. The procedure would be repeated 2-3 times to produce 2-3 layers of the resin, depending on the type of fibreglass sheet used. After a few hours curing, an underfloor manure channel platform would be created that would be essentially in one piece with no possibility of leakage, no corners or potential blockage areas and would be easily cleaned and flushed. Finally, the slats would be installed on the beams, while securing the fibreglass platform in between the slats and the beams.

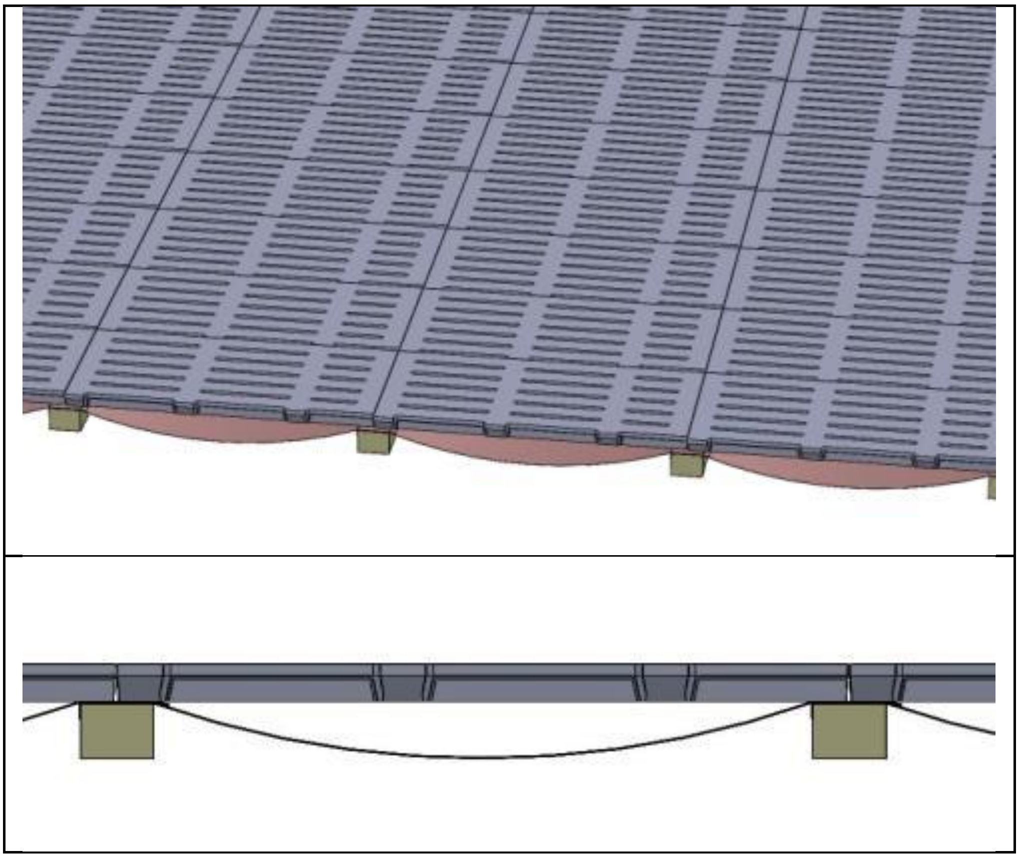

Figure 4: The envisaged layout of the slatted area with water proof under slat manure collection area from above and from the side-view

The material used to manufacture the slats would be reinforced concrete, but other materials could also be considered, such as steel, hardwood or plastic. However, relevant animal welfare considerations, engineering considerations, finished surface requirements (slip resistance, hardness, clean-ability etc.) all have to be taken into considerations, as explained previously

An automated cleaning and flushing system should also be installed with the proposed manure management system (Figure 5.). As the envisaged manure management system is designed with minimal vertical space usage (total assembly high would be only 25 cm to minimise space loss) there would be not much manure storage capacity under-slat, so continuous water flow would ensure essentially permanent manure removal. This would be achieved by pumping sea water from one end of the channel towards the outlet that could be a tank (temporary storage facility) that would facilitate filtering or pre-treatment of the manure before the cleaned water would be released back to the oceans (Figure 6.). The envisaged system would also significantly assist the industry to reduce the environmental impact of the operations.

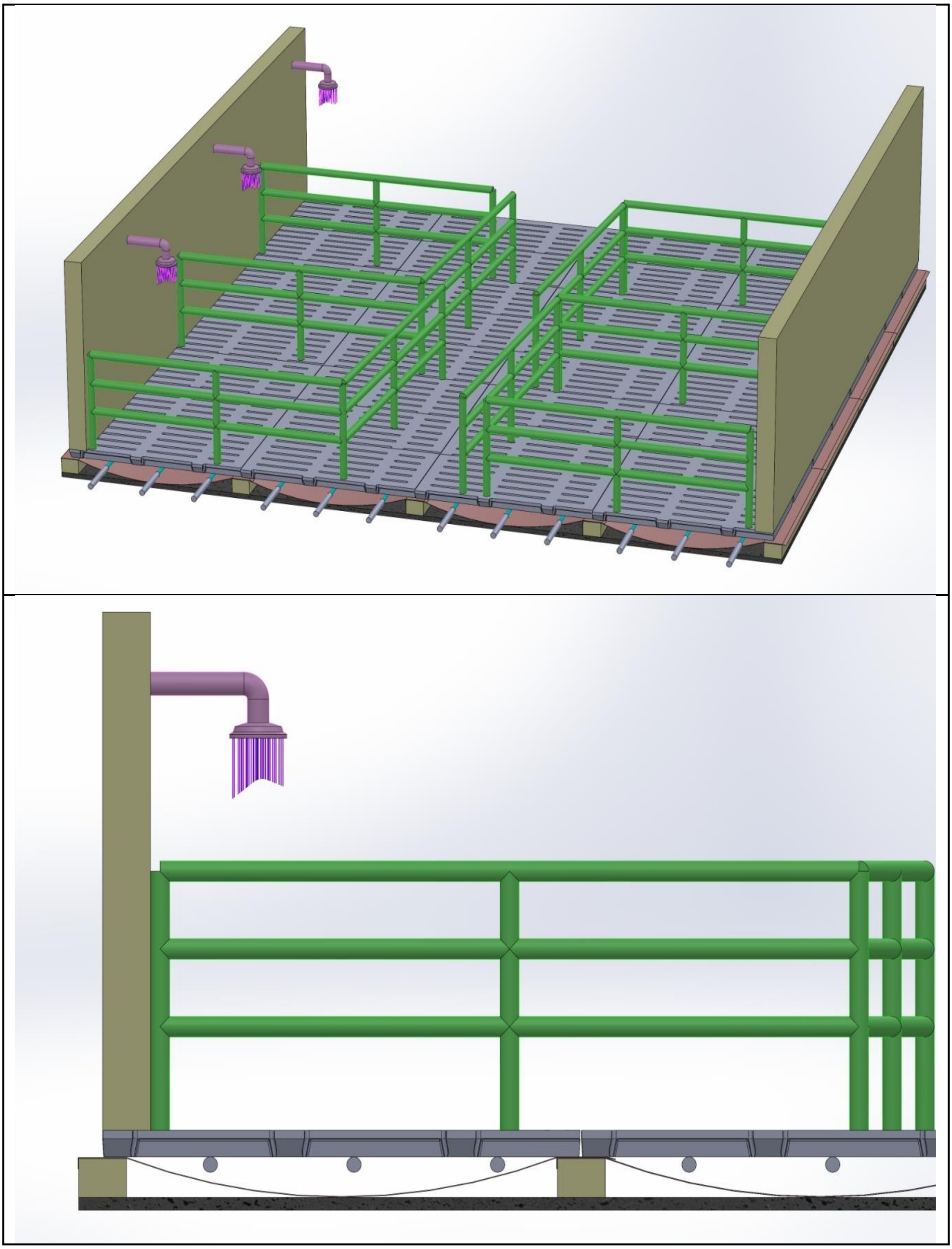

Figure 5: Concept drawing of the envisaged system completes with under slat drainage and cleaning system and above slat spray system to keep the slats permanently clean.

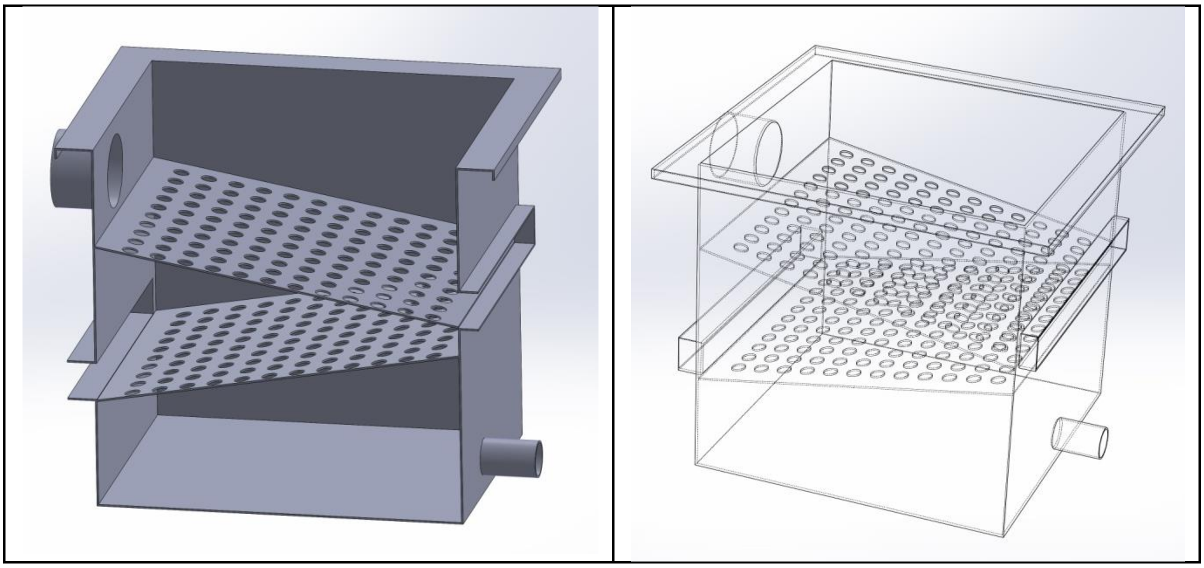

Figure 6: Concept drawing of the envisaged solid removal system to facilitate the separation of solid bedding (potentially large wood chip) from liquid waste and thus facilitates the pumping of liquid waste to a separate treatment system.

5.6.6.2 Potential benefits and drawbacks of the envisaged system

Potential benefits:

- No wash-downs procedures and thus no delays in feeding and watering the stock.
- Reduced labour use.
- Wash-downs can be automated at a daily frequency via spray heads secured on the pen walls.
- Reduction or elimination of organic bedding materials that would free up storage space, reduce variable costs, and improve profitability.
- No need to artificially create 'trim' during wash-down events thus increase the wear on engines.
- Animal welfare conditions would be improved significantly.

Potential drawbacks:

- Extra capital costs involved.
- Loss of vertical pen space.
- Significant additional weight affecting draft.
- Design and arrangement of main drainage pipes could be a challenge to ensure reliable four directional drainage.
- Quarantine inspections.

5.7 Bedding additives

There has been a considerable amount of industry work undertaken to determine the possible benefits bedding additives (as distinct from bedding materials) (McCarthy 2004). Most of the industry work has been directed toward how they might be used to control odour

(Philippe *et al.* 2011). It is conceivable that bedding additives could perform other functions such as maintaining consistency, providing rivulets for water drainage and/or ‘wetting’ type agents to promote evaporation on the bedding surface.

The addition of various acids (e.g. acetic acid) has been shown to effectively reduce NH_3 levels for a period. However, the effect is short lived and has had limited practical application (McCarthy 2004). Both gypsum and lime have been shown to affect the pH of bedding but again these have limited practical application (Accioly *et al.* 2004). There are a plethora of other products that claim to mitigate odour but the mode of action is either not well understood or lacking in scientific rigour (Shi *et al.* 2001; Varel and Miller 2001; Sevi *et al.* 2003). Odour is composite of a number of different gases working together. In general, the sheer bulk of manure added to the bedding each day overwhelms any possible effects of bedding additives.

Based on current literature, it is not recommended that bedding additives be pursued as a knowledge gap nor is it a candidate for future research. There is nothing in the current literature that appears to have practical application to the on-board situation at this point in time. The possible exception is impregnating sawdust with some form of acid (acetic) prior to spreading.

5.8 Feed additives and dietary manipulation

As with bedding additives, there are a plethora of other feed additive products that claim to mitigate odour and/or reduce NH_3 but the mode of action is either not well understood or lacking in scientific rigour. The exceptions are gypsum and lime.

Dietary manipulation is the recommended way of reducing NH_3 on-board livestock vessels. Keeping protein levels to a minimum and/or utilizing a more digestible form of roughage have been shown to reduce NH_3 emissions and represent a practical and effective way of managing NH_3 (Tudor *et al.* 2003) in cattle and in other livestock species as well (Philippe *et al.* 2011).

There has been limited work completed to demonstrate how diet can affect the moisture content or consistency of manure and this is an area that begs further exploration (Frank *et al.* 2002). This is a significant knowledge gap and research in this area is highly recommended.

6 Reporting

As mentioned in the introduction of this report, this review acknowledges a hierarchy of reporting functions. The first is the reporting of monitoring information to onboard personnel. This information can be used to influence onboard decision-making and achieve the best possible outcomes on the voyage in question. The same information can be reported to the exporter (and possibly the ship owner) in a way that may influence the next or subsequent voyages (e.g. more sawdust/reduced stocking density). Information can also be collected that can be used to assist industry decision-making and/or support research and development. At another level the information meets the mandatory reporting requirements of the Government and supports both Industry and Government in determining regulation.

6.1 Current reporting requirements

The current reporting procedures stem from the ASEL requirements. These consist of a daily report that is forwarded from either the accredited stockman (or the accredited veterinarian) to the exporter and the government regulatory body (Department of Agriculture). This is only required for designated long haul voyages and is not required for short haul voyages. These reports are required to address a number of headings but they are not standardised due to the significant differences in ship sizes and design, The ASEL requirement and an example of daily report format is included in the Appendix (See Appendix 12.8).

With regards to bedding management and air quality, the requirement is fairly basic. Dry bulb, relative humidity and the derived wet bulb measurements for each deck are recorded and reported daily. The temperatures and humidity at the bridge (i.e. the ambient challenge) is also recorded and reported daily. In most cases this information is obtained manually by a designated shipboard person (using hand held equipment).

Although not required by ASEL, most exporters include a heading that describes bedding and will generally make comment on washing events and the use of sawdust (pers. comm.). This recognises the importance of sound bedding management on voyage outcomes.

ASEL also require an end of voyage (EOV) report that will generally make reference to the bedding management program utilized for the voyage.

6.2 Real time monitoring technologies

Some pilot work on data logging has been completed (McCarthy 2003a). Recommendations at the time were not to use data loggers routinely. The rationale for this was that the downloading and collation of data was time consuming and error prone and there were reservations about whether the data would be correctly interpreted (In most cases the information needs to be modified to encompass the different time zones. This added greatly to the complexity of collating the data).

New technology suggests real time monitoring with computer capture has more practical application and should be seriously considered by the industry. It is envisaged that this would automate much of the data collection and provide alerts both in terms of real time monitoring but also in terms of predicting deck conditions based on anticipated weather.

Real time monitoring in combination with deck mapping (based on CO_2 measurements and/or the wet bulb rise) would identify areas that may require washing and/or be at risk of heat stress (Parkin *et al.* 2007; Banhazi 2009b; Gray *et al.* 2013a, 2013b).

7 Review of Current Best Practice Guidelines

There is no formal industry document that outlines best practice air quality and bedding management guidelines. The most relevant document is the industry Stockman's manual that contains a substantial section on bedding management, Some best practice recommendations were made by Banney in the report entitled 'The management of bedding during the live export process' (Banney *et al.* 2009). The ASEL standards have sections that relate to both air quality and bedding management. AMSA regulations have sections that relate to bedding management.

This review made no findings that substantially change the current industry best practice guidelines as referred to in the above documents. The stockman's manual is written as a handbook for onboard stockmen and is written in a style that suits that purpose. The manual notes the differences between long and short haul voyages and echoes the findings of this review (i.e. that it is not possible to be prescriptive about best practice in regards to wash-down procedures due to the interplay of the large number of factors that contribute to making decisions on-board). The wording in the handbook is as follows:

> *"No single management method is considered to be the most appropriate on short voyages. Good results are obtained from a range of approaches, which include some voyages where no deck cleaning is done to those where decks are thoroughly washed every day. The decision on deck management for short haul voyages should be a matter for all of the parties involved to decide based on the individual circumstances faced during each voyage".*

Best practice involves understanding all the factors and implementing a dynamic program that is influenced by the way in which events unfold over the course of the voyage. The overarching statement in the manual is also valid:

> *"The general aim of the bedding management program is to clean the deck the least number of times during the voyage while maintaining animal comfort and preventing the build up of ammonia gas."*

It is noted, however, that the recent changes the MARPOL regulations are not described in the Stockman's manual and the inclusion of a brief discussion outlining these changes and the possible inclusion of the regulations themselves (in the Appendix) would assist stockman to be better prepared to factor these into their overall bedding management program.

The 'Banney' report includes quite detailed best practice recommendations in regards to long haul cattle voyages (Chapter 5.3) short haul cattle voyages (Chapter 5.4) and sheep voyages (Chapter 5.5). It is now somewhat out-dated (it was written in 2009) because both ventilation and vessel design has improved considerably onboard livestock vessels since it was written. However, the principles (and many of the specifics) remain the same. The only possible area of contention is in regards to NH3. Banney implies that NH3 emission (and levels) are directly linked to the bedding score (or pad moisture). More recent work (Banhazi

2013) suggests that NH_3 emissions are episodic and related to both pad moisture and a host of other factors (e.g. urine on bare floors, CO_2 accelerated release). There is also anecdotal evidence that the pad can become almost inert once the NH_3 substrate is exhausted. Further work is recommended to study NH_3 levels on a continuous basis (over time) to provide a better understanding of the linkages involved.

The ASEL requirements are quite specific and straightforward. It is not within the scope of this study to recommend any changes to the regulatory framework, however, it is noted that there is no reference to the MARPOL regulations (this may be seen as unnecessary). It is noted also that the requirement in regards to sawdust refers to quantity only (kg/m^2). This study has highlighted the very different quality characteristics (such as absorbency and the ability to provide a buffer against abrasive flooring) between many bedding products and subsequently the very different practises adopted by exporters. Further study that develops a set of quality assessment criteria that allows a cost-benefit comparison of bedding materials would also enable regulators to address this irregularity.

The review also noted that although not required by ASEL, most exporters include a heading that describes bedding and will generally make comment on washing events and the use of sawdust (industry pers. comm.). This recognises the importance of sound bedding management on voyage outcomes. Again, it is not within the scope of this study to recommend any changes to the regulatory framework, but it is noted that many daily report formats substitute the heading ‘faeces’ with the heading ‘bedding condition’. This reflects the way in which the industry perceives the relative importance of these headings. Again, further study that establishes repeatable linkage between pad moisture and a standardised bedding score would facilitate discussion around this subject.

The only other practice that may be underutilised is the use of CO_2 mapping to help identify areas that are less well ventilated. This is a simple procedure that could be easily utilised by onboard personnel.

There are a number of technological developments that could be addressed for the possible benefit of the industry (Parkin *et al.* 2007; Banhazi 2009b; Gray *et al.* 2013a, 2013b). These are noted within this document, but all of these would need to be trialled and refined before they could be commercially applied to the on-board situation. These are identified as knowledge gaps and accompanied by the appropriate recommendations for future research (see next chapter). These initiatives would provide a foundation for future improvement.

8 Recommendations for Future Research

Suggestions for further research have been noted throughout the body of the report. They are listed below under the same headings used in the report. Some of the research suggestions may lend themselves to be combined. Accordingly, there is a summary chapter included that prioritises the recommendations and makes suggestions as to how they might be packaged together.

8.1 Environmental Monitoring

In regards to environmental monitoring the following areas have merit enough to justify further investigation.

8.1.1 Automation of temperature and humidity readings

The current method of taking temperature and humidity readings is to allocate the task to a ship's officer (usually the 2nd or 3rd Officer but sometimes the cadet). Temperature and humidity readings are taken using either a whirling hygrometer, hand held digital devices or from wet and dry bulb thermometers that are placed strategically around the vessel. The task can take up to an hour and is undertaken at roughly the same time every day (usually around 11.00am). The routine varies from vessel to vessel. The ambient temperature is also recorded (usually adjacent to the bridge).

The use of dataloggers to record temperature and humidity was trialled in 2003, and whilst this provided an accurate and continuous record, several limitations were noted. Firstly, the dataloggers (at that time) had no real-time read out, so that the information was only available at the end of the voyage or if required earlier, the dataloggers had to be taken down whilst data was downloaded onto a computer. The downloading process was time consuming and prone to errors. One of the challenges was that most voyages travel through several time zones and data must be adjusted to be consistent with ship's time. Wet bulb temperature was derived from the temperature and relative humidity readings using a formula that accesses data from wet bulb tables. The positioning of dataloggers was all important (particularly at that time when ventilation system was not as even and/or predictable as those seen on the more recent vessels). This applies also to the ambient readings that should truly reflect the ambient challenge (i.e. ambient temperatures may be affected by wind direction; for example, if the bridge is forward and there is a following breeze with a net breeze from behind, bridge readings may be artificially high). The difference between the hold wet bulb temperature (WBT) and the ambient wet bulb temperature (WBT) should reflect the wet bulb rise and remain unchanged throughout the voyage.

In fact, once a fully enclosed vessel has been stowed and calibrated against stocking density and breed type of the animals, the anticipated wet bulb rise can be mapped for the entire vessel and determined from a single ambient reading. This is not to suggest that hold readings should not be taken since any discrepancy between the actual and anticipated wet bulb rise should be investigated. It may point to a mis-description of the cargo, ventilation deficiency or an unidentified heat source. Furthermore, if the animal factors (as calculated by the industry heat stress assessment (HSRA) model) are known and mapped against the stowage plan, alerts could be generated based on both real time and anticipated weather. These alerts could be further sophisticated by factoring an accumulated heat load as is utilized by the Australian feedlot heat load forecasting model and measured in heat load units (HLU). Heat risk assessment would then be calculated pre-voyage, in real time and on the basis of an updated, location-specific weather forecast.

The preceding discussion highlights the significant benefits that could be accrued by introducing a more sophisticated and automated system of measuring temperature and humidity. This technology now exists and the capture of temperature and humidity values with computer capture allows the full spectrum of possibilities hinted to at above.

The following websites provide a brief indication of what is available:

Maxim integrated digital solutions

Elpro central monitoring systems

Base-Q - Building assessment system for environmental quality (Banhazi)

These are just a few examples of what is available. It is suggested that a study be undertaken that explores all the available technologies to determine a short list of possible equipment that is best suited to the onboard situation. The short listed equipment would then be evaluated for their suitability for both experimental and routine use. The way in which information can be linked to the stowage plan to provide a meaningful alert system could also be explored.

8.1.2 Continuous monitoring of ammonia

It is noted in the body of the report that the industry has yet to monitor NH_3 levels on a continuous (time weighted) basis and has conducted very little formal monitoring since 2003. To date, NH_3 has been measured as a single point daily basis using hand held equipment. Monitoring equipment is now far more sophisticated. As stated previously, continuous measuring techniques exist but the equipment requires mains power and is relatively expensive.

There is no doubt that further research that determines NH_3 levels over time (using the equipment described) would be informative and address this identified knowledge gap. It would determine ammonia emmisions and confirm the episodic nature of NH_3 emissions and the links to the factors evolved. This, combined with a better understanding of pad moisture (and the pad generally) would facilitate a better understanding of the cause and effect in the onboard situation.

If the industry wishes to use a time-weighted average as its benchmark, it should be able to demonstrate the effect of NH_3 not simply on the basis of a single point level but also in terms of duration of exposure.

It is envisaged that further investigation into NH_3 would be looked at in three stages: Firstly, this study notes that research into NH_3 is a 'moving feast' with a large body of work that is being added to on a daily basis. In recognition of this, and in anticipation that there may be some lag in time before further research is commenced, it is suggested that further investigation into NH_3 production and management be preceded by a more targeted literature review.

The second part of the study would explore the equipment that might be suitable to measure NH_3 onboard and reduce this to a well-considered short list. This equipment could then be trialled in pilot studies to assess the practical aspects involved. It is envisaged that the equipment would initially have experimental application, but the possibility of equipment that suits a more routine usage could also be evaluated.

Once the choice of equipment has been determined, the equipment could then be trialled to generate the information required. NH_3 and NH_3 levels are a well-scrutinised area of interest and the industry would get good value from the work that is suggested.

8.1.3 Methane emissions from livestock vessels

Very little work has been undertaken to determine (or confirm) either methane levels and/or methane emissions from livestock vessels. Methane is not considered to be a health risk to either animals or humans on the vessels but methane is of significance due to its contribution to global greenhouse gas emissions. For this reason, it is suggested that investigations into methane emissions be undertaken separately and not included in the environmental monitoring suggested above. A life cycle assessment for the livestock export trade has been completed but the results are based on estimations. This study was undertaken in 2011 (Eady 2011).

The overall emissions were estimated (using information on the quantity and quality of feed consumed by the animals and the size of the animals involved) and followed the international standards for estimating the carbon footprint of a product (PAS2050, British Standards 2008). The GHG emissions that were calculated included:

- Methane (CH_4) from enteric fermentation (digestion) of fodder
- Methane (CH_4) from manure
- Direct nitrous oxide (N_2O) from dung and urine
- Indirect nitrous oxide (N_2O) emissions

Work that determines both the level and patterns of methane emission would contribute toward validating the LCA assumptions and provide an insight into the factors involved. Unlike trying to measure emissions from livestock in a grazing situation, the measurement of methane on fully enclosed livestock vessels would be relatively straightforward with a relatively small number of strategically place measuring points. The most defining part of the study would be the choice of equipment.

Monitoring would look to validate the assumptions of the LCA study. It could also look for diurnal variation, variation between breed types and variation between feed type and intakes. Experimentally it could look at the effect of feed additives.

This work is not seen as being particularly urgent, but it is an opportunity for the industry to face up to its global responsibilities and contribute to the bigger debate. A project of this nature may attract alternative funding (e.g. Filling the research gaps – FTRG).

8.1.4 The measurement of dust and airborne micro-organisms

This study identified that there is a growing body of work that dust, when combined with other airborne contaminants such as NH_3 and remnant microorganisms is a major contributing factor in the pathogenesis of respiratory disease.

Dust measurement is not a simple process but techniques exist. It is suggested that the industry explore these techniques and determine the method that is best suited to the onboard situation (either experimentally or as a routine measurement).

8.2 Bedding Management

In regards to bedding management the following areas have merit enough to justify further investigation.

8.2.1 Quality assessment criteria for bedding materials

Whereas ASEL is quite specific about the amount of bedding material required for long haul voyages, it is less specific about the quality of the bedding and its suitability to do the job required.

As indicated in the body of the report, there are huge differences between some of the products used by the industry to meet the bedding requirements. Kiln dried, compressed, pine shavings are, by far, the best product with superior qualities in regards to absorbency, grip, animal comfort, the ability to extend the pad for a long period and the ability to provide an effective protection against abrasive flooring.

Other products that are used within the industry include a fine (usually red) ‘sawdust’ that is often referred to as ‘potting mix’. This is a much cheaper option. This product is often quite moist and offers very little absorbency, grip and/or protection from an abrasive surface and extends the pad for a far shorter period than the pine shavings. The product is more easily removed from the hold at washdown. Other bedding materials can be used (e.g. rice hulls) and each bedding material will have different qualities in regards to its capability to meet its task.

In regards to the transport by sea, ASEL states that:

> *“Cattle and buffalo exported on voyages of 10 days or more must be provided with sawdust, rice hulls or similar material to be used*

> *exclusively for bedding at a rate of at least 7 t or 25 m^3 for every 1000 m^2 of cattle pen space."*

and that….

> *"When bedding is used, it must be maintained in adequate condition to ensure the health and welfare of the livestock."*

It is suggested, therefore, that each product be assessed against a list of pre-determined quality criteria. This could include:

- absorbency
- buffer against feet abrasions
- dust
- ease of removal
- animal comfort, and
- cost.

This would assist exporters in their choice of bedding material. Where possible, these products would be evaluated quantitatively, however criteria such as animal comfort would require some sort of subjective score.

8.2.2 Determination of pad moisture levels

As stated in this study, the management of the manure pad is critical to long haul voyage outcomes and is generally well understood by industry personnel. Despite this, little is known about the actual moisture content of the pad and how this may change over the course of a voyage. Unpublished work by McCarthy (2003) has shown that pad moisture can be measured using a soil moisture probe and the accuracy of the probe can be calibrated (or confirmed by the oven drying samples). The soil probe was shown to be less accurate at high levels of moisture and better equipment may be available to study manure with high moisture content.

The same work mentioned above, showed how the manure pad (in the case of sheep) can layer in a way that reflects the conditions experienced during the course of a voyage. A profile is created with each layer demonstrating a different moisture content. At some point, if the moisture level increases, the moisture may diffuse through the pad and a more even profile will develop. This will be influenced by a tendency for moisture to gravitate to the bottom of the pad and by the hygroscopic nature of the manure that will tend to draw moisture back to the surface. These dynamics influence the ability of the ventilation system to dry the pad.

A further finding of the work mentioned above, was a measurable and repeatable link between a visual bedding score and pad moisture. Similar links were demonstrated in relation to a pugging score. It should be noted that the current ASEL daily reporting requirements do not include any reference to bedding, however, in recognition of its importance, many exporters include a heading on bedding in their daily reporting template.

In many cases this includes a bedding score but understandably, these vary from exporter to exporter and there is a need to better define and standardize the scores used. Furthermore, a different scoring system is required for cattle (as distinct from sheep) due to the entirely different nature of the pad and its associated management.

On the basis of the discussion above, it is suggested that pad moisture be investigated in more detail to gain a better understanding of the pad and its linkage to the factors that influence it over the course of a voyage. Once this is achieved it is recommended that a reference to bedding is included in the mandatory daily reporting requirements.

8.2.3 Determination of the overall water balance equation

The first and primary task of the ventilation onboard livestock vessels is to remove heat and water vapour from the animals. In most cases this will also address the task of removing any potentially noxious gases from the hold (as discussed previously). The other task of the ventilation is to lift moisture from the pad. Whereas the task in regards to heat and water vapour had been well researched (and quantified), the task in regards to lifting moisture form the pad has been less researched and is less understood. Ventilation is generally designed so that animal’s get first exposure to the air as it moves through the hold. Air generally reaches the surface of the pad later in the mixing phase of its passage through the hold. This air has the least potential to lift moisture, but whatever potential is left is used to lift moisture from the pad. This potential can only be accessed for the finite time that the air is in the hold.

The extent to which moisture can be added to the air is almost entirely limited by the extent to which it is saturated (i.e. its relative humidity), but it is also influenced by the way in which air is passed over the pad’s surface and the resultant gradients in water vapour pressure involved. These dictate the rate at which moisture is evaporated and consequently the amount of moisture evaporated.

Consequently, the ability to lift moisture from the pad is highly dependent on the ventilation design and the environmental conditions experienced over the course of a voyage. An added factor is the polydipsia/polyuria that is triggered by high temperatures. This can lead to the ventilation system being overwhelmed and the pad deteriorating (at least in terms of moisture levels) during periods of high temperature and humidity.

It has been noted previously that, because of the hygroscopic properties of manure, it is not necessary to remove all the moisture that is added to pad via faeces and urine. The water balance required is simply the amount of moisture to maintain the pad at a consistency that provides animal comfort. The determination of the overall water balance equation would therefore assist in management decisions and may lead to better practice. It may also influence ventilation design and be of interest to future ship builders.

Discussion around the water balance equation would include ventilation theory in regards to pen air turnover, air exchanges, residence times and mixing ratios. It would also need to examine the way in which heat is shed from the animal and discuss heat loss compartments (both evaporative and convective). It would also make reference to the enthalpy equation and the wet bulb rise. It would examine the potential to add moisture to the air both in regards to its dry bulb temperature and the capacity remaining after water vapour has been added via evaporation from the animal. It would explore how gradients drive the rate of evaporation and look at how jetting and/or ventilation design might influence these gradients. The findings of the previous heading (determination of pad moisture levels) would complement these investigations.

8.2.4 Linkages between feed type and manure consistency

This study identified that there may be strong linkages between feed type and manure consistency. There are links to both roughage and fibre content. It remains to be seen whether this may provide a real strategy for managing the pad, and further is required to determine whether or not it affects the overall water balance (i.e. drier manure is of little benefit if water consumption remains the same and more water is shed in the form of urine). This work could link to work that is directed toward determining pad moisture.

8.2.5 Desiccated manure as a bedding material

Manure has a surprising ability to absorb and hold water. It has ten times the absorbing capacity than sawdust (Jeppsson 1999b). As the pad builds, so too does the amount of water in the hold and this is an important factor in the stability calculations made on livestock vessels on a routine basis. Furthermore, those who have dealt with manure will verify that water rarely drains out of manure due to its highly hygroscopic nature. In fact, it will only really ‘run away’ after it turns to slurry or is diluted out and washed away during a washing event.

The converse is also true. Manure can be dried and used as very suitable bedding with exceptional hygroscopic capabilities. Furthermore, livestock vessels are not the only source of manure, and there is an abundance of manure stored beneath sheds in sheep feedlots and/or in assembly centres that prepare animals prior to export. Currently this manure is bagged and sold as fertilizer. It may have a much higher value if utilized as bedding (especially when compared to sawdust which can sometimes reach a price of over $AUD 1,500 per tonne).

The major obstacle may be related to biosecurity issues since the manure may never become completely sanitized or inert. Moreover, it has been explained that remnant microorganisms have the potential to trigger strong immune responses even if the organisms are not viable. This may only be a problem if the bedding becomes dusty, but it is a factor that must be considered.

Techniques to remove water from manure have been proven commercially viable (Michigan State University 2014). Further modification of these techniques may allow this technology to have application onboard livestock vessels whereby manure could be processed onboard. This is a ‘blue sky’ vision but not completely out of the realms of possibility.

8.2.6 Acid impregnated sawdust to lower ammonia levels

Adding acetic acid to bedding has been shown to be an effective short-term mitigation strategy to reduce NH_3 levels. NH_3 levels tend to be high during the loading of livestock (particularly in sheep) as urine falls on bare floor. This tends to dissipate fairly quickly as the pad takes up moisture. Impregnating sawdust with acid (or other materials) may prove to be a real and practical fix for this short-term problem. This work could link into the work that is directed at the continuous monitoring of NH_3 levels.

8.2.7 New flooring possibilities

This report contains quite a large chapter that describes a possible slatted system of flooring that would allow manure to be removed on a continuous basis. It requires considerable refinement before it could be applied to the onboard situation. Whilst it is usually the role of commercial entities to design and develop livestock vessels, an industry based investigation may hasten the adoption of the proposed system should it be proven to be viable. It is therefore suggested that further investigation into new flooring possibilities be considered for future research. Investigations could also look into the use of rubber matting in hospital pens and any other proposed flooring systems.

8.2.8 Complying with MARPOL regulations

The MARPOL recommendations (Annex IV and 14) regarding to the discharge of sewage from vessels are included in the appendix (Appendix 10.1 and 10.2). The AMSA orders that underpin these recommendations are also included in the Appendix (Appendix 10.3). The recommendations make a distinction between 'treated' and 'untreated' sewage. Since there are no vessels in the current fleet that have the capacity to treat sewage onboard, the recommendations for untreated sewage apply.

The regulation for untreated sewage requires that sewage must be discharged at least 12 nautical miles from the nearest land and at a rate that depends on the ship's swept volume (which is a function of its speed, its breadth and its draft).

Accordingly, the discharge of sewage is permitted only if:

a) the ship is proceeding at a minimum rate of 4 knots and…
b) the sewage is discharged at a maximum discharge rate of 1/200,000 of its swept volume.

The formula used to calculate this rate is as follows:

$$DR_{max} = 0.00926\ V\ D\ B$$

Where: DR_{max} is the maximum permissible discharge rate (m^3/hr)

V is the ship's average speed over the period (in knots)

D is draft (m)

B is breadth (m)

From a practical point of view, it should be noted that although the ship's breadth will be fixed, both ship's speed and draft will vary considerably both during the voyage as fodder and fuel are consumed and after discharge whereby sewage may be removed on the return voyage after the cargo has been unloaded. To cater for this, most vessels usually draw up a table that reflects the range of possibilities specific to the vessel involved. This may appear as follows:

Table 20: Rate of effluent discharge*.

		DISCHARGE RATE (m^3/hr)			
Speed (knots)	4	6	8	10	12
Draft (m)					
5	4.63	6.94	9.26	11.57	13.89
6	5.56	8.33	11.11	13.89	16.67
7	6.44	9.72	12.96	16.20	19.45
8	7.41	11.11	14.82	18.52	22.22
9	8.33	12.50	16.67	20.83	25.00

*Source: MARPOL Annex 14.

Note that the discharge rate determined above refers to an average over a 24-hour period. Although this may apply on the return (unloaded) voyage on some vessels, for the most part planned washdown events do not normally take more than about 8 hours (usually much less). Consequently, the default position applies whereby the maximum rate must not exceed 20% more than the rate calculated above, if the rate is to be measured on an hourly basis. This rate is rarely exceeded under normal washing conditions.

A further complication is MARPOL's increasing use of designated special areas. The Persian Gulf is a designated special are, however, so far the restrictions do not apply to the removal of sewage. As best can be ascertained, the only designated area where the discharge of sewage is currently prohibited is the Baltic Sea. There is some confusion in this regard and ship's personnel have differing views on this subject.

The other area of contention is in regard to the assumed moisture content of sewage. The rate determined above treats sewage on the basis of volume (m^3). The MARPOL recommendations note that the use of sea water to assist in washdowns effectively dilutes the sewage (in this case manure), prior to discharge and recognises that this offers a *"higher level of protection to the marine environment due to mixing prior to the actual discharge in addition to the mixing action of the ship's wake".* Essentially this offers no concession in regards to the use of sea water in the washdown process. The point of contention, however, is that the regulation treats sewage (manure) as a homogenous material. The preceding discussion points out the very real differences between sheep and cattle manure and how the moisture content of manure can vary over the course of the voyage.

There are many situations where ship's staff may wish to wash extensively prior to arriving at critical areas. For example, larger vessels that wish to travel through the Red Sea, and carry on through the Suez may wish to wash down extensively prior to entering the canal. If washing is restricted in the Red Sea (either due to proximity to land or due to discharge rate), then some parts of the vessel may need to be washed prior to entering the Red Sea.

These areas on the vessel would then incur an extended period without a further washdown. In this situation ship staff may wish to 'push the envelope' (within the legal limits) in the interests of the animal's welfare. It is important then that everyone is 'on the same page' with a consistent industry interpretation of the MARPOL restrictions. Other critical areas exist (e.g. prior negotiating the Yangtze River, the Persian Gulf and in situations where there is inadequate time to wash down between ports in voyages involving multiple port discharge).

There is no easy way to calculate either the weight or volume of manure in a hold at the time of washing. In practice, this is estimated as a percentage of the fodder consumed from the onset of the voyage (or since the last wash). The industry standard suggests a dry matter figure of 30% (see Table 14). Note that this is a dry matter figure and the total volume of manure would include a significant amount of water.

Again there appears to be some conjecture as to how much water content to include in the calculations. Furthermore, ship's captains demonstrate different attitudes towards these restrictions. Some have a quite laisse-faire approach whilst others take a highly conservative position. It is imperative that shipboard personnel (stockmen and veterinarians) have a strong and accurate understanding of the MARPOL restrictions to ensure that animal welfare is not compromised unnecessarily.

Given the level of conjecture involved, it is suggested that the industry re-convene ship owners and AMSA personnel to determine a consistent industry approach to the restrictions. The work suggested earlier (investigating pad moisture) would provide accurate assessment of the likely moisture levels. Once a consistent approach is agreed upon, this should be included as a heading in the industry Stockman's manual and addressed in the stockman's accreditation course. It could also be sent to accredited stockmen and veterinarians as an industry circular. This is an important issue with significant implications.

Note that this recommendation does not include any investigation into the onboard processing of manure. As noted in the body of the report, techniques exist to remove moisture and process manure through pyrolysis and/or carbonisation. Under current restrictions the onboard processing of manure is probably unwarranted. However, it is conceivable that these techniques may provide an additional income stream and/or prove to be commercially viable. It is therefore suggested that the industry keep an open mind in regard to the onboard processing of the manure (especially in the case of new ship builds).

8.3 Reporting

Although many of the initiatives suggested above can be progressed by individual business houses and the industry generally, there may be instances where a co-ordinated approach is required involving LIVECORP (ASEL), DAFF and/or AMSA.

8.3.1 Improved reporting of temperature and humidity

The automated temperature and humidity reading suggested above might have implications for the way in which these parameters are reported in either the daily or final voyage reports. This may require them to be formally addressed in a group forum.

8.3.2 Improved reporting of bedding management

Similarly, the suggestion to formally include bedding as a heading in the daily report format requires due process. It also could be addressed in a group forum.

8.4 Summary of Recommendations

It would be prudent to combine the environmental monitoring into a single project, (with the exception of methane which should be managed and possibly funded separately). The investigations would therefore determine the best way to automatically capture real time temperature, humidity, NH_3 and dust as described earlier. It would also look at the possibility of using the captured information to provide alerts based on both actual and forecast weather conditions. This is a high priority research project.

The investigation into pad moisture and the determination of the overall water balance equation could also be combined. This project also leads to improvements in reporting. This has also been designated as a high priority research project. The other project that has been designated as a high priority is the development of quality assessment criteria for bedding materials. This addresses an anomaly within the industry. The objectives of these projects are outlined in Table 21. It is noted that the environmental monitoring project may not necessarily include a more targeted investigation into NH_3. A more targeted investigation would include a focussed literature review and the evaluation of any identified mitigation measures (such as the use of acid impregnated sawdust). As suggested, methane should be investigated as a stand-alone project. It would determine both methane levels and methane emissions. The objectives of a project that addresses MARPOL restrictions and a project that investigates new flooring possibilities are outlined in Table 22. All four of these projects have been designated as medium priority.

Table 21: Recommendations for future research – High priority

Possible Project Title	**Objectives**	**Priority**
Improved environmental monitoring on livestock vessels.	1. Identify the best automated technique for measuring and monitoring temperature and humidity on a continuous basis on livestock vessels 2. Identify the best technique for measuring and monitoring NH_3 levels on livestock vessels and determine an industry time-weighted average. 3. Identify the best technique for measuring dust and airborne micro-organisms on livestock vessels 4. Identify and trial the real time capture of temperature and humidity information (with the aid of computers) and investigate how this information could be linked to the heat stress risk assessment (HSRA) model to provide alerts based on actual and forecasted weather information.	*****

	5. Determine how improved environmental monitoring might be reported in keeping with ASEL requirements.	
Determination of pad moisture levels on livestock vessels.	1. Identify the best method of determining pad moisture levels on livestock vessels. 2. Monitor pad moisture levels in both sheep and cattle pads over the course of a voyage. 3. Identify the factors that affect pad moisture in both the sheep and cattle pad. 4. Determine the overall water balance equation involved. 5. Establish the linkage between a visual bedding score and pad moisture in both the sheep and cattle pad. 6. Review the ASEL requirements and add a bedding management consideration to the daily reporting requirements.	*****
Quality assessment criteria for bedding materials used on livestock vessels.	1. Develop a set of quality assessment criteria for bedding materials used on livestock vessels. 2. Compare bedding materials based on the identified criteria. 3. Review ASEL requirements in regards to the provision of bedding.	*****

Table 22: Recommendations for future research – Medium priority

Possible Project Title	Objectives	Priority
Further investigation into NH_3 mitigation strategies on livestock vessels.	1. Conduct a targeted literature review aimed at NH_3 mitigation strategies in the livestock industries (in acknowledgement of the large bulk of existing and new material available). 2. Identify and/or refine both existing and new NH_3 mitigation measures that have practical application to the onboard situation. 3. Trial both existing and new measures that might provide the industry with further tools to mitigate NH_3 levels on livestock vessels.	****

Complying with MARPOL requirements.	1. Initiate an industry workshop (ship owners and AMSA) to determine a consistent industry approach to the MARPOL requirements. 2. Use the findings of the pad moisture investigations to better identify quantity of manure involved. 3. Document the findings of the workshop and include this as a heading in the industry Stockman's Manual.	****
Investigation into methane levels and emissions from livestock vessels.	1. Identify the best technique for monitoring methane levels on livestock vessels. 2. Identify the best technique for measuring methane emissions from livestock vessels. 3. Determine time-weighted averages for both methane levels and emissions.	***
Investigation into new flooring possibilities on livestock vessels.	1. Identify possible flooring alternatives that have practical application to the onboard situation. 2. Determine pros and cons for each of the identified alternatives. 3. Evaluate the practicalities of developing small scale prototypes to test and trial possible alternatives. 4. Compare these to existing industry flooring. 5. Test small scale prototypes in sea trial scenarios to evaluate possible application. 6. Discuss findings in the context of what is currently known about ship's flooring.	***

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10 Appendix

10.1 MARPOL – Annex IV

Annex IV: Regulations for the Prevention of Pollution by Sewage

Regulation 8

Discharge of sewage

(1) Subject to the provisions of regulation 9 of this Annex, the discharge of sewage into the sea is prohibited, except when:

(a) the ship is discharging comminuted and disinfected sewage using a system approved by the Administration in accordance with regulation 3(1)(a) at a distance of more than 4 nautical miles from the nearest land, or sewage which is not comminuted or disinfected at a distance of more than 12 nautical miles from the nearest land, provided that in any case, the sewage that has been stored in holding tanks shall not be discharged instantaneously but at a moderate rate when the ship is *en route* and proceeding at not less than 4 knots; the rate of discharge shall be approved by the Administration based upon standards developed by the Organization; or

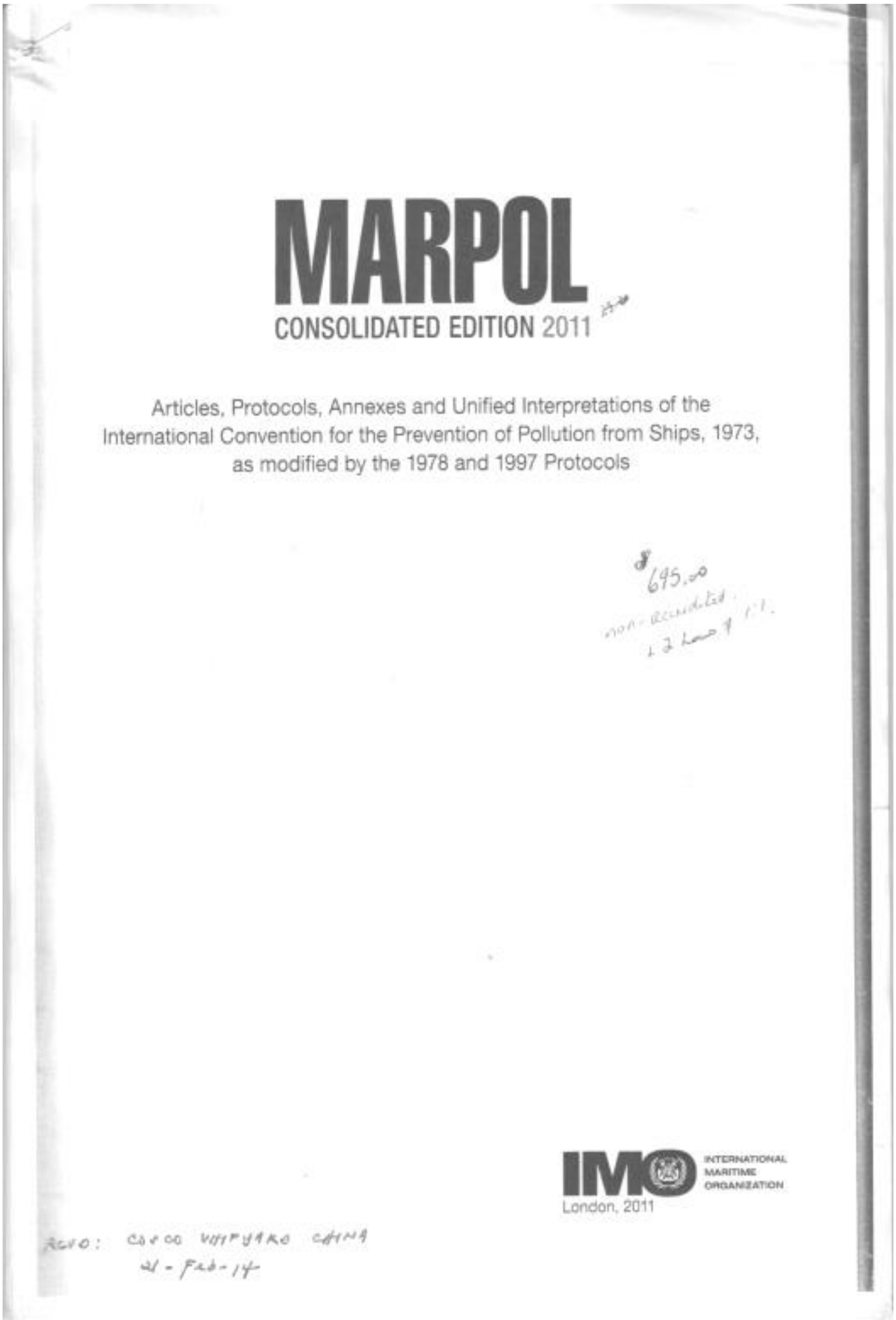
(b) the ship has in operation an approved sewage treatment plant which has been certified by the Administration to meet the operational requirements referred to in regulation 3(1)(a)(i) of this Annex, and

(i) the test results of the plant are laid down in the ship's International Sewage Pollution Prevention Certificate (1973);

(ii) additionally, the effluent shall not produce visible floating solids in, nor cause discoloration of, the surrounding water; or

(c) the ship is situated in the waters under the jurisdiction of a State and is discharging sewage in accordance with such less stringent requirements as may be imposed by such State.

10.2 MARPOL – Annex 14



MARPOL

CONSOLIDATED EDITION 2011

Articles, Protocols, Annexes and Unified Interpretations of the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the 1978 and 1997 Protocols

$695.00

non-accredited

IMO INTERNATIONAL MARITIME ORGANIZATION

London, 2011

Rcvd: COSCO SHIPYARD CHINA

21-Feb-14

ANNEX

RECOMMENDATION ON STANDARDS FOR THE RATE OF DISCHARGE OF UNTREATED SEWAGE FROM SHIPS

1 INTRODUCTION

1.1 Regulation 11.1.1 of the revised Annex IV of MARPOL 73/78 requires that untreated sewage, which may be discharged at more than 12 nautical miles from the nearest land, should not be discharged instantaneously but at a moderate rate of discharge when the ship is en route and proceeding at a speed not less than 4 knots, while the rate should be approved by the Administration based upon standards developed by the Organization. This Recommendation provides the standard and guidance for the approval and calculation of a moderate rate of discharge.

1.2 A moderate rate of discharge applies to the discharge of untreated sewage that has been stored in holding tanks.

1.3 This standard does not incorporate the dilution of sewage with water or greywater into calculations of the discharge rate. Therefore the rate is a conservative estimate and it is recognised that discharges of sewage in accordance with this standard will present a higher level of protection to the marine environment due to mixing prior to the actual discharge in addition to the mixing action of the ship's wake.

2 DEFINITIONS

2.1 *Swept volume* means ship breadth x draft x distance travelled.

2.2 *Untreated sewage* means sewage that has not been treated by a type approved sewage treatment plant, or that has not been comminuted and disinfected.

3 DISCHARGE RATE

3.1 The maximum permissible discharge rate is 1/200,000 (or one 200,000th part) of swept volume as follows:

$$DR_{max} = 0.00926\ V\ D\ B$$

Where:

DR_{max} is maximum permissible discharge rate (m^3/h)
V is ship's average speed (knots) over the period
D is Draft (m)
B is Breadth (m)

3.2 The maximum permissible discharge rate specified in 3.1 refers to the average rate as calculated over any 24 hour period, or the period of discharge if that is less, and may be exceeded by no more that 20% when measured on an hourly basis.

4 APPROVAL OF RATE BY ADMINISTRATION

4.1 The Administration should approve the rate of discharge specified in 3.1 based upon the ship's maximum summer draft and maximum service speed[1]. Where sewage is to be discharged at a different combination of draft and speed one or more secondary discharge rates may also be approved[2].

5 METHOD OF CALCULATION

5.1 The calculated swept volume of the ship is to be determined for drafts up to and including the summer draft assigned in accordance with Article 3 of International Convention on Load Lines, 1966.

5.2 Where a ship is to discharge sewage from a holding tank using a pump calibrated at a fixed rate, the pump can either be:

- calibrated at a the rate permitted at 4 knots; or
- calibrated for a specific minimum ship's speed in excess of 4 knots.

5.3 Where the intended actual discharge rate exceeds that permissible at 4 knots, the actual discharge rate may need to be reduced or the speed increased. The rate and speed is to be detailed in the approval issued by the Administration.

6 COMPLIANCE WITH THE RATE

6.1 Before undertaking a sewage discharge in accordance with this standard, the crew member responsible for sewage operations should ensure that the ship is en route, is more than 12 nautical miles from the nearest land and the navigation speed is consistent with the discharge rate that has been approved by the Administration. Ships with high discharge requirements are encouraged to keep notes of calculations of the actual discharges to demonstrate compliance with the approved rate.

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1 The attention of ship operators and personnel is drawn to the reduction in permissible rate of discharge at reduced draft and/or speed.

2 Presentation may be tabular, refer to table below. For ships other than those having a high requirement for untreated sewage discharge, such as passenger ships and livestock carriers, the discharge rate criterion will generally not be exceeded at ship speed of 4 knots.

DISCHARGE RATE (m^3/h)					
SPEED (kt)	4	6	8	10	12
DRAFT (m)					
5	4.63	6.94	9.26	11.57	13.89
6	5.56	8.33	11.11	13.89	16.67
7	6.48	9.72	12.96	16.20	19.45
8	7.41	11.11	14.82	18.52	22.22
9	8.33	12.50	16.67	20.83	25.00

***

10.3 AMSA – Marine Order 96 – Marine pollution prevention - 2013

Australian Government
Australian Maritime Safety Authority

AMSA MO 2013/18

Marine Order 96 (Marine pollution prevention — sewage) 2013

I, Mick Kinley, Chief Executive Officer of the Australian Maritime Safety Authority, make this Order under subsection 342(1) of the *Navigation Act 2012* and subsection 34(1) of the *Protection of the Sea (Prevention of Pollution from Ships) Act 1983*.

9 December 2013

Mick Kinley
Acting Chief Executive Officer

MO96 issue-131204Z docx

Contents

Division 1 Preliminary

1 Name of Order

This Order is *Marine Order 96 (Marine pollution prevention — sewage) 2013*.

2 Commencement

This Order commences immediately after the commencement of *Marine Order 1 (Administration) 2013*.

3 Repeal of *Marine Order 96*

Marine Order 96 (Marine pollution prevention — sewage) 2009 is repealed.

4 Purpose

This Order:

(a) gives effect to Annex IV of MARPOL (which deals with prevention of marine pollution by sewage from ships); and

(b) provides for matters for Chapter 4 of the Navigation Act (which deals with prevention of pollution from vessels); and

(c) prescribes matters for Division 2 of Part IIIB of the Pollution Prevention Act (which deals with the discharge of sewage in areas other than the Antarctic area).

5 Power

(1) This Order is made under both the Navigation Act and the Pollution Prevention Act.

(2) The following provisions of the Navigation Act provide for this Order to be made:

(a) section 130 which provides that the regulations may provide for pollution certificates;

(b) section 314 which provides that the regulations may prescribe various matters about certificates;

(c) subsection 339(1) which provides for regulations to be made prescribing matters required or permitted to be prescribed, or which are necessary or convenient to be prescribed for carrying out or giving effect to the Act;

(d) paragraph 340(1)(c) which provides that the regulations may provide for giving effect to MARPOL;

(e) subsection 342(1) which provides that AMSA may make orders about matters that can be provided for by regulations.

(3) The following provisions of the Pollution Prevention Act provide for this Order to be made:

(a) paragraphs 33(1)(a) and (b) which provide for regulations to be made prescribing matters required or permitted to be prescribed, or that are necessary or convenient to be prescribed for carrying out or giving effect to the Act;

(b) paragraph 33(1)(c) which provides for regulations under paragraphs 33(1)(a) and (b) to be made to give effect to MARPOL;

(c) subsection 34(1) which provides that AMSA may make orders for any matter (other than the imposition of penalties) for which provision may be made by regulation.

6 Definitions

In this Order:

2012 Guidelines means the *2012 Guidelines on implementation of effluent standards and performance tests for sewage treatment plants* adopted by IMO Resolution MEPC.227(64), as in force from time to time.

Annex IV means Annex IV of MARPOL.

existing passenger ship has the same meaning as in Annex IV.

ISPP certificate (or ***International Sewage Pollution Prevention Certificate***) means a certificate that:

(a) is a pollution certificate relating to sewage issued under section 132 of the Navigation Act; and

(b) is in the form of the International Sewage Pollution Prevention Certificate set out in the Appendix to Annex IV.

new passenger ship has the same meaning as in Annex IV.

Note 1 Some terms used in this Order are defined in *Marine Order 1 (Administration) 2013*, including:

- IMO
- MARPOL
- Navigation Act
- Pollution Prevention Act.

Note 2 Other terms used in this Order are defined in the Navigation Act or Pollution Prevention Act including, in the Navigation Act:

- AMSA
- inspector
- recognised organisation (for organisations that have been prescribed for the definition — see *Marine Order 1 (Administration) 2013*)
- regulated Australian vessel.

Note 3 Most provisions of this Order are expressed using terms used in the Navigation Act (eg ***vessel***). However, some provisions of this Order that are made solely under the Pollution Prevention Act use terms used in that Act (eg ***ship***). An example of a provision using terms used in the Pollution Prevention Act is section 22.

Note 4 A copy of IMO documents mentioned in this Order is available on the IMO website at http://www.imo.org. Information on obtaining copies of IMO documents is also on AMSA's website at http://www.amsa.gov.au.

Note 5 For delegation of AMSA's powers under this Order — see the AMSA website at http://www.amsa.gov.au.

7 Application of this Order

(1) Subject to subsection 33(2) of the Pollution Prevention Act and section 12 of the Navigation Act, this Order:

(a) applies to:

(i) a regulated Australian vessel; and

(ii) a domestic commercial vessel; and

(iii) a recreational vessel that has Australian nationality; and

(b) other than Divisions 2 and 3 — applies to a foreign vessel to which Annex IV applies.

(2) For this Order, Annex IV is taken to apply to a vessel that is owned or operated by the Commonwealth and used, for the time being, on government non-commercial service.

8 Review of decisions

A decision under sections 9 to 11 of this Order is taken to be a reviewable decision for *Marine Order 1 (Administration) 2013*.

Note 1 Section 17 of *Marine Order 1 (Administration) 2013* provides for internal review of decisions. A person affected by the review of a decision under section 17 may apply to the Administrative Appeals Tribunal for review (section 18 of *Marine Order 1 (Administration) 2013*).

Note 2 Subsection 313(1) of the Navigation Act provides for review by the Administrative Appeals Tribunal of decisions under sections 132, 133 and 134 of the Act relating to pollution certificates.

Division 2 Systems, equipment etc required by Annex IV

9 Sewage systems

[MARPOL IV-9]

A vessel to which Annex IV applies and section 4.2 of the 2012 Guidelines does not apply must be equipped with:

(a) a sewage treatment plant approved by AMSA or a recognised organisation, that complies with:

(i) regulation 9 of Annex IV; and

(ii) for a system installed on a vessel after 31 December 2015 — IMO Resolution MEPC.227(64), other than the requirements of section 4.2 of the 2012 Guidelines; and

(iii) for a system installed on a vessel after 31 December 2009 and before 1 January 2016 — IMO Resolution MEPC.159(55); and

(iv) for a system installed on a vessel before 1 January 2010 — IMO Resolution MEPC.2(VI); or

(b) a sewage comminuting and disinfecting system approved by AMSA or a recognised organisation, that complies with Regulation 9 of Annex IV; or

(c) a holding tank approved by AMSA or a recognised organisation, that complies with Regulation 9 of Annex IV.

10 Sewage systems for vessels discharging in special areas

[MARPOL IV-9]

A vessel to which both Annex IV and section 4.2 of the 2012 Guidelines apply must be equipped with:

(a) a sewage treatment plant approved by AMSA or a recognised organisation, that complies with section 4.2 of the 2012 Guidelines; or

(b) a holding tank approved by AMSA or a recognised organisation, that complies with Regulation 9 of Annex IV.

Note Section 4.2 of the 2012 Guidelines applies to new passenger ships after 31 December 2015 and to existing passenger ships after 31 December 2017. Section 4.2 deals with passenger ships discharging sewage in special areas designated in Annex IV.

11 Standard discharge connections

[MARPOL IV-10]

(1) The vessel must have a standard discharge connection mentioned in Regulation 10 of Annex IV.

(2) However, for a passenger vessel, the vessel's discharge pipeline may be fitted with a discharge connection approved by AMSA (eg a quick-connection coupling).

Division 3 Certificates

[MARPOL IV-5]

12 Certificates required

For subsection 130(3) of the Navigation Act (which enables the regulations to provide that specified kinds of vessels are required to have specified pollution certificates), a vessel to which Annex IV applies must have an ISPP certificate.

13 Applying for certificates

(1) For subsection 131(1) of the Navigation Act (which enables a person to apply to an issuing body for a pollution certificate specified in the regulations), an ISPP certificate is specified.

(2) Division 3 of *Marine Order 1 (Administration) 2013* (other than section 17) applies to an application to AMSA for a certificate mentioned in subsection (1).

Note Division 3 of *Marine Order 1 (Administration) 2013* prescribes some general rules about the making and determination of various kinds of applications. Section 17 of that Order provides for internal review of decisions about applications. That section does not apply to decisions about pollution certificates because those decisions are reviewable under subsection 313(1) of the Navigation Act.

14 Criteria for issue of ISPP certificates

For paragraph 132(1)(b) of the Navigation Act, the criteria for the issue of an ISPP certificate for a vessel are that the vessel:

(a) has been surveyed in accordance with regulation 4 of Annex IV; and

(b) complies with the requirements that apply to it under regulation 4 of Annex IV.

15 Conditions of ISPP certificates

For paragraph 132(2)(a) of the Navigation Act, an ISPP certificate is subject to the following conditions:

(a) the condition of the vessel and its equipment must be maintained to comply with Annex IV;

(b) any survey mentioned in regulation 4 of Annex IV must be completed in accordance with the requirements of that regulation;

(c) after a survey mentioned in regulation 4 of Annex IV has been completed, any change to the structure, equipment, systems, fittings, arrangements or materials covered by the survey (apart from direct replacement of equipment and fittings) must be approved by AMSA.

16 Commencement and duration of certificates

An ISPP certificate comes into force and ceases to be in force in accordance with Regulation 8 of Annex IV.

Note A certificate may be revoked in accordance with the criteria mentioned in this Division.

17 Criteria for variation of ISPP certificates

For subsection 133(1) of the Navigation Act, the criteria for variation of an ISPP certificate for a vessel are that:

(a) the vessel complies with the requirements that apply to it under Annex IV; and

(b) the variation is in accordance with regulation 8 of Annex IV.

Note A variation may be in the form of an endorsement to a certificate. Endorsements are provided for in paragraphs 3 to 6 of regulation 8 of Annex IV.

18 Criteria for revocation of ISPP certificates

For section 134 of the Navigation Act, the criteria for revocation of an ISPP certificate for a vessel are that:

(a) a condition of the certificate has been breached; or

(b) the vessel ceases to be registered in Australia.

19 Notifying alterations

For paragraph 137(1)(c) of the Navigation Act, the period within which AMSA and an issuing body must be informed of an alteration to a vessel is 7 days after the alteration is made.

Note 1 An approved form for the reporting of alterations to vessels is available from AMSA's website — see http://www.amsa.gov.au.

Note 2 For other reporting requirements — see *Transport Safety Investigation Act 2003*, sections 18 and 19.

Division 4 Requirements for foreign vessels

20 Requirements for foreign vessels

A foreign vessel must comply with the requirements of Annex IV that apply to the vessel.

Division 5 Marine incidents

21 Marine incidents

For paragraph (l) of the definition of ***marine incident*** in subsection 14(1) of the Navigation Act, the following incidents are prescribed:

(a) equipment failure that may affect compliance by the vessel with Annex IV;

(b) an incident involving the vessel that may affect compliance by the vessel with Annex IV;

(c) anything that substantially affects the integrity of the vessel or the efficiency or completeness of the vessel's equipment covered by Annex IV.

Note 1 The owner and master of a vessel must report marine incidents to AMSA — see sections 185 and 186 of the Navigation Act.

Note 2 For the prescribed periods and the forms for reporting marine incidents — see *Marine Order 31 (Ship surveys and certification) 2006*. The forms are set out in that Order and are also available from AMSA's website at http://www.amsa.gov.au.

Division 6 Matters prescribed for the Pollution Prevention Act

22 Rate of discharge of untreated sewage

(1) For paragraph 26D(6)(c) of the Pollution Prevention Act the discharge rate is:

(a) over any period up to 24 hours — not more than DR_{max} m^3 per hour; and

(b) in any 1 hour during that period — not more than $1.2 \times DR_{max}$ m^3.

(2) For subsection (1):

$DR_{max} = 0.00926 \times B \times D \times V$

where:

B = breadth in metres.

D = draft in metres.

V = the ship's average speed in knots over the period.

Note The calculations in this section give effect to IMO Resolution MEPC.157(55).

23 Discharge of sewage by prescribed passenger ships in special areas

For paragraphs 26D(6)(d), 26D(7)(c), 26D(8)(b) and 26D(9)(a) of the Pollution Prevention Act:

(a) a passenger ship is prescribed if it is:

(i) a new passenger ship after 31 December 2015; or

(ii) an existing passenger ship after 31 December 2017; and

(b) a prescribed day is the day fixed under paragraph 2 of regulation 13 of Annex IV.

Note Section 26DAA of the Pollution Prevention Act provides that a prescribed officer may require the owner or master of a vessel to discharge sewage at a reception facility. See subsection 3(2) of the Act for the definition of prescribed officer.

Note

1. All legislative instruments and compilations are registered on the Federal Register of Legislative Instruments kept under the *Legislative Instruments Act 2003*. See http://www.frli.gov.au.

10.4 Example of a sewage and greater discharge record book

Page No 2

Appendix to Annex V
Form of Sewage and Graywater Discharge Record Book

Introduction

In accordance with CFR title 33 Navigation and Navigable Waters.

CHAPTER I: COAST GUARD, DEPARTMENT OF HOMELAND SECURITY (CONTINUED) SUBCHAPTER O: POLLUTION PART 159: MARINE SANITATION DEVICES. Subpart E: Discharge of Effluents in Certain Alaskan Waters by Cruise Vessel Operations 159.315 - Sewage and graywater discharge record book.

(a) While operating in the applicable waters of Alaska each cruise vessel shall maintain, in English, a legible Sewage and Graywater Discharge Record Book with the vessel's name and official number listed on the front cover and at the top of each page.

(b) Entries shall be made in the Sewage and Graywater Discharge Record Book whenever any of the following is released into the applicable waters of Alaska:

(1) Treated or untreated sewage;

(2) Graywater; or

(3) Sewage and graywater mixture.

(c) Each entry in the Sewage and Graywater Discharge Record Book shall, at a minimum, contain the following information:

(1) Name and location of each discharge port within the ship;

(2) Date the start of discharge occurred;

(3) Whether the effluent is treated or untreated sewage, graywater, or a sewage and graywater mixture and type of treatment used;

(4) Time discharge port is opened;

(5) Vessel's latitude and longitude at the time the discharge port is opened;

(6) Volume discharged in cubic meters;

(7) Flow rate of discharge in liters per minute;

(8) Time discharge port is secured;

(9) Vessel's latitude and longitude at the time the discharge port is secured; and

(10) Vessel's minimum speed during discharge.

(d) In the event of an emergency, accidental or other exceptional discharge of sewage or graywater, a statement shall be made in the Sewage and Graywater Discharge Record Book of the circumstances and reasons for the discharge and an immediate notification of the discharge shall be made to the COTP.

(e) Each entry of a discharge shall be recorded without delay and signed and dated by the person or persons in charge of the discharge concerned and each completed page shall be signed and dated by the master or other person having charge of the ship.

(f) The Sewage and Graywater Discharge Record Book shall be kept in such a place as to be readily available for inspection at all reasonable times and shall be kept on board the ship.

(g) The master or other person having charge of a ship required to keep a Sewage and Graywater Discharge Record Book shall be responsible for the maintenance of such record.

(h) The Sewage and Graywater Discharge Record Book shall be maintained on board for not less than three years.

10.5 ASEL – Bedding requirements

Bedding requirements relating to transport by sea.

ASEL Appendix 4.3 Provision of bedding

4.3.1 Cattle and buffalo

(1) Cattle and buffalo exported on voyages of 10 days or more must be provided with sawdust, rice hulls or similar material to be used exclusively for bedding at a rate of at least 7 t or 25 m^3 for every 1000 m^2 of cattle pen space.

(2) This does not apply to cattle and buffalo loaded from Brisbane or a port north of latitude 26° south and exported to Southeast Asia or Japan.

4.3.2 Deer

(1) Bedding, such as straw, shavings or sawdust, must be provided on all voyages and must be spread at a rate of at least 7 t or 25 m^3 for every 1000 $m^2$of deer pen space before animals are loaded.

4.3.3 Camelids

(1) Bedding, such as straw, shavings or sawdust, must be provided on all voyages and must be spread at a rate of at least 7 t or 25 m^3 for every 1000 m^2 of camelid pen space before animals are loaded.

S5.9 When bedding is used, it must be maintained in adequate condition to ensure the health and welfare of the livestock.

Bedding requirements relating to transport by air.

ASEL Appendix 4.4

(1) The floor surface of a portable livestock unit (PLU) must be non-slip and non-abrasive.

Note. This can be achieved through the use of sufficient and suitable bedding material for the class and species of livestock to be transported.

(2) For cattle, bedding material (kiln-dried sawdust/shavings or equivalent) must be applied at a minimum of 4 kg per m^2 before loading.

(3) Soiled bedding material must be replaced as necessary (subject to type and species).

(4) The consistency and depth of bedding material must be continually monitored.

(5) Bedding management must minimise abrasions, lameness, pugging, faecal coating and ammonia production.

10.6 Bedding cost calculations

For the sake of completeness, the following tables present previous bedding cost calculation, bedding cost variation and the advantages and disadvantages of using bedding materials (Banney *et al.* 2009). These issues have been discussed earlier in the report.

Table 16: Bedding cost calculation – long haul voyage

Assumed deck area	5,000 m^2
Stock numbers	3,225 head
Average weight per head	400kg
Stocking density (minimum as per ASEL)	
Total Live Weight	1.55 m^2 per head
Voyage duration	1,290 tonne
Timing of fresh bedding applications	16 days
Bedding material	Days 0, 7, 11 and 15
Quantity of bedding material required*	Kiln-dried pine shavings or sawdust
Depth of bedding material after each application	80 tonne
Loaded cost of bedding material	2.4 cm
Cost of bedding – Total	$700 per tonne
Cost of bedding – per m^2	$56,000
Cost of bedding – per kg	$11.20
Cost of bedding – per head	$0.04
	$17.40

* Source: Banney et al (2009)

Based on 4 tonnes of bedding material per 1,000m^2 over four applications

Table 17: Estimated costs varying amount of bedding material (Banney *et al.* 2009)

Rate of Application (t/1,000m^2)	Rate of Application (m^3/1,000m^2)	Quantity loaded per voyage (t)	Quantity loaded per voyage (m^3)	Bedding material cost per voyage*	Bedding material cost per head	Bedding material cost per kg LW
2.7	16	54	320	$37,800	$11.70	$0.029
4.0	24	80	480	$56,000	$17.40	$0.044
5.3	32	106	640	$74,200	$23.00	$0.058

* Source: Banney et al (2009)

Assumes bedding material applied on four occasions at the same rate.

Table 18: Estimated costs varying price of bedding material

Cost of loaded bedding material ($/tonne)	Bedding material cost per voyage*	Bedding material cost per head	Bedding material cost per kg LW
$300	$24,000	$7.50	$0.019
$400	$32,000	$9.90	$0.026
$500	$40,000	$12.40	$0.031
$600	$48,000	$14.90	$0.037
$700	$56,000	$17.40	$0.044
$800	$64,000	$19.80	$0.050
$900	$72,000	$22.30	$0.056

* Source: Banney et al (2009)

* Assumes a constant rate of application of 4.0 tonne/1,000 m^2.

Table 19: Advantages and disadvantages of using bedding material in cattle pens

Advantages	Disadvantages
• Reduces slippage • Minimises abrasions • Increases comfort during standing and lying • Improves hygiene • Reduces ammonia levels • Minimises feet and leg injuries • Minimises lameness • Decreases air humidity and wet bulb temperature • Improves presentation at discharge • Reduces time spent lying in wet faeces • Reduces amount of faecal matter adhering to coat • Improves public perceptions of industry	• Cost not directly recoverable in terms of decreased mortality • Takes up valuable space on ship • Increases demands on drainage and pumps • Increases labour time to handle and apply • Increases labour required to handle and remove

* Source: Banney et al (2009)

Table 20: Advantages and disadvantages of using bedding material in sheep pens

Advantages	Disadvantages
• Assists in maintaining firmness of natural manure pad • Reduces ammonia level • Decreases air humidity and wet bulb temperature • Reduces slippage during loading and unloading • Improves presentation at discharge • Reduces time spent lying in wet faeces • Reduces amount of faeces adhering to fleece • Improves industry perceptions	• Cost not directly recoverable in terms of decreased mortality • Takes up valuable space on ship • Increases labour required to handle and apply • Increases labour required to handle and remove

* Source: Banney et al (2009)

10.7 ASEL – Daily reporting requirements (Australian Government)

Port of loading	eg Portland	eg Fremantle
Cattle		
Buffalo		
Sheep		
Goats		
Camelids		

Veterinarian ……………..

Stockman ……………..

Vessel ……………..

Date ……………..

Day No* ……………..

Vessel's position and ETA at next port ……………..

1 Dry bulb temperature and humidity

- One average recording for each deck, each day
- Bridge temperature (ambient)

2 Wet bulb reading – per deck

3 Feed consumption – average per head

4 Water consumption – average per head

5 Health and welfare issues – sick pen report including medication and treatments

6 Respiratory character

- 1 = normal
- 2 = panting
- 3 = gasping

7 Faeces - average for each cattle deck

- 1 = normal
- 2 = sloppy
- 3 = runny diarrhoea
- 4 = like sheep pellets

8 Issues from daily meeting

9 Mortality

Mortality	Euthanasia	Natural causes	Species
Daily			
Cumulative			
	General		