Department of **Employment, Economic Development and Innovation**

Environmental science and the Queensland chicken meat industry

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Toward Q Tomorrow's Queensland

Queensland Government

Contents

Summary

Purpose

The purpose of this document is to provide a summary of the broader science relating to environmental issues for the chicken meat industry; to link these findings to the current knowledge and practices in the industry; and to identify critical opportunities, risks and knowledge gaps.

The simultaneous expansion of the chicken meat industry to meet consumer demand and explosion of urban development in south-east Queensland has resulted in an increased potential for land use conflicts, especially relating to odour and dust impacts as well as health concerns from pathogens. This industry directly or indirectly employs a significant number of people in farms, integrator companies, feed mills, processing plants, distribution chains and through relevant contractors.

Science has and will continue to develop tools and processes to assist in both the planning for new sheds and the better management of existing sheds. It will contribute to the long-term sustainable outcomes sought by the industry and community, but will not deliver the immediately required 'silver bullet' to alleviate planning issues and environmental concerns.

The focus of this document is the recent scientific research on the formation, emission and measurement of odour, dust and pathogens from tunnel ventilated meat chicken sheds. Only tunnel ventilated sheds are considered because these represent current and likely future best practice shed design. Abatement techniques will also be briefly covered.

State of the science

Pathogens

Researchers with the Department of Employment, Economic Development and Innovation (DEEDI) are undertaking world-leading research in this field to:

- understand movement and survival of pathogens in and around meat chicken sheds (as well as other intensive animal industries)
- develop broadly applicable principles that will allow the chicken meat industry to manage pathogen/environment interactions
- understand survival of pathogens in litter when re-used within the shed.

Current research activities are focused on the effects of litter re-use on pathogens and food safety.

There are a number of topics requiring future research, including:

- pathogens in free-range and organic production systems
- the effect of larger particles on pathogen survival and transport
- adoption of the concept of marker organisms to monitor the impact of shed aerosols
- re-use of litter outside the shed in the context of the possible survival and transport of pathogens in the broader agricultural environment

Odour

Recent odour research undertaken by DEEDI has been dedicated to:

- quantifying odour emission rates
- investigating odour treatment technologies
- identifying the odorants that combine to form broiler odour.

Measurement of emission rates has been necessary because of a lack of available data; changes to olfactometry standards; and recent evolutionary changes to broiler shed design, diet formulation,

litter management and husbandry practices. Emission rate data is necessary for the development and validation of odour emission rate models, which provide inputs to dispersion modelling. The odour emissions measured at the shed have no direct relationship with odour impacts or complaints due to atmospheric dispersion of the odour plume between the farm and receptors.

Investigation of various treatment technologies has been undertaken to assess their efficacy and compatibility with tunnel ventilated broiler sheds. Capturing and treating odour is challenging due to complex chemical interactions that require odorants to be treated using biological, physical and/or chemical processes. The extremely high ventilation requirements of tunnel ventilated sheds magnify the challenges associated with treating odours. The result is a range of technical, practical and economical challenges that are currently unsolved, and therefore no suitable odour treatment technology exists.

Identifying and quantifying odorants is an essential element of odour research because understanding the chemistry of broiler odour and identification of the major odorants will significantly improve the likelihood of developing control strategies and improved techniques for odour measurement.

Odour researchers are currently focusing on fundamental odorant formation and emission processes, with an ultimate objective of developing strategies to control these. Successfully and strategically reducing the formation or emission of odour (or at least the primary odorants) will reduce the potential for impacts and the current reliance on atmospheric dispersion.

Dust

Dust research for tunnel ventilated broiler sheds has focused on measuring emission rates and investigating dust control technologies.

Dust emission rate data will enable modelling of dust transport and deposition but, as with odour, measurements at the sheds have no direct relationship with dust impacts or complaints due to dust settling on the ground in the vicinity of the sheds and atmospheric dispersion.

Treatment technologies have been investigated, with a few showing some promise. A research proposal to assess one of the most promising dust treatment technologies is currently being evaluated. Vegetative environmental buffers, that are specifically designed and use appropriate plant species to capture dust particles, have been investigated in the United States of America (USA) and are promoted there as an effective means to reduce off-farm dust impacts.

Future research on dust is likely to focus on developing and evaluating abatement methods.

Findings

This section provides a brief list of findings from the science undertaken to date.

Pathogens

The Australian poultry industry is unique in that it:

- is free of the two major pathogens that are of concern to human health in other countries
- does not contain any viruses that pose public (or even mammalian) health problems
- does not contain any protozoal agents that could be considered as a serious or major risk to human health
- most of the bacterial pathogens that are present do not pose any significant threat to human health.

The key bacterial pathogens that pose a problem are *Salmonella* and *Campylobacter*, with both causing self-limiting gastrointestinal illness in humans. However. both require ingestion rather than

inhalation to cause infection. Infection usually occurs either via the food chain or direct chicken faecal-to-human oral transmission. Clinical disease resulting from inhalation of air expelled from chicken sheds is unlikely because it requires sufficient organisms to survive the environmental challenges to provide an infective dose for establishment of gastrointestinal infection.

Importantly:

- *Campylobacter* (the most important cause of bacterial gastroenteritis in the Australian human population) are very fragile organisms that are unlikely to survive any drying process in the environment and cannot replicate outside of the gut environment
- Salmonella (the most common serovar of *Salmonella* (serovar Sofia) found in litter) does not appear to infect humans; the most common serovar of *Salmonella* isolated from humans (serovar Typhimurium) was rarely detected in litter in poultry sheds; and *Salmonella* (serovar Enteritidis), the major cause of human illness in the USA and other countries, is absent from the Australian commercial poultry industry
- *E.coli* serotypes isolated from poultry are pathogenic only for birds and are regarded as only a low risk of disease for humans or other animals.

Litter piling (treatment) processes between batches results in rapid die off of *Salmonella*, *Campylobacter* and *E.coli* in piled litter, resulting in low levels in the litter and minimal infection of new batches of chickens.

While there is a link between levels of an organism in the litter and subsequent airborne levels, these levels were always lower outside the shed. *Salmonella* and *Campylobacter* were only detected at very low levels in broiler sheds and *Salmonella* was only detected once outside the shed, and then only in close proximity to the shed. Thus, the public risk from well-managed broiler sheds associated with *Salmonella* and *Campylobacter* exposure via the aerosol route is minimal.

The dominant airborne organisms inside and outside meat chicken sheds are harmless bacteria described as staphylococci/coryneforms, with formal identification showing absence of any organisms of known pathogenicity to humans. Airborne fungal levels did not show any rise in the presence of chickens or over the broiler cycle, suggesting that the meat chicken shed has little influence on the levels of these organisms.

Once removed from the sheds, broiler litter is a valuable soil amendment and fertiliser resource to agriculture. This spent litter contains low levels of the above-mentioned pathogens and the overall risks are low, especially on well-managed farms. DEEDI research has provided baseline knowledge and the underlying principles to underpin appropriate industry and planning guidelines.

A wide range of bacteria are normally present in semi-rural and rural environments, with some of these bacteria being capable of causing infection in humans. These pathogens are potentially present in domestic and farmyard pets as well as commercial livestock and wildlife. There is now a good understanding of the risks associated with commercial meat chicken sheds, but the risks from these other sources remain to be considered.

DEEDI researchers continue to conduct research to further identify any potential public health impacts from pathogens, and to further develop management strategies and guidelines to minimise any potential public health impacts from poultry production.

Odour

Recent measurement of odour emission rates (OERs) from a selection of tunnel ventilated broiler sheds in south-east Queensland has provided never-before-seen detail of OERs, especially regarding daily and intra-batch variability. OERs varied with total live weight, time of day, weather

conditions and between farms; however, not all of the observed variability could be explained by the environmental and production conditions measured while sampling.

In time, these latest OER measurements will be useful for assessing the current methods of predicting OERs during odour dispersion modelling and impact assessment. If the current methods are found to be inadequate, the OER data will be useful for re-calibrating the current OER models or developing alternative OER models. Together, these will ensure that predictions of odour impacts from new broiler farms will be based on the most reliable OER data.

Odour measurement using olfactometry can be expensive, time consuming and labour intensive. Recent development and application of an artificial olfaction system (AOS, sometimes referred to as an electronic nose) by DEEDI researchers has helped to overcome some of the restrictions usually associated with olfactometry. This AOS was calibrated to measure broiler odour and then used to continuously measure shed odour emissions throughout a batch. The continuous OER profile recorded by the AOS complemented olfactometry odour measurements and was invaluable for demonstrating the dynamic nature of odour emissions from tunnel ventilated broiler sheds.

Broiler shed odour is a mixture of hundreds of odorous compounds called odorants. Knowledge of these odorants has little relevance to the planning of new broiler farms, but is fundamental to the production and transport of odour. Identification of principle odorants will contribute to the strategic development of odour reduction strategies and improved odour measurement techniques.

Odour dispersion modelling is commonly used during odour impact assessments, but the selection of inputs and configuration of the models can be contentious. During a series of investigations by DEEDI researchers, some dispersion model configurations and inputs, including plume thermal buoyancy, have been investigated. It was found that these inputs considerably changed odour impact predictions. The development of a consistent modelling approach was recommended. Alternatively, separation distance formulas should be considered to simplify the calculation of separation distances and increase consistency in development approvals.

Development and commercialisation of odour mitigation strategies/technologies is a primary goal for researchers in Australia and overseas. Despite the concerted research effort, no suitable odour treatment technologies are currently available. Good management practices at the broiler farm and ensuring adequate buffer distances remain the most effective ways to prevent odour nuisance. In addition, properly designed vegetative environmental buffers have been found useful for alleviating odour impacts caused by broiler farms in the USA.

DEEDI researchers continue to develop improved odour measurement techniques, and are collaborating with other research organisations to improve understanding of odour formation and emission processes with the aim of developing and evaluating innovative odour solutions.

Dust

Dust emission rates have been measured from a selection of tunnel ventilated broiler sheds in south-east Queensland. The dispersion and fate of dust from broiler sheds has not been the focus of research to date, and will require dust dispersion modelling or long-term, in-field dust monitoring to quantify the potential impacts for neighbours.

Conclusions and implications

Pathogen, odour and dust research has focused on developing a sound scientific platform for long-term benefits including:

- identifying and quantifying pathogens in and around meat chicken sheds
- quantifying odour emission rates to provide knowledge about the range and variability of emissions from tunnel ventilated sheds

- identifying and quantifying primary odorants
- quantifying dust emission rates.

Pathogen research is well developed and has produced some clear outputs relating to planning and operation of meat chicken farms. In particular, on well-managed farms there is minimal risk to human health due to airborne *Campylobacter* or *Salmonella,* and there is virtually no risk from viruses or protozoal agents. *Campylobacter* and *Listeria* are of minimal concern in the use of spent litter outside the shed. *Salmonella*, a good environmental survivor does need to be considered, although it's survivability is balanced by the survey results of low levels and a serovar that does not infect humans. In summary, DEEDI pathogen research has provided a solid basic knowledge and the underlying principles that can and should be used in industry and planning guidelines.

Odour and dust research only commenced in 2003/04 and is still in the early stages, so the current research outputs are unlikely to contribute to planning processes at this stage. Of value are the recently measured odour emission rates, which could be used to ensure that odour emission rate inputs to dispersion modelling of proposed farms are within an appropriate range. Additionally, investigations into treatment technologies have demonstrated that there are no suitable odour treatment options currently available for tunnel ventilated broiler sheds.

Background

The chicken meat industry has long been established in south-east Queensland and directly or indirectly employs a significant number of people in farms, integrator companies, feed mills, processing plants, distribution chains and through relevant contractors. The industry needs to expand in order to meet the growing requirements for chicken meat products by Queensland consumers. Industry expansion can only be achieved by building new farms or expanding existing farms.

The simultaneous expansion of the chicken meat industry and explosion of urban development in south-east Queensland has resulted in an increased potential for land use conflicts, especially relating to odour and dust impacts as well as health concerns from pathogens. The industry has recognised these issues and has subsequently supported targeted research through the provision of research co-funding. DEEDI researchers have been at the fore in investigating these environmental and microbiological issues, and are recognised nationally as leaders in these fields. The issues have also been recognised by the community, planners, policy makers and regulatory agencies, and this has resulted in ongoing re-assessment of the planning requirements and operating conditions imposed on new or expanding meat chicken farms.

Research to address odour, dust and pathogen issues from meat chicken production (as well as other poultry and intensive livestock production systems) is not unique to Queensland, with relevant research being undertaken elsewhere in Australia and internationally. Significant amounts of research are undertaken in the USA and Europe, which is a reflection of their much larger poultry industries. In situations when research capacity or capability in Australia are not able to deliver all of the required outcomes, it is often necessary to draw on overseas research and adapt it to Australian conditions and production methods.

One well-recognised hurdle for researchers is the rapidly evolving design of the meat chicken sheds, production methods and animal husbandry techniques, which all have a bearing on environmental performance. One revolutionary change was the introduction of tunnel ventilation in the late 1990s and early 2000s, which the industry needed to remain price competitive and meet consumer demands and expectations by delivering increased production and improved production efficiency with improved animal welfare. As a result, producers began converting their naturally ventilated sheds to tunnel ventilation and, since about 2004, all new farms have been built with tunnel ventilation. One further challenge for environmental researchers has been a corresponding evolution of research methods along with the tunnel ventilation revolution, especially regarding olfactometry standards (odour measurement) and dust measurement equipment. The new methods provide significant benefits; however, historical odour emission measurements (which were also predominately from naturally ventilated poultry sheds) are usually not truly comparable to recent measurements at modern tunnel ventilated buildings. This makes comparison of odour emissions from the two production styles virtually impossible.

Key points

- Urban (residential) and chicken meat industry expansion are both necessary but has resulted in land use conflicts, reportedly due to dust and odour impacts.
- There are concerns about pathogens.
- Scientists are working on the issues but there are numerous challenges.
- The focus of this paper is the science, but resolution of the issue will require good planning policy and a commitment to resolve impacts/concerns as they happen.

The major issues

In 2003, the then Department of Primary Industries and Fisheries surveyed local councils in Queensland to identify the major issues relating to poultry farming (Galvin 2004). At the time the survey was conducted, the majority of poultry farms were still naturally ventilated. The survey identified odour, dust, noise, litter management and pathogens as the leading reasons for complaints. These issues (especially odour, dust and pathogens) remain the leading reason for complaints and criticism of the chicken meat industry.

Odour, dust and pathogen loading in the air and water of regional and agricultural areas can be generated from a variety of sources, such as application of manure to arable land; carriage of livestock by road and rail; unsealed roadways; and roosting of birds on roofs, in dams and in waterways. The production and dispersion of such aerial pollutants is a normal part of many agricultural practices. Emissions from meat chicken farms are often highly scrutinised due to the close proximity of the main chicken growing areas to urban and peri-urban development, and may be influenced by a perception that meat chicken farming is not a 'traditional' agricultural production system.

The following sections summarise the research on the major issues affecting the chicken meat industry—pathogens, odour and dust.

Key points on the major issues affecting broiler farms in south-east Queensland

- In 2003, odour was the leading cause of complaints against poultry farms, closely followed by dust and pathogen concerns.

Pathogens

In this section, the pathogens potentially present in chickens that are of public health concern in the Australian chicken industry are reviewed.

The approach taken includes:

1. a brief overview of potential pathogens
2. a brief overview of the knowledge gained in recent DEEDI research evaluating the potential for transmission from chicken sheds in south-east Queensland
3. identification of areas where further research would provide benefits to the community and to the poultry industry.

Key points on pathogens

The Australian poultry industry is unique in that it:

- is free of the two major pathogens that are of concern to human health in other countries
- does not contain any viruses that pose public (or even mammalian) health problems
- does not contain any protozoal agents that could be considered as a serious or major risk to human health
- most of the bacterial pathogens that are present do not pose any significant threat to human health.

Overview of pathogens and Australian chickens

The Australian chicken industry is quite unique in that it is free of two of the most important disease agents that pose threats to public health—avian influenza (an exotic agent) and *Salmonella enterica* serovar Enteritidis, with the latter essentially absent from the commercial meat chicken industry.

The key bacterial pathogens that pose a public health problem in the Australian chicken industry are *Salmonella* and *Campylobacter*; however, most of the bacterial pathogens that are present do not pose any significant threat to human health. Of the many viral diseases present in Australian poultry, none present a realistic or a widely accepted risk to either human health or the health of other mammals without direct bird infection/human contact. There is no protozoal agent present in poultry that can be considered as a serious or major risk to human health.

Thus this section will only highlight the relevant information on key bacterial pathogens of public health concern. A full technical review of the majority of pathogens seen in Australian chickens and their role or lack of a role in infections of humans and other mammals is provided in appendices 1 (viruses), 2 (bacteria) and 3 (protozoal).

Bacterial pathogens and Australian chickens

There is a range of bacterial pathogens present in Australian chickens that have the potential to also infect humans and other animals. A full review of these bacterial pathogens is presented in Appendix 2. The review highlights that some of these chicken pathogens are specific for chickens only. As an example, while *Mycobacterium avium* infections occur in both humans and chickens, the serovars are different—meaning that bird-to-human transmission is not regarded as a risk (Fulton & Thoen 2003).

An important fact is the relative freedom of chickens from contamination with the particular form of *Escherichia coli* known as EHEC (enterohaemorrhagic *E. coli*). The best known of the EHEC strains is the 0157 type that has caused frequent human health problems in the USA (Gray 1995). These strains, mainly associated with inadequately cooked beef and sheep products, can cause serious conditions such as haemolytic urealytic syndrome (Gray 1995). The evidence to date is

that there is only a low occurrence of natural infection with *E. coli* 0157 in chickens, based on studies in Asia and Europe (Heuvelink et al. 1999).

Recent USA-based research has shown that some forms of *E. coli* that are pathogenic to chickens (called avian pathogenic *E. coli* or APEC) share a genetic composition found in *E. coli* that is associated with extra-intestinal infections in humans (called ExPEC)—particularly those associated with uro-genital infections (Johnson et al. 2008). To date, there is no evidence of any direct connection between chickens and these ExPECs. However, there is a need for ongoing monitoring of the potential role of APEC in human health. At this stage, there appears to be no Australian-based research in this area.

Clostridium botulinum is an important pathogen due to the severity of botulism outbreaks in susceptible animals, such as cattle exposed to used poultry litter. It is important to understand that there is no major risk to public health associated with this organism and the presence of this organism in poultry. The types of *Cl. botulinum* associated with human cases (types A, B, E and F) are not the types associated with chickens (types C and D) (Onderdonk & Allen 1995).

Based on the available information in the literature, the following bacteria are a high priority group that must be addressed in any research program dealing with human health:

1. *Campylobacter coli/jejuni*
2. *Salmonella* spp.

Campylobacter jejuni and *Salmonella* spp. have been identified as significant pathogens as they are common in chickens and there is good evidence of chicken-to-human transmission. The accepted means of transmission of these pathogens from chicken to human is via the food chain or by direct chicken faecal-to-human oral transmission.

Campylobacter coli/jejuni are two bacterial species that are difficult to separate and are often treated as a single entity (Nachamkin 1995). *C. jejuni/coli* together are the most important cause of bacterial gastroenteritis in the Australian human population (OzFoodNet 2008). Poultry are recognised as one of the primary reservoirs of this pathogen (Shane & Stern 2003). *C. jejuni/coli* are fragile organisms that are unlikely to survive any drying process in the environment (Shane & Stern 2003). Unlike *Salmonella*, *Campylobacter* cannot replicate outside the gut environment (Shane & Stern 2003).

Salmonellosis of humans is typically acute gastroenteritis following the consumption of contaminated food (Kelly et al. 1985). It is usually a self-limiting illness and fatalities are uncommon (Kelly et al. 1985). Infections due to *Salmonella* spp. are not a common cause of disease in poultry in Australia. *Salmonella* serovar Enteritidis, which is a major cause of human illness in countries such as the USA (Gast 2003), is absent from the Australian commercial poultry industry. In addition, the most common serovar of *Salmonella* in Australian chickens—*Salmonella* Sofia—is not among the top 10 serovars associated with human infections in Australia (Davos 2002). Nevertheless, it is widely recognised that poultry can harbour *Salmonella* organisms as part of their normal intestinal flora and thus act as a reservoir with the potential for transmission to humans.

When evaluating the risk of both *Salmonella* and *Campylobacter*, the impact of infectious dose and exposure route must be considered. Both of these pathogens are gastrointestinal pathogens, meaning that regardless of the exposure route (skin contact, oral or respiratory) the organisms must gain access to the gastrointestinal tract to cause disease. The other key factor to be considered is the number of organisms that are needed to cause an infection, with some infections causing clinical disease (i.e. illness) while other infections will result in no apparent illness. The numbers of organisms required to cause an infection is expressed as the ID_{50}, which is the infectious dose/number of organisms that are required to cause an infection in 50% of people

exposed to that dose. The generally accepted ID_{50} for the types of *Salmonella* present in Australian poultry is around 100 000 to 1 000 000 organisms (Shuval et al. 1986). For *Campylobacter*, the widely accepted figure is 500 organisms (Robinson 1981).

The infectious dose differences in these two pathogens are reversed in terms of the ability to survive outside the chicken. *Salmonella* is known to be a hardy organism, capable of prolonged survival in the environment. It has been known to survive for up to 300 days in cattle manure (Jones 1986). In contrast, *Campylobacter* is a fragile organism with a poor survival capacity—e.g. only a maximum of 20 days in cattle manure (Stanley et al. 1998).

One bacterial pathogen provides challenges in assessing the potential health risk for humans—*Chlamydophila psittaci* (the causative agent of psittacosis). This bacterial pathogen can cause disease in a wide range of birds and mammals, including humans (Vanrompay et al. 1995). While this pathogen can infect all forms of poultry, the generally accepted position is that infections are more common in turkeys and ducks than in chickens (Vanrompay et al. 1995). Recently, there has been a report of atypical pneumonia cases in poultry slaughterhouse workers in France associated with an apparently new, as yet unnamed *Chlamydophila*-like agent (Laroucau et al. 2009).

Overall, while there is no firm, direct evidence to suggest that *Chlamydophila*-like agents in poultry are a health risk, the situation requires monitoring. Awareness and monitoring of the situation is important as *Chlamydophila* and related agents have a low infectious dose and can be spread by aerosols (Vanrompay et al. 1995). *Chlamydophila* agents are difficult pathogens to detect and identify, and require specialised laboratories and techniques. The Australian chicken meat industry is funding research into the development of suitable identification and typing methods at the University of Melbourne. This research needs to be monitored.

Key points on bacterial pathogens

- There are a range of bacterial pathogens potentially present in Australian chickens but most do not pose any significant threat to human health.
- The key bacterial pathogens that do pose a threat to human health are *Salmonella* and *Campylobacter*—both of which cause gastrointestinal illness in humans.
- The infectious dose required to induce illness in humans (ID_{50}) is relatively high for *Salmonella* (100 000 to 1 000 000 organisms) and low for *Campylobacter* (500 organisms). This is balanced by the fact that *Salmonella* survives well in the environment while *Campylobacter* is a poor survivor.
- *Chlamydophila* agents (including *Chlamydophila psittaci*) are not widely accepted as a realistic risk to humans exposed to poultry.
- Overseas-based research has suggested a possible connection between chickens and a subclass of human pathogenic *E. coli* (called ExPECs). There is a need for Australian-based research to look at this potential connection between chickens and humans.

Pathogens in litter

DEEDI research, co-funded by the Rural Industries Research and Development Corporation (RIRDC), has provided the first definitive knowledge of the levels of key pathogens at the end of the broiler cycle (Chinivasagam et al. 2010a). The key findings from this research are included below.

Litter from 28 sheds (1 shed per farm, 10 farms in Queensland, 9 in New South Wales and 9 in Victoria) was examined for the presence and level of three pathogens—*Campylobacter coli/jejuni*, *Listeria monocytogenes* and *Salmonella* spp. The levels of *E. coli* were also determined. The farms were selected to represent the market share of the various producers in each state and the litter management policies. Hence, 22 farms had a policy of single use of the litter, while on six farms

the litter was multi-use litter that had been re-used several times in the standard partial re-use practice undertaken by segments of the Australian industry.

E. coli was present in all 28 litters, with a geometric mean of 200 000 organisms per gram of litter. There was no obvious variation across the states or the different litter types and litter use practices.

Listeria spp. were not detected in any sample and this pathogen is apparently not relevant in the Australian context.

Salmonella was detected in 20 litters, with the geometric mean of these positive samples being 44 organisms per gram of litter. Five litters had *Salmonella* levels of between 100 and 1000 organisms per gram, while the maximum level was 100 000 organisms per gram of litter. The dominant *Salmonella* serovar found in the litter samples was *Salmonella* Sofia (70% of isolates), the serovar that dominates the Australian poultry industry but which is rare in humans. Other serovars detected were *S.* Bovismorbificans (8%), *S.* Chester (10%), *S.* Infantis (8%) and *S.* Virchow (10%). *S.* Typhimurium, the most common serovar isolated from humans (Davos 2002), was detected only in one of the states and was only present at around a 4% overall level.

Campylobacter was detected in 10 litters, with the geometric mean being 30 organisms per gram.

Overall, the work of Chinivasagam et al. (2010a) has provided the first definitive knowledge of pathogen levels in used broiler litter from Australian chickens. The only pathogen that was consistently present in most litters (around 75%) was *Salmonella*. The work indicates that neither *Campylobacter* nor *Listeria* are a major concern in used litter.

While *Salmonella* was present in the majority of litters, the levels were low (44 organisms per gram) and the most common form of *Salmonella* present (*S.* Sofia) does not appear to infect humans. This solid basis of knowledge can now be used to develop appropriate guidelines that will allow the safe and sustainable use of broiler litter in a variety of agricultural settings.

Key points on pathogens in used broiler litter

- DEEDI research, co-funded by the chicken meat industry, has shown that neither *Listeria* nor *Campylobacter* are important pathogens when considering how broiler litter is to be used after leaving the broiler shed.
- The DEEDI research has shown that around 75% of used litters are likely to contain *Salmonella*.
- The levels of *Salmonella* are low (a mean of 44 organisms per gram) and the most common form of *Salmonella* present in the litter (a serovar called Sofia) does not appear to infect humans.
- Used broiler litter can be a valuable resource to agriculture and DEEDI research has provided the baseline of knowledge to ensure that appropriate guidelines and management practices can be used/adopted.

Pathogens in aerosols from tunnel ventilated meat chicken sheds

DEEDI research, co-funded by the RIRDC, has provided the first definitive knowledge of both the general aerobiology around Australian meat chicken sheds and specific knowledge on the levels of *Campylobacter* and *Salmonella* inside and outside Australian meat chicken sheds. The work has been formally published in the scientific literature (Chinivasagam et al. 2009b; Chinivasagam et al. 2010b) and a short summary is included below.

In the aerobiology component of this work, six trials were carried out from 2004 to 2007. In each trial, aerosol samples were collected weekly on four different south-east Queensland broiler farms across the full broiler cycle (Chinivasagam et al. 2010b). Aerosol samples were collected both

inside the sheds and at distances from the fan end of the sheds. Litter and dust within the shed were also studied. The dominant organisms in the air in the presence of chickens were members of two genera—*Staphylococcus* and *Corynebacterium*.

Formal identification showed that these dominant organisms did not include any organisms of known pathogenicity to humans. The level of these organisms—collectively described as staphylocci/coryneforms—was around 100 million per cubic metre of air at 20 metres from the shed in the presence of chickens. This level is markedly above the level detected when no chickens were present in the sheds—around 100 organisms per cubic metre of air.

The levels of the staphylococci/coryneform organisms dropped with distance and generally reached background levels (100 organisms per cubic metre of air) at distances of around 400 metres from the shed. The results of this research suggest that these organisms (staphylococci/coryneforms) could be used as airborne marker organisms to measure the extent of the effect of meat chicken sheds on the surrounding environment.

In this study, the levels of *E. coli* were found to be low at 20 metres from the shed (a maximum of around 100 organisms per cubic metre). Fungal levels were uniform across the broiler cycle and the shed does not seem to have a major impact on airborne fungal levels.

Key points on the aerobiology in and around meat chicken sheds

- DEEDI research, co-funded by the chicken meat industry, has shown that the dominant airborne organisms inside and outside meat chicken sheds are harmless bacteria described as staphylococci/coryneforms.
- While present in the absence of chickens, these organisms rise from a background level of around 100 organisms per cubic metre to around 100 million organisms per cubic metre at 20 metres from the fan end of the shed. The levels drop with distance, returning to background levels at around 400 metres.
- DEEDI research suggests that the influence of meat chicken sheds on the surrounding aerobiology can be monitored, in a cost-effective manner, by measuring the levels of airborne staphylococci/coryneform organisms.
- The levels of *E. coli* outside the shed were low (around 100 organisms per cubic metre of air) at a distance of 20 metres from the fans.
- Airborne fungal levels did not show any rise in the presence of chickens or over the broiler cycle, suggesting that the meat chicken shed has little influence on the levels of these organisms.

The second aspect of DEEDI research concentrated on assessing the levels of the two key pathogens (*Salmonella* and *Campylobacter*) as well as the indicator organism *E. coli* in the air inside and outside south-east Queensland meat chicken sheds (Chinivasagam et al. 2009b). Four poultry farms (all with tunnel ventilated sheds) were studied in six trials that involved weekly testing of litter and aerosols. The inside sampling was done at the fan end of the shed (10 metres from the fans) while the external samples were collected at 10 metres from the fans as well.

This work showed a linkage between the levels of an organism in the litter and the subsequent airborne levels. This relationship was best demonstrated by *E. coli*. The typical levels of *E. coli* in litter were around 100 million organisms per gram of litter and, as a consequence, the airborne levels were around 100 to 10 000 organisms per cubic metre (inside and outside the shed). The external levels of *E. coli* were always lower than the internal levels.

In contrast, *Salmonella* was only intermittently present in the litter and at lower levels (1000 to 100 000 organisms per gram) and consequently present only intermittently and at low levels in the internal air (at levels of two organisms or less per cubic metre of air). There were over 60 sampling

dates in this work and *Salmonella* was detected only once outside the shed and then at a low level (2.5 organisms per cubic metre of air).

Campylobacter was only detected in the litter late in the broiler cycles, with levels being around 10 million per gram of litter. There was only one internal air sample that was positive for *Campylobacter* (and then at a low level of around two organisms per cubic metre of air). *Campylobacter* was never detected in the external air samples.

Overall, this study showed that the aerosols coming from well-managed meat chicken sheds pose minimal public health risks associated with aerosol exposure to the recognised major human pathogens potentially present in meat chickens—*Salmonella* and *Campylobacter* (Chinivasagam et al. 2009b).

Key points on the levels of foodborne pathogens in the air inside and outside meat chicken sheds

- DEEDI research, co-funded by the chicken meat industry, has shown a linkage between levels of an organism in the litter and subsequent airborne levels.
- This is best illustrated in the instance of *E. coli* where litter levels of one hundred million per gram resulted in airborne levels of *E. coli* from 100 to 10 000 organisms per cubic metre inside the shed.
- The levels of *E. coli* outside the shed at 10 metre distance were always lower than the internal levels.
- *Salmonella* was only intermittently present and then at low levels in the litter. Consequently, *Salmonella* was only intermittently present in the internal air of the shed, and then at low levels of around two organisms per cubic metre of air. While over 60 sampling dates were used, *Salmonella* was detected only once outside the shed at a low level (two organisms per cubic metre of air).
- *Campylobacter*, a poor environmental survivor, only occurred late in the production cycle in litter and was detected only once in the internal air (two organisms per cubic metre) and never outside the shed.
- The public health risk from a well-managed broiler shed associated with *Campylobacter* and *Salmonella* exposure via the aerosol route is minimal.

Current DEEDI research on pathogens and litter management practices

DEEDI has continued to perform research on the impact of litter management practices and the impact of these practices on the levels of *Salmonella* and *Campylobacter* in both the litter and the chickens grown on the litter.

In the first of these projects, DEEDI researchers—with funding from the Australian Poultry Cooperative Research Centre (CRC)—looked at the levels of *Salmonella* and *Campylobacter,* as well as indicator organisms such as *E. coli* and *Clostridium perfringens*, in litter. This project evaluated the Australian-based practice of windrowing litter that is to be re-used within the shed for the next broiler cycle.

In this practice, the litter is windrowed in the break between cycles. New bedding is used at the brooder end of the shed and the windrowed litter is spread at the grower end of the shed. The windrowing typically occurs over a four to seven day period and the growing chickens are not exposed to the spread of old litter until around 14 days of age. While the research has not yet been formally published, a presentation at an international conference by the researchers has reported that the piling process results in a rapid die off of *E. coli, Campylobacter* and *Salmonella* in the piled litter (Chinivasagam et al. 2009a).

This work has now been extended to look at the impact of litter management practices and the level of the key foodborne pathogens (*Salmonella* and *Campylobacter*) in the caeca of chickens raised using differing litter management practices (with funding from the RIRDC). The practices being evaluated are:

1. new bedding each cycle
2. new bedding at the brooder end and old windrowed litter at the grow-out end
3. old windrowed litter at both the brooder and grow-out ends of the shed.

This research is currently underway and no results have been published or presented at conferences.

Key points on current DEEDI research on foodborne pathogens

- DEEDI research, co-funded by the chicken meat industry and the Australian Poultry CRC, has focused on the impact of litter management practices on the levels of *Campylobacter* and *Salmonella* in litter and in the caeca of chickens grown on the litter.
- This research is current and no formal peer-reviewed publications are yet available.
- A presentation at an international conference has reported that the Australian practice of windrowing litter results in rapid die off of *E. coli*, *Campylobacter* and *Salmonella*.

Areas where further research is required

The national data for gastrointestinal illnesses in Australia in 2009 list Campylobacteriosis (15 841 cases) and Salmonellosis (9523 cases) as the two major causes of gastrointestinal illness. This creates pressure on the poultry industry, as these two organisms can be normal inhabitants of poultry. Thus the broader research areas listed below are linked to overall food safety issues and the future growth of the industry.

Litter re-use in conventional production systems (production and disposal)

- Bedding scarcity in the future will push the chicken meat industry to a more widespread adoption of litter re-use options across sequential broiler cycles.
- Current industry-funded DEEDI research has started to look at the impact of litter re-use on the levels of foodborne pathogens in the litter and the caeca of chickens.
- When the outcomes of the current research are available, further research (particularly in the area of final end use outside the shed of litter) is likely to be required.
- This research could include methods for cost-effective pathogen reduction (litter piling, litter windrowing) outside the shed as well as appropriate end-use guidelines.
- Impacts of disposal of used litter on the environment will also be of concern

Alternative production systems

- Free-range and organic production systems in both the meat and egg industries are emerging sectors.
- There is a need for detailed studies of the type performed to date (see above sections) by DEEDI/industry on conventional meat chicken production systems.
- This research should focus on the impact of these different systems (as compared with conventional systems) on the levels of foodborne pathogens.
- Research should cover issues of whether these systems:
  a. result in pathogen build up in the production environment
  b. have aerobiological characteristics different from those established already for conventional meat chicken sheds
  c. impact on the presence and level of foodborne pathogens in any litter used as well as in the chickens produced in the system.

Larger particulate matter and transfer of key foodborne and waterborne pathogens

- As detailed above, DEEDI research has concentrated on particles small enough to remain as aerosols and move considerable distances.
- Research into the impact of larger particulate matter and the associated pathogens is required. While these particles settle at a short distance from the shed, they may assist in the survival of the pathogens in this external environment. The surviving pathogens may then be re-aerosolised and/or move into water systems via rainfall events or adjacent agriculture (food crops).

Regulations, guidelines and codes of practice

- There may be a need for guidelines on the acceptable air levels of foodborne pathogens such as *Salmonella* and *Campylobacter* in and around poultry sheds.
- Regulations may be required to assist in the implementation of the concept of a 'marker organism' to assess the impact of shed emissions on local aerobiology characteristics.
- As litter ultimately has to enter the environment outside the shed, there may be a need to develop guidelines that match the quality of the litter (in terms of pathogen presence) and the end-use application. Research into cost-effective pathogen reduction methods for used litter is also needed.

Potential new pathogens

This section deals with potential new pathogens that may be of concern to the poultry industry.

- *Chlamydophila* and *Chlamydophila*-like agents are an area where a watching brief is required. The Australian poultry industry has provided funds to a research group at the University of Melbourne to develop both identification and typing tools. The outcomes of this research need to be understood before any further work can proceed. Due to the specialised and difficult nature of *Chlamydophila* and *Chlamydophila*-like agents, any required future research work should involve the University of Melbourne due to their experience in the area.
- The potential role of APEC as zoonotic agents in the Australian setting needs to be examined. There has been considerable research performed in the USA to date. However, there is no publicly available data on APEC sourced from Australian chickens and their potential similarities or differences to ExPECs.

Key areas where further research is required on pathogens and aerosols

- Litter management and impact on foodborne pathogens—In the future there is likely to be increased adoption of litter re-use across broiler cycles. This increasing adoption rate will fuel the need for ongoing research into the impact of litter re-use on foodborne pathogen levels.
- Free-range/organic systems—There is a need for detailed studies on the levels (in the litter, chicken and surrounding environment) of foodborne pathogens in these emerging, newer production systems.
- 'Marker organisms'—Further research to extend and strengthen the use of staphylococci or coryneform bacteria as markers of the impact of bio-aerosols derived from meat chicken sheds would be useful.
- Settled, heavier particles—DEEDI research to date has concentrated on the issue of pathogens in aerosols capable of moving significant distances from the source sheds. There is a need to understand the risks, if any, of any pathogens that are associated with the large particles that deposit quickly on leaving the shed (i.e. within the first 20–30 metres). Are these large particles a source of pathogens? Will any pathogens associated with these deposited particles survive long enough to move (e.g. by re-aerosolisation as the particle breaks apart into smaller pieces or as a result of rainfall events)?
- New potential pathogens—The current industry-funded work on *Chlamydophila* and *Chlamydophila*-like agents needs to be monitored. Australian-based research into the possible role of avian pathogenic *E. coli* as a potential zoonotic agent should be initiated.

Odour

Odour is one of the leading reasons for complaints against meat chicken farms. As such, there has been substantial investment into odour research specifically targeted toward meat chicken production.

Odour research can be divided into several categories:

- developing/improving odour measurement methods
- quantifying odour emissions
- studying the odorant compounds present in meat chicken odour
- modelling meat chicken odour and the dispersion of odour in the atmosphere
- developing technologies to abate the potential for odour complaints.

Odour is described using four dimensions:

1. strength/concentration
2. intensity (perceived odour sensation)
3. quality (what it smells like)
4. hedonic tone (pleasantness).

During odour impact assessments, odour strength is the only dimension that is considered and, consequently, odour research tends to focus on measuring odour strength. This is reasonable because the other odour descriptors for similar sources, such as a chicken farm, can be reasonably assumed (i.e. it smells like a chicken farm, which for many people is unpleasant).

Odour is reported as odour concentration or odour emission rate (OER). In simple terms, OER is the product (multiplication) of odour concentration and ventilation rate, and in effect is the quantity of odour. When considering the impact of odour from poultry sheds from a planning perspective, OER is considered the more useful measure. For odour abatement research, however, all four dimensions of odour need to be considered as changing the character, hedonic tone or perceived intensity will all influence the likelihood of complaints.

The processes that occur between odour generation and odour nuisance, which may lead to a complaint about meat chicken sheds, are very complex and have been summarised by the Environment Agency, United Kingdom (2002). The following flow diagram provides a simple way to consider links between the main elements of this complex process.

Formation of odorants
↓
Transfer to atmosphere
↓
Atmospheric dispersion
↓
Exposure
↓
Perception
↓
Appraisal
↓
Annoyance
↓
Nuisance
↓
Complaints

Once exposed to an odour, the process towards a complaint is influenced by the receptor's physical and psychological characteristics, history of exposure and exposure to other stressors. In short, this means that the same odour may be more or less acceptable to different people, or the same odour may be more or less acceptable to a single person at different times or in different circumstances, which makes planning to prevent complaints extremely challenging.

The most effective ways to prevent odour or dust nuisance are to prevent excessive odour generation through good management practices (McGahan et al. 2002) and ensure adequate buffer distances between farms and receptors (McGahan & Tucker 2003). These will ideally reduce or control the intensity, frequency and duration of the odour exposure to a point where it will not cause annoyance. In addition to ensuring adequate buffer distances, enhancing dispersion of the plume will have similar benefits.

This section outlines the research that has been undertaken to address the issue of meat chicken odour.

Key points on odour and the process of odour complaints

- Multiple research approaches are required to understand and address the complex processes from odour formation to odour nuisance and complaints.
- The most effective ways to prevent odour nuisance are to prevent excessive odour generation (on-farm management) and ensure adequate buffer distances (planning policy and management).
- OER is the product of odour concentration and ventilation rate.
- OER contributes to odour impacts, but atmospheric dispersion processes are equally important.
- The receptor's odour exposure history as well as physical and psychological characteristics will influence complaints.

Developing/improving odour emission measurement methods

Methods to measure odour have been established and well defined by the Australian and New Zealand Standards (Standards Australia 1995; Standards Australia/Standards New Zealand 2001). These standards can be applied to tunnel ventilated meat chicken sheds with only minor adaptations required. It is essential to understand that OERs measured prior to the olfactometry standard (for odour analysis) in 2001 cannot be directly compared with current measurements.

Recent developments in odour measurement techniques have largely occurred in the field of artificial olfaction systems (AOS) and odorant identification using gas chromatography-mass spectrometry-olfactometry.

An AOS, sometimes referred to as an 'electronic nose', uses an array of specially selected sensors and a sophisticated data acquisition and processing system to mimic human olfactory and neurological processes. An AOS needs to be calibrated using conventional olfactometry measurements to enable it to quantify the strength of a particular odour. DEEDI has been a world leader in the development of AOS and its application to poultry odour sources. This has been made possible with co-funding through the Australian Poultry CRC and RIRDC. Progress in the development of AOS for poultry odour measurement has been presented at scientific conferences and in scientific publications (Sohn et al. 2008a; Sohn et al. 2007a, b; Sohn et al. 2008b) and the research is ongoing. Future developments of AOS will yield a stand-alone odour assessment instrument, specifically tuned for poultry odours, capable of measuring odour strength in and near poultry sheds.

One particular advantage of the current generation research-grade AOS system is semi-continuous odour measurement. This feature has been applied in recent odour monitoring

research (see ‘Quantifying odour emissions’ below) to monitor odour emissions from meat chicken sheds in unprecedented detail. This capability will significantly improve understanding of the variability of OERs, will aid assessors to identify periods of likely odour impacts and will contribute to improved odour emission models.

The AOS alone is not able to measure OERs because it is only capable of measuring odour strength. To measure the OER, ventilation rate also needs to be monitored. In a recent monitoring study undertaken by DEEDI and co-funded by RIRDC, ventilation rate was monitored at five meat chicken farms in major growing areas in the eastern states (Dunlop & Duperouzel 2008). When published, this data should aid dispersion modellers to improve estimations of odour emissions from meat chicken farms (see ‘Modelling meat chicken odour and the dispersion of odour in the atmosphere’ overleaf) and will provide researchers and consultants with data to improve the design of exhaust air treatment technologies as they become available (see ‘Technologies to abate the potential for odour complaints’, p. 23). The fan activity monitoring methods used in this project have since been applied in partnership with the AOS to continuously monitor OERs from a meat chicken farm. Other fan activity monitoring methods have been used in the USA to enable estimation of ammonia, dust and other emissions from meat chicken sheds (Darr et al. 2007; Gates et al. 2004; Hoff et al. 2004; Wilhelm & McKinney 1998). Current methods for externally monitoring fan activity are invasive and laborious to install and therefore development of a more convenient, low cost system for fan monitoring would be beneficial.

Key points on odour measurement methods

- All odour measurements must be made to the current Australian Standards (AS4323.1:1995 for sampling position and AS/NZS4323.3:2001 for olfactometry assessment).
- Recent advancements in the development of AOS have been very promising, especially for measuring highly variable broiler shed odours.
- AOS needs to be paired with ventilation rate measurement to measure OERs.

Quantifying odour emissions

Accurately measured odour and dust emission rates from poultry farms are essential for providing realistic predictions of impacts using odour dispersion modelling. However, achieving these measurements can be extremely challenging, especially due to the highly dynamic nature of the production system. Only limited odour and dust emission rate data has been published for intensive poultry production. Much of the previously measured OER data is no longer relevant due to changes in olfactometry standards and recent changes to poultry farm design and management that will influence OERs.

A recently completed four-year research project led by DEEDI and conducted through the Australian Poultry CRC (Dunlop et al. 2009b) will significantly improve the available odour and dust emission rate data. In this recently completed study measuring odour emissions from 13 meat chicken and layer sheds located in Queensland and Victoria, odour measurements were complemented with simultaneous dust measurements and odorant analyses undertaken by collaborating research agencies. The range of odour emissions need to be considered along with environmental and in-shed conditions at the time of measurement (e.g. ambient temperature, ventilation rate, litter moisture content, bird age, health status, stocking density and total bird live weight). The final report of this project is currently undergoing peer review.

The AOS was also used to continuously measure OERs at two of the farms included in this monitoring study. Figure 1 shows the continuous OER measured at a meat chicken farm using the AOS. Throughout the batch, there is a general trend for OER to increase along with the total live weight in the shed, and then decrease slightly with each pickup (corresponding to a reduction in total live weight). Figure 1 also clearly shows large diurnal variability in OER with much lower OERs occurring at night. This diurnal trend needs to be clearly understood, as it will influence the

potential for odour impacts to occur and also influence the design of air treatment technologies. Much of the daily OER variation occurs due to changes in the ventilation rate. The level of detail in OERs measured with the AOS are unmatched and are providing essential detail about OERs at times of the day when conventional odour sampling is not practical.

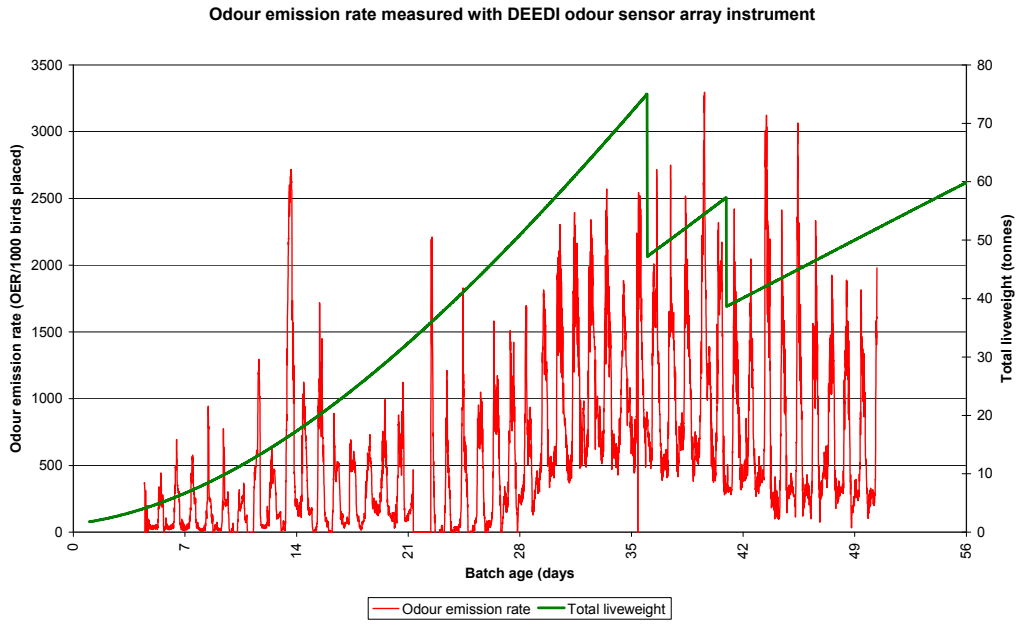

Figure 1: Example of daily average OER output from artificial olfaction system technology

Aside from this research project, there have been very few other measurements of odour emissions from tunnel ventilated meat chicken sheds. Odour consultants in Australia have measured odour emissions at a number of farms in the past (Ormerod & Holmes 2005); however, descriptions of the farms and sampling conditions have not been published. Other odour emission measurements have been undertaken in Victoria (Simons 2006) and in the United Kingdom. Very few OER measurements have been reported in the USA due to their greater interest in dust, ammonia, sulphur dioxide and greenhouse gas emissions.

While there has been a substantial investment in quantifying odour emissions, more research will be required to identify the causes for odour emissions and the conditions that result in higher emission rates. This will be required to improve prediction and modelling of OERs for planning purposes. The Australian Poultry CRC have committed to a research program that will fill some of these knowledge gaps, and are currently assessing research proposals. Successful outcomes in this ongoing research will require a multi-organisational and multi-skilled approach.

Key points on odour emission measurement

- High quality odour emission data is necessary for dispersion modelling.
- Accurately measuring representative OERs from poultry farms can be extremely challenging, especially due to the highly dynamic nature of the production system.
- Instrumental odour measurement (with an AOS) has demonstrated that odour emissions from broiler sheds are extremely variable. This makes accurate modelling very challenging.
- There has been substantial investment in surveying odour emissions, but more research will be required to identify the causes for odour emissions and the conditions that result in higher emission rates.

Studying odorant compounds present in meat chicken odour

Odours are formed by the complex mixture of many odorous compounds, which are referred to as odorants. These odorants can be classified into chemical sub-groups, such as non-methane

volatile organic compounds (NMVOCs) and sulphur compounds. Different odours, for example coffee and wet socks, will be formed with different combinations of odorants.

Understanding which compounds are contained in meat chicken odours will help researchers:

- identify the source of the odours
- establish whether odours are formed by anaerobic or aerobic decomposition of manure, which may influence the offensiveness of the odour
- improve selection of sensors for AOS systems
- design treatment systems that target the strongest and most offensive odorants
- improve testing (including reduced costs) of odour treatment technologies.

Odorants are identified and quantified using highly specialised laboratory techniques, including gas chromatography-mass spectrometry-olfactometry (GC-MS-O). While GC-MS technology is not new, improved detection resolution and application to meat chicken odours and other livestock odours are relatively new advancements (Cai et al. 2006; Chen et al. 2008; Parcsi & Stuetz 2007; Parcsi et al. 2007; Zhang et al.). In Australia, research to identify and quantify odorants in poultry odour has been led by the University of New South Wales through the Australian Poultry CRC. This research has been undertaken in partnership with DEEDI (Dunlop et al. 2009b); the final project report of which is currently undergoing peer review. One important finding from this research was the identification of different odorants contained in the odours from meat chicken and layer sheds, with some of the principle odorants in meat chicken odour being absent from the layer shed odour. A conclusion that can be drawn from this is that odour from layer sheds is different than that from meat chicken sheds.

Odorant research is ongoing and there is a strong focus on linking the principle odorants to their bacterial origins and developing targeted odorant abatement strategies.

Key points on studying odorants

- Odour is comprised of hundreds of odorants (NMVOCs and sulphur compounds).
- Understanding the odorants will lead to improved measurement techniques and odour abatement strategies.

Modelling meat chicken odour and the dispersion of odour in the atmosphere

There are two types of modelling relating to odour. The first is odour emission modelling, used to predict OERs from meat chicken sheds. The second is dispersion modelling, which will use the data from an odour emission model to predict likely odour impacts following dispersion of the odour plume into the atmosphere.

Measuring OERs (as described in ‘Quantifying odour emissions’ p.18) is an important step toward developing OER models for meat chicken farms. Models will be required because of the highly dynamic variability in OERs between farms, diurnally, seasonally and throughout each batch. DEEDI attempted to develop an odour emission model using the emission rate data collected from broiler farms; however, there was a substantial amount of variability in the data that was unable to be explained by the input variables and hence the model was not adequate. This outcome was not surprising considering the number of interrelated factors that influence OER, many of which cannot easily be quantified (see Figure 2).

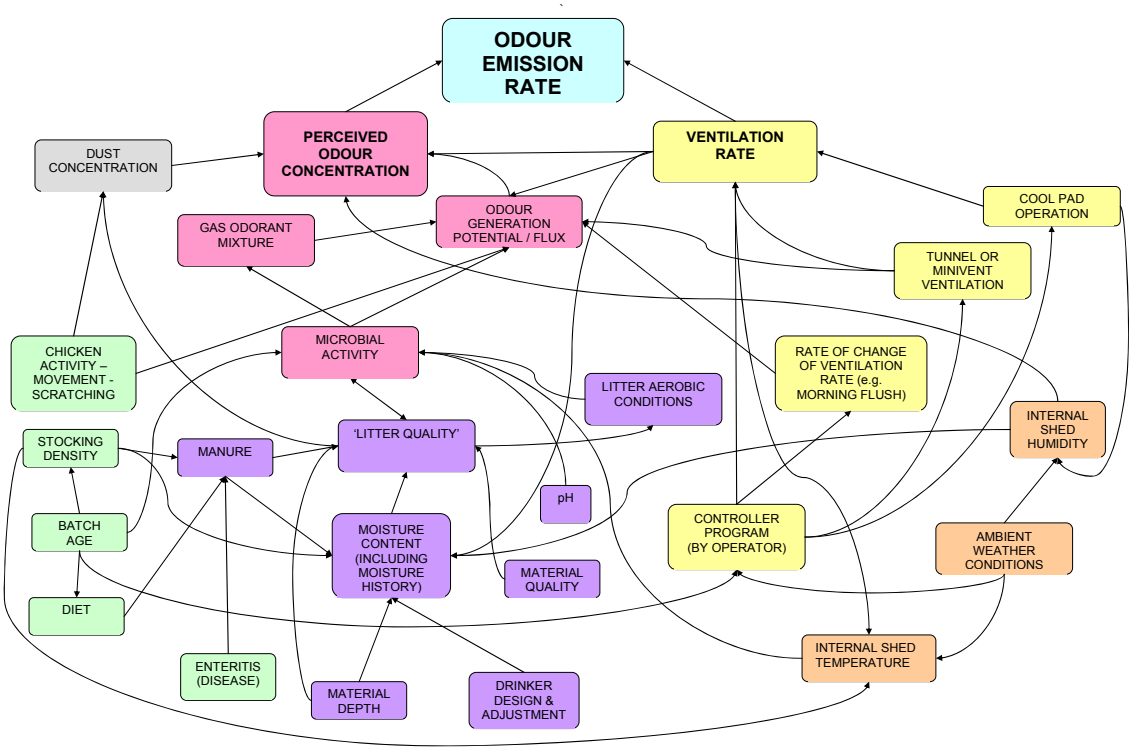

Figure 2: Diagram showing interaction between farm conditions, environmental conditions and OER

As mentioned in 'Developing/improving odour emission measurement methods' (p.17), data collected in the ventilation monitoring study undertaken by DEEDI may contribute to improved prediction of OERs by improving the prediction of the ventilation rate, because OER is strongly influenced by the ventilation rate. Additional research should be allocated to developing a robust ventilation rate model.

Odour dispersion modelling has been used for many years to model the likely impacts, especially of odour, from intensive livestock farms as well as industrial sources. Odour impact criteria are used to assess whether the strength, duration and frequency of odours in the surrounding landscape, predicted by the model, is likely to create an odour nuisance. In Queensland, the odour impact criteria is 2.5 ou (odour units), 1 hour averaging time, 99.5th percentile. This criteria, whilst not designed to provide complete protection from ever experiencing odour, outline the odour concentration, averaging period and recurring frequency (expressed as a percentile) that would limit the frequency and intensity of odour nuisance below a reasonable level.

Dispersion modelling (using a selection of different computer programs) is accepted worldwide as the most effective method to predict impacts from aerial contaminants. Despite this, dispersion models have not been designed to specifically model the horizontal discharge from tunnel ventilated sheds and the selection of modelling parameters for meat chicken shed emissions has been a major cause of contention between dispersion modellers, local government and developers.

Additional arguments have arisen due to the inclusion of thermal buoyancy parameters and the best way to describe the emission point (e.g. as stacks with vertical velocity, as stacks with no velocity or as volume sources). A recent investigation by DEEDI focused on addressing the issue of thermal buoyancy (Dunlop et al. 2009a). This project demonstrated that poultry exhaust air is usually warmer than the ambient air and will therefore normally rise. A combination of temperature measurements, plume visualisation techniques and computational fluid dynamics modelling were used during the study.

An alternative to dispersion modelling is the use of separation distance formulas. These formulas use inputs that include a farm factor (to predict likely odour emissions), receptor factor (likely sensitivity), landscape and land use factors (likely odour dispersion), and may also include a weather factor (effect of prevailing winds) to calculate a required odour separation distance. The use of these formulas is more transparent than odour dispersion modelling. Separation distance formulas are accepted in Victoria (Department of Primary Industries, State Government of Victoria 2009), South Australia (Environment Protection Authority South Australia 2007) and New South Wales (Department of Environment and Conservation NSW 2006). Farm size limits apply in some of these states.

A formula was proposed for Queensland (Queensland Chicken Growers Association 2005); however, this has not been accepted for use. DEEDI recently completed a short study where the proposed Queensland separation distance formula was compared with Calpuff dispersion modelling and the formulas used interstate using a selection of five existing and 12 hypothetical broiler farms. During this comparison, the proposed separation distance formula calculated larger separation distances compared with Calpuff for the majority of receptors, but also calculated some shorter distances. During this study, there was no consideration of complaint data.

Application of the proposed separation distance formula to existing meat chicken farms (for research investigation purposes only), for direct comparison of calculated separation distances with the location of actual complainants, would be a more thorough way to test the formula. However, the logistics and legislative constraints on accessing complaint information would make this virtually impossible for anyone other than regulatory agencies.

One outcome from DEEDI's investigation of separation distances was that separation distances predicted by Calpuff using a selection of modelling configurations produced considerably different distances for the same farm/receptor combination. Each of the modelling configurations (stack source using realistic emission temperatures, stack source with the emission temperature equal to ambient temperatures to simulate no plume thermal buoyancy, and volume sources) have been used during odour assessments. This begs the question as to which configuration is the most appropriate. The industry would likely benefit from a more consistent approach for estimating separation distance requirements, whether it be with separation distance formulas or using a consistent dispersion modelling methodology.

Key points on odour models

- There are two types of odour models—odour emission models and odour dispersion models.
- Odour emission models:
  - They are necessary due to high variability and great number of contributing factors.
  - They need to be based on accurate OER data.
  - Variability in the OERs measured by DEEDI could not be explained by corresponding environmental and production data.
- Odour dispersion models:
  - Odour impacts are predicted against odour impact criteria (2.5 ou, 1 $hour_{99.5}$). This does not provide complete protection from odour, but is aimed to limit the exposure to a reasonable level for a 'statistically average' person with average odour sensitivity.
  - Calpuff is commonly used for broiler farms.
  - Horizontal discharge is difficult to model.
  - Input parameters and modelling outputs are a cause of contention (e.g. thermal buoyancy parameters, building downwash, OER inputs and terrain resolution).
- An alternative to the dispersion model is separation distance formulas, but these are not currently used or accepted in Queensland.

Technologies to abate the potential for odour complaints

Abatement of odour is a hot topic for researchers internationally, as it is seen as a way to reduce complaints, reduce the size of buffer zones and will allow increased production on the same land parcel. Some of the challenges preventing the development of treatment technologies for tunnel ventilated meat chicken farms are:

- highly variable OER
- widely ranging ventilation rates
- small profit margins that restrict capital investment and operating expenditure
- low-pressure, high-volume fan performance
- dust (which may clog some treatment systems).

In general, odour control technologies target the odour in different ways by:

- preventing or reducing the generation of odour
- preventing or reducing the amount of odour released from the shed
- changing the characteristics of the odour as it is released
- improving dispersion.

Each of these will reduce or eliminate the amount of odour that reaches receptors, hopefully to the point were odour nuisance would not be experienced and complaints would not be made. Gates (2008) reported that there is no 'silver bullet' to abate odour complaints, and it is likely that a combination of odour control techniques will be required to achieve an affordable, effective and reliable solution. DEEDI researchers recently reviewed a selection of odour control technologies that were designed to control odour, dust or ammonia emissions from chicken sheds, or could be adapted for that purpose (Dunlop 2009). The review demonstrated that there were no effective, reliable and cost-effective technologies specifically designed to control odour emissions. Several technologies were highlighted as being potentially suitable for this purpose, but require testing and adaptation.

Preventing or reducing the generation of odour

Preventing the generation of odour would be the most effective form of odour control, because it would reduce the reliance on odour capture or dispersion-enhancing techniques. Technologies to reduce the generation of odour tend to focus on altering diet or changing conditions within the odour source (assumed to be the litter in the case of meat chicken sheds) to reduce microbial activity and odour generation.

Very limited research has focused on controlling or changing diets to specifically reduce odour from meat chicken sheds. McGahan (2002) reported on studies that showed reducing protein levels in feed could be used to reduce ammonia emission. However, ammonia emission have very little relation with OER. Jacobson et. al. (2001) also reported on research where dietary manipulation was trialled to control gaseous emissions with varying success. While dietary manipulation may have potential to abate odour, this approach is unlikely to be successful due to the realities associated with diet formulation, availability of specific ingredients and the potential to decrease productivity.

There has been very limited research into changing litter properties or using litter amendments to reduce odour generation in the litter. Techniques such as applying amendments, aerating litter or drying litter in-situ are overwhelmed by technical challenges.

On-farm management strategies are more likely to be successful at controlling odour emissions, or at least preventing excessive emissions. The industry has recognised this and actively promotes a range of management practices, primarily aimed at preventing excessive litter moisture. These techniques include maintaining the ventilation system, preventing air leakage into the shed and maintaining drinkers. At the industry's biennial conference, the Poultry Information Exchange, the

industry regularly offers a workshop to show producers how to improve the operation and maintenance of their sheds to improve productivity and reduce emissions. Much of the information presented at the workshop, which the presenters try to adapt for the Australian audience, is available from the University of Georgia website at www.poultryventilation.com.

Preventing or reducing the amount of odour released from the shed

Technologies to capture or reduce odour as it leaves the shed need to treat the odour biologically, chemically or physically. A review of a selection of these products by DEEDI researchers (Dunlop 2009) was unable to identify any technologies that were able to effectively reduce odour emission that are suitable for tunnel ventilated sheds or cost effective.

Researchers have attempted to reduce odour using ozone, thermal oxidation, biofiltration, chemical scrubbing, chemical odour neutralisation and dry filtration. The major technical challenge for these techniques is being able to treat the air flow rate that is required to provide adequate ventilation within the shed. A typical broiler shed may have a maximum ventilation rate of 130 m^3/s (which would remove the air from a container the size of an Olympic-sized swimming pool in about eight seconds!). The other challenge is that ventilation fans on chicken sheds are designed to efficiently move large volumes of air with little restriction. The addition of any back-pressure by a filter would significantly reduce flow rate and compromise chicken health.

One approach that may be possible to improve the feasibility of installing an air treatment system (when a suitable one becomes available) would be to install the system on only some of the exhaust fans. In this way, lower volumes of air (presumably exhausted at night and other times of poor dispersion) will be treated while the largest volumes (presumably exhausted in the warmer parts of the day when there is great dispersion) would be left untreated. This approach has been suggested by Gates (2008) and Dunlop (2009) and has actually been adopted in several farms in Germany that are trialling ammonia scrubbing systems.

Changing the characteristics of the odour as it is released

Changing the characteristics of odour, such as its hedonic tone or character, could potentially be successful for reducing complaints by making the odour less offensive so that a receptor may be more tolerant of the odour.

Dunlop (2009) and Simons (2006) have reviewed or tested odour-neutralising or masking agents. None of the tested products were found to be successful. Anecdotally, the use of certain masking agents may actually increase the potential for complaints by changing the chicken odour to another distinct or unnatural scent, such as lemon or bubblegum. Consequently, trials of these products using only olfactometry would be unlikely to confidently conclude if they would actually reduce complaints.

Improving dispersion

Techniques to improve dispersion allow odour to be released from the shed, but additional dilution reduces the amount of odour that will reach a receptor. Technologies aimed at improving dispersion, such as windbreak walls and short stacks, have been investigated by DEEDI researchers (Dunlop 2009; Dunlop et al. 2007; Dunlop & Galvin 2006; Dunlop et al. 2008). Computational fluid dynamics modelling and plume visualisation techniques were used to evaluate these technologies. It was concluded that these technologies may help to improve dispersion in some situations but may be ineffective in critical situations (for odour impacts), such as highly stable atmospheric conditions.

In the development of the *Victorian broiler code* (Department of Primary Industries, State Government of Victoria 2009) and supporting legislation, short stacks and windbreak walls are not considered to be a technology capable of significantly reducing odour emission. This isn't to say

that these technologies shouldn't be considered as a means to reduce complaints at an existing farm (if deemed suitable for that particular situation), but new farms will not be allowed to be built if they rely on dispersion enhancing technology to prevent odour impacts (based on dispersion model predictions).

Significant research and extension activities have been undertaken in the USA to promote the value of vegetative environmental buffers (VEBs or tree shelterbelts). This has culminated in the development of a step-by-step guide on how to establish a vegetative buffer around poultry farms (Scott & Delmarva Poultry Industry Inc. 2007). The benefits of VEBs include abatement of air quality impacts, but they also improve neighbour relations by improving the aesthetic appearance of the meat chicken farm (Malone et al. 2006). Additional research is required to identify and test trees that would be suitable for Australian conditions, and extension activities are required to demonstrate and promote the benefits of strategic tree planting around meat chicken farms (individual tree planting and landscaping designs are required for each individual farm). Planning agencies also need to support and encourage the planting of VEBs and recognise the benefits. One limitation of VEBs is that they may take 3–10 years to become established (Jacobson et al. 2001).

Evaluation of these dispersion enhancing technologies is very challenging because of the reliance of these technologies on atmospheric dispersion to be effective. The effectiveness of these technologies to reduce downwind odour concentration will therefore be almost completely dependent on weather and atmospheric conditions.

Key point on odour abatement technologies

- There are major technical and engineering challenges associated with the use of air treatment technologies in broiler sheds.
- There is no system to reduce the formation of excess odour, other than good management practices.
- There is currently no technology available to capture and treat odour from broiler sheds.
- Technologies to enhance dispersion are dependent on the weather.
- VEBs may help to alleviate odour and dust impacts, but require research to select suitable Australian tree species and ensure appropriate VEB design and landscaping.

Dust

Compared with odour, dust has been a lesser cause of complaints against meat chicken farms. Nonetheless, the industry, community and regulatory agencies recognise that dust can be an issue.

Quantifying dust emissions

Recent monitoring studies undertaken through the Australian Poultry CRC measured dust emissions from tunnel ventilated meat chicken sheds in Queensland and Victoria (Dunlop et al. 2009b). This project report is undergoing peer review before release. Dust was measured at the fan and no attempt was made to measure or model the transport of this dust from the sheds.

Dust concentrations varied on a daily basis, throughout the batch cycle, and from farm to farm. In general, dust emission rates peaked on the measurement day prior to the first pickup. Dust concentrations in the exhaust air from meat chicken sheds were occasionally very high. In addition, poultry dust was composed of large numbers of fine particles (< 1 μm). This implies that workers should wear appropriate dust masks (e.g. P2 Australian Standard or N95 USA Standard) at all times when working inside poultry sheds, especially for workers that consistently spend extended periods of time in a shed.

No conclusions regarding the potential health effects or dispersion of dust in the areas surrounding poultry sheds could be made because this was beyond the scope of the work undertaken to date. Dispersion and deposition of dust particles near the shed would be likely to significantly reduce airborne dust concentration to near-ambient levels. It must be recognised that meat chicken farms are not the only source of dust in agricultural areas. Tillage, slashing, manure spreading and unsealed roads are other dust sources.

Key points on dust measurement

- Dust emissions have been quantified from broiler sheds.
- Dispersion and fate of emitted dust requires further research/modelling.
- Many agricultural activities generate dust.

Reducing dust impacts

Dust impacts may be reduced by:

- reducing dust generation and entrainment
- capturing dust
- increasing dust deposition
- improving dust dispersion.

In a review undertaken by DEEDI researchers, a selection of dust control technologies were investigated (Dunlop 2009). These technologies included dry dust filters, wet scrubbers and electrostatic precipitation technologies. Of these, the dry dust filter and wet scrubbers had been tested (by the manufacturer) and shown to be effective at capturing dust. However, their high cost and high resistance to airflow raise a number of significant technical challenges that need to be overcome before adoption could be considered.

Electrostatic dust precipitation is a technology that has been developed, tested (by the developer and independently) and is now being adopted in piggeries, meat chicken farms and layer houses in the USA. This technology charges dust particles, which makes them aggregate and become attracted to the shed floor and walls. DEEDI researchers are in the process of submitting a funding proposal to evaluate this technology in a Queensland meat chicken farm.

Properly designed and established VEBs have been demonstrated to effectively capture dust particles emitted from poultry sheds (Colletti et al. 2006). Further research is required to assess the suitability and durability of Australian trees for capturing dust particles.

Dust capture was observed by Dunlop and Galvin (2006) while assessing the efficacy of windbreak walls for improving odour dispersion. The authors suggested that the design of the windbreak wall could probably be changed to further enhance dust interception and deposition.

Oil sprinkling has been trialled successfully in pig houses to control dust (Jacobson et al. 2001); however, this method would not be suitable for meat chickens raised on litter-covered floors.

Farmers could potentially reduce dust generation if they were able to increase litter moisture content; however, this could increase odour generation and compromise bird health and welfare.

Key points on technologies to control dust

- Technology exists to capture dust, but is very expensive and cannot treat the enormous volume of ventilation air.
- Fine dust from broiler sheds is more challenging to capture.
- Testing of electrostatic dust treatment system has been proposed.
- Methods such as oil sprinkling are unsuitable.
- There is a conflict between controlling litter moisture for dust and odour control.

Dust as a carrier of odour

Dust has been found to carry odorants (Cai et al. 2006; Hammond et al. 1981; Heber et al. 1988). It has been hypothesised that odorant accumulation on dust particles can produce a strong odour response within the human nose; however, there is no supporting evidence in the literature.

Key points on dust as a carrier of odour

- Dust particles carry odorants.
- Removal of dust may simultaneously reduce odour; however, there is no evidence in the literature to support the hypothesis that odorants carried by dust particles actually produce an odour response in the human nose.

Conclusions and implications

Pathogen, odour and dust research has focused on developing a sound scientific platform for long-term benefits including:

- identifying and quantifying pathogens in and around meat chicken sheds
- quantifying OERs to provide knowledge about the range and variability of emissions from tunnel ventilated sheds
- identifying and quantifying primary odorants
- quantifying dust emission rates.

Pathogen research is well developed and has produced some clear outputs relating to planning and operation of meat chicken farms. In particular, in well-managed farms there is minimal risk to human health due to airborne *Campylobacter* or *Salmonella,* and there is virtually no risk from viruses or protozoal agents. *Campylobacter* and *Listeria* are of minimal concern in the use of spent litter outside the shed. *Salmonella*, a good environmental survivor does need to be considered, although it's survivability is balanced by the survey results of low levels and a serovar that does not infect humans. In summary, the DEEDI pathogen research has provided a solid basic knowledge and the underlying principles that can and should be used in industry and planning guidelines.

Odour and dust research is still in the early stages, and the current research outputs are unlikely to contribute to planning processes at this stage. Of value are the recently measured OERs, which could be used to ensure that OER inputs to dispersion modelling of proposed farms are within an appropriate range. Additionally, investigations into treatment technologies have demonstrated that there are no suitable odour treatment options currently available for tunnel ventilated broiler sheds.

Appendix 1: A technical review of viral pathogens and Australian chickens

Newcastle disease is a well-known viral disease of poultry that is of great economic importance (Alexander 2003). Newcastle disease virus (NDV) is widely present in Australian chickens, although clinical disease in Australian chickens is not common as most Australian strains of NDV are of low pathogenicity. Currently, the Australian chicken industry is considering adoption of a national vaccination program to reduce the likelihood of clinical disease. Human infections with NDV result in eye infections and have usually resulted from direct contact with infected chickens—e.g. rubbing the eye with hands immediately after handling infected chickens (Alexander 2003). Casual contact with infected chickens represents a low risk of human infection (Alexander 2003).

Rotaviruses (as well as atypical rotavirus and rotavirus-like viruses) are now accepted as the cause of enteritis and diarrhoea in chickens (McNulty 2003). There is little knowledge on the prevalence of rotavirus in Australian chickens. The general overseas experience is that the infection is ubiquitous (McNulty 2003). Rotavirus is a major cause of enteritis and diarrhoea in humans, particularly young children (Blacklow & Cukor 1985). Transmission of avian rotaviruses to mammals is regarded as rare and avian rotaviruses have no known public health significance (McNulty 2003).

Reticulendothelial (RE) viruses cause a number of diseases in chickens—runting, stunting disease, chronic neoplasia of lymphoid tissues and acute reticulum cell neoplasia (Witter & Fadly 2003). These viruses are accepted as being common in chickens in Australia. There have been two reports of antibodies in humans to RE viruses (Johnson et al. 1995). However, it has been argued that these antibody positives are of no major concern and even that RE viruses may be suitable vectors for use in gene therapy in humans (Dornburg 1995).

Infectious bronchitis virus, infectious laryngotracheitis virus, infectious bursal disease virus, chicken infectious anemia virus, inclusion body hepatitis virus, egg drop syndrome virus, fowl pox virus, avian encephalomyelitis virus, Marek's disease virus and avian leukcosis virus are all viruses that are present in Australian chickens at varying levels of prevalence. All of these viruses are regarded as being pathogens of chickens (as well as some other poultry species for some of the viruses) with no evidence of transmission to humans or other mammals (Calnek 2003; Cavanagh & Naqi 2003; Fadly & Payne 2003; Guy & Bagust 2003; Lukert & Saif 2003; McFerran & Adair 2003a; McFerran & Adair 2003b; Schat 2003; Tripathy & Reed 2003; Witter & Schat 2003).

The overall summary is that the Australian chicken flock does not contain any viruses that pose public health problems or problems for mammals in general.

Appendix 2: A technical review of bacterial pathogens and Australian chickens

Bordetella avium is an opportunistic pathogen of chickens, being associated with complicated respiratory disease conditions (Blackall & Doheny 1987). While this bacterium has many similarities to the human pathogen (*Bordetella pertussis*), there is no evidence that *B. avium* can either colonise or produce disease in humans (Gentry-Weeks et al. 1988).

Brachyspira pilosicoli, an anaerobic spirochaete, has been isolated from the blood of critically ill patients (Trott et al. 1997) as well as from biopsies of homosexual men with minor non-specific gastrointestinal symptoms (Trivett-Moore et al. 1998). Recent Australian studies have shown that *B. pilosicoli* infection is common in meat breeders and laying hens (Stephens & Hampson 1999). As infection in meat chickens is unknown (disease is restricted to older birds), *B. pilosicoli* is not likely to be a significant pathogen in terms of public health or infection of other animals.

Campylobacter coli/jejuni are two bacterial species that are difficult to separate and are often treated as a single entity (Nachamkin 1995). *C. coli/jejuni* are the most important cause of bacterial gastroenteritis in the Australian human population. Poultry are recognised as one of the primary reservoirs of this pathogen (Shane & Stern 2003). *C. coli/jejuni* are fragile organisms that are unlikely to survive any drying process (Shane & Stern 2003).

Chlamydia psittaci is a well-recognised zoonotic agent. Human infections can vary from inapparent to severe systemic disease with pneumonia (Andersen & Vanrompay 2003). Human infections are associated with exposure to an infected avian species (Andersen & Vanrompa, 2003). The available evidence is that chickens are relatively resistant to disease caused by *C. psittaci* (Andersen & Vanrompay 2003). Recently, there has been a report of atypical pneumonia cases in poultry slaughterhouse workers in France associated with an apparently new, as yet unnamed *Chlamydophila*-like agent (Laroucau et al. 2009). Overall—while there is no firm, direct evidence to suggest that *Chlamydophila*-like agents in poultry are a health risk—the situation requires monitoring. An awareness and monitoring of the situation is important as *Chlamydophila* and related agents have a low infectious dose and can be spread by aerosols (Vanrompay et al. 1995). *Chlamydophila* agents are difficult pathogens to detect and identify and require specialised laboratories and techniques. The Australian chicken meat industry is funding research into the development of suitable identification and typing methods at the University of Melbourne. This research needs to be monitored.

Clostridium perfringens can cause gas gangrene as well as food poisoning in humans (Onderdonk & Allen 1995). In chickens, *Cl. perfringens*, particularly type A, causes necrotic enteritis (Wages & Opengart 2003). Botulism (caused by *Cl. botulinum*) is an important disease of both humans and animals (Onderdonk & Allen 1995). The types of *Cl. botulinum* associated with human cases (types A, B, E and F) are not the types associated with chickens (types C and D) (Onderdonk & Allen 1995). However, other animals (e.g. dairy cattle) are at risk from *Cl. botulinum* types C and D (Onderdonk & Allen 1995). Both *Cl. perfringens* and *Cl. botulinum* are widely distributed in the general environment, including chicken sheds. *Clostridium* spp. are spore-forming organisms with a capacity to survive for prolonged periods in the environment. *Cl. botulinum* is an important pathogen in litter re-use applications due to severity of botulism outbreaks in susceptible animals (such as cattle) and grazing pasture treated with poultry litter. *Cl. perfringens* is a low-risk pathogen as there is no strong existing link between human infections and poultry products or poultry litter.

Enterococcus species are found in soil, food, water, animals, birds and insects (Facklam & Sahm 1995). The organisms are associated with urinary tract infections and septicemia in humans, with a majority of the infections being nosocomial in nature (Facklam & Sahm 1995). *Enterococcus* species are regarded as part of the normal intestinal micro flora of poultry (Devriese et al. 1991). *Enterococcus* species are associated with endocarditis in chickens (Wages 2003) and amyloid arthropathy in brown layer chickens (Landman 1999). The major public health concern with poultry enterococci has been the association with the use of avoparcin in poultry (as an in-feed growth promotant) and the occurrence of vancomycin resistant enterococci (VRE) in both poultry meat and humans (Gambarotto et al. 2001). While there is still continuing debate about whether the VRE in poultry and on poultry meat are the same VRE associated with human disease, avoparcin is no longer used in the Australian poultry industry due to concerns about a possible link.

Erysipelothrix rhusiopathiae causes erysipeloid in humans, a local skin lesion that occurs chiefly as an occupational disease of persons engaged in handling and processing meat, poultry and fish (Bricker & Saif 2003). The disease can also be septicaemic in nature, with occasional fatalities (Bricker & Saif 2003). Erysipelas of birds is an acute, fulminating infection of few individuals within a flock and is of more importance in turkeys than in chickens (Bricker & Saif 2003). Human infections have been linked with direct handling of infected turkeys and infected chickens (Bricker & Saif 2003). The organism is rarely seen in the commercial Australian chicken industry.

Escherichia coli is the most common bacterium isolated in human clinical microbiology laboratories (Gray 1995). The organism is present in the faeces of humans and a wide range of animals (Gray 1995 #4828). In recent years, there has been an emergence in humans of particular subtypes of *E. coli*—the so-called EHEC (enterohaemorrhagic *E. coli*), often also called VTEC (verotoxin producing *E. coli*) or STEC (shiga-toxin producing *E. coli*) strains, that are associated with animal sources (Gray 1995). The best known of these EHEC strains is the 0157 type that has caused frequent problems in the USA (Gray 1995). These strains, mainly associated with inadequately cooked beef and sheep products, can cause serious conditions such as haemolytic urealytic syndrome (HUS) (Gray 1995).

Most *E. coli* serotypes isolated from poultry are pathogenic for birds only and are regarded as only a low risk of disease for humans or other animals (Caya et al. 1999). The evidence to date is that there is only a low occurrence of natural infection with *E. coli* 0157 in chickens, with studies based in Asia and Europe (Heuvelink et al. 1999). Natural contamination of chicken meat with this organism has been found and a foodborne outbreak of human diarrhoeal disease associated with turkey meat has occurred in the USA (Griffin & Tauxe 1991). In recent times, there have been suggestions from USA-based researchers that avian pathogenic *E. coli* (APEC) shares a very large genetic background, including a similar range of virulence mechanisms, with *E. coli* associated with extra-intestinal infections in humans—so called ExPECs (Johnson et al. 2008). There have been no direct connections between chickens and these human infections (which are predominantly urogenital infections). The American research has not yet been supported by research in other countries and there is apparently no active research in the area in Australia.

Listeria monocytogenes causes meningitis, encephalitis or septicaemia in non-pregnant humans (Swaminathan et al. 1995). In pregnant women, *L. monocytogenes* can cause a flu-like septicaemia that can result in an infected foetus, the end result being abortion, stillbirth or premature birth (Swaminathan et al. 1995). Outbreaks of listerosis are only sporadic in poultry and are rarely reported in Australian poultry. There have been reports of human infections associated with either direct contact with infected chickens or via consumption of contaminated poultry meat, especially cooked, ready-to-eat products.

Mycobacterium avium infection is common in AIDS patients (Fulton & Thoen 2003). However, most human infections are associated with *M. avium* serovars 1, 4, 8, 9, 16 and 19, while *M. avium* serovar 2 is the most common form isolated from chickens (Fulton & Thoen 2003). It is accepted that most human cases of *M. avium* infection are human-to-human contact and not bird-to-human contact (Fulton & Thoen 2003).

Pasteurella multocida infection is rare in humans, generally being associated with cellulitis resulting from animal bites (Holmes et al. 1995). *P. multocida* causes fowl cholera, a severe septicaemic disease of chickens (Glisson et al. 2003). The organism is a common inhabitant of the upper respiratory tract of many warm-blooded animals, with animals generally being accepted as the reservoir for human infections (Holmes et al. 1995). However, chickens are not regarded as a common reservoir of infection for other animals. Indeed, horses, cattle, sheep, pigs, dogs and cats are quite resistant to infection with fowl cholera-derived isolates of *P. multocida* (Glisson et al. 2003). The fragile nature of the organism (Glisson et al. 2003) combined with the usual exposure route for humans (animal bites or licks) mean that chicken-derived *P. multocida* isolates are not an important cause of disease in other animals.

A number of bacteria are associated with respiratory diseases of chickens, the major and common causes being *Haemophilus paragallinarum* (Blackall & Matsumoto 2003) and several *Mycoplasma* species—*M. gallisepticum* and *M. synoviae* (Kleven 2003). None of these bacteria have ever been associated with human disease and are accepted as being pathogens of chickens and a small range of other poultry species (Blackall & Matsumoto 2003; Kleven 2003).

Salmonellosis of humans is typically an acute gastroenteritis following the consumption of contaminated food (Kelly et al. 1985). It is usually a self-limiting illness and fatalities are uncommon (Kelly et al. 1985). Infections due to *Salmonella* spp. are not a common cause of disease in poultry in Australia. *Salmonella* serovar Enteritidis, which is a major cause of human illness in countries such as the USA (Gast 2003), is absent from the Australian commercial poultry industry. In addition, the most common serovar of *Salmonella* in Australian chickens—*Salmonella* Sofia—is not among the top 10 serovars associated with human infections in Australia (Davos 2002). Nevertheless, it is widely recognised that poultry can harbour *Salmonella* organisms and thus act as a reservoir with the potential for transmission to humans.

Staphylococcus aureus is both an opportunistic pathogen of humans and a common cause of food poisoning in humans (Kloos & Bannerman 1995). *S. aureus* infections are common in poultry (Andreasen 2003). Approximately 50% of poultry isolates of *S. aureus* produce enterotoxins capable of causing food poisoning in humans (Andreasen 2003). There is a long history of an association of food poisoning caused by *S. aureus* in poultry (Andreasen 2003). *S. aureus* is a relatively resistant organism. Overall, *S. aureus* is a pathogen that moves from chickens to humans, but the evidence to date is that this movement is associated with contaminated or poorly handled poultry meat.

Appendix 3: A technical review of protozoal pathogens and Australian chickens

Cryptosporidium spp., a relative of *C. parvum,* can infect the cloaca and the bursa of Fabricus of chickens (McDougald 2003). Respiratory cryptosporidiosis can occur and can result in high morbidity and mortality if associated with other respiratory disease agents (McDougald 2003). Infection with *C. baileyi* has been widely reported wherever intensive chicken production occurs and where relevant diagnostic tools have been used (McDougald 2003). *C. baileyi* is regarded as non-pathogenic for humans and other mammals (McDougald 2003).

Overall, there is no protozoal agent present in Australian chickens that could be considered as a serious or major risk to human health.

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