Resource Consent Applications under the Resource Management Act 1991

an application to discharge contaminants (including odour) into the air from the Roto-o-Rangi piggery at 30 Kairangi Road, Roto-o-Rangi (renewal of existing consent AUTH 136796.01.01)

to irrigate treated piggery waste water onto land and associated discharge to air at 83 and 62 Kairangi Road, Roto-o-Rangi (renewal of existing consent AUTH 136796.02.01)

STATEMENT OF EVIDENCE OF BINDI GROUND

Witness introduction and background information

1. My full name is ANTHONY BINDI GROUND.

2. I am a Director of Waratah Farms Limited (**WFL**). WFL is the Applicant in this matter.

Scope of Evidence

3. My evidence addresses the following matters:

    a. Overview of WFL Operations
    b. Background to Current Application
    c. Complaints History pre-2012 and upgrade
    d. Complaints History post-2016
    e. Waikato Regional Council – Odour Response Plan
    f. Investment and Upgrades 2016 – present
    g. Engagement of Other Experts
    h. Further consultation with neighbours
    i. Additional Mitigation
    j. Additional Mitigation and Changes to Operations – summary
    k. Responses to section 42A report

Overview of WFL Operations

4. WFL operates a pork grower facility at 30 Kairangi Road in Roto-o-Rangi (**the ROR Facility**).

5. The ROR Facility is part of a larger pork operation run by WFL. The ROR Facility has been in operation for around 50 years, and WFL have owed the facility for around 30 years.

6. WFL also owns a farm at Ormsby Road, Pirongia (**Ormsby Road Facility**). The Ormsby Road Facility holds approximately 12,00 sows and 10,000 50kg equivalent pigs. The Ormsby Road Facility is used for the breeding and farrowing of sows.

Once some of the pigs reach 30-40kg equivalent they are moved to the ROR Facility.

7. The ROR Facility is used for growing pigs. No farrowing or breeding occurs on site. The ROR facility can hold approximately 1700 50kg equivalent pigs.

8. Pigs sourced from the Ormsby Road Facility are housed at the ROR Facility for approximately seven weeks from arrival to departure. While at the ROR Facility they grow from approximately 35kg to up to 100kg. The target weight may vary depending on market demand. Once pigs reach the target weight they are removed for slaughter.

9. The ROR Facility is maintained at a reasonably consistent stocking rate, with the weekly removal of approximately 120 – 140 pigs that have achieved target weight and the replacement of these pigs with pigs from the Ormsby Road Facility.

Background to Current Application

10. The ROR Facility holds three Resource Consents. WFL is seeking to renew two of these consents (Resource Consent Number 113384 relating to the discharge of irrigated treated piggery wastewater to land and Resource Consent 113384 relating to the Discharge of Contaminants, including odour, to air) (**The Consents**) . A third consent (Resource Consent 113383 - relating to the discharge of treated piggery wastewater to a drain) has been surrendered.

11. The Consents were granted by the Waikato Regional Council (**WRC**) on 29 November 2006 and expired on 1 November 2016.

12. On 28 April 2016 WFL filed an application with WRC to renew the Consents.

Complaints History pre-2012

13. During the period 2010-2012 WFL received a series of complaints about the smell from the piggery. Some complaints were made to Waikato Regional Council and some came directly to me from one particular neighbour (Amber Griffiths) who lived at 772 Roto-o-Rangi Road who had experienced problem smells. .

14. We took the complaints seriously and improved the flushing routine to be more targeted, flushing ¼ of the buildings each time rather than the whole shed. We also ceased taking effluent from the Animal Breeding Services site for processing.

15. Immediately following completion of the targeted works the complaints and comments from the neighbour ended. We began to receive comments on how effective the upgrades were and how pleased the neighbour was with the outcome. We maintained regular contact with the neighbour.

16. The effectiveness of those upgrades has also been demonstrated by the response that WFL received to the proposal for renewal of resource consents in 2017. All but two of the neighbours in Kairangi Road supported the application, including the school and the hall. Many of those neighbours gave their written approvals and positive comments, as set out in the application documents and the s42A Report by Mr Rademeyer.

17. In the period from 2012 until the current application was notified in 2016, the WRC records indicate that no complaints had been received relating to odour from the ROR Facility. WFL did not

receive any direct complaints from neighbours during this period.

Complaints History post-2016

18. Since the current application was notified, the WRC and WFL, have received 37 odour complaints (to the date of this Statement of Evidence). 25 of those complaints were received during the period March 2017 to February 2018. 12 complaints were received during the period March 2018 to August 2018. No complaints were received during September and October 2018. Three complaints were received in November 2018 (one on 26 November and two on 28 November).

19. It is my understanding from WRC that all of these complaints have come from Janet Smith. The Smith property is located at 37 Kairangi Road.

20. In her submission, Mrs Smith raised a number of concerns relating to the ROR Facility. In an effort to understand and address these concerns, on 28 February 2017 (at the invitation of WFL) Mrs Smith came to view the ROR Facility. The purpose of the visit from WFL's perspective was to enable Mrs Smith to better understand what work had been done to mitigate odour and to discuss what else (if anything) could be done to address her concerns.

21. Unfortunately that visit was unable to offer any practical solutions to address Mrs Smith's concerns. At the end of that visit, Mrs Smith still expressed the view that the ROR facility needed to be moved or closed.

22. Since that time, WFL has undertaken a number of steps to try and understand and address Mrs Smith's concerns. These steps are outlined in more detail below:

Waikato Regional Council

23. On 16 March 2017 WFL was notified that Mrs Smith had made an odour complaint to WRC relating to an odour she experienced the day before.

24. WFL raised a concern that the failure to notify us promptly about complaints meant that we could not immediately investigate whether there was an odour beyond the boundary and, if there was, what we could specifically identify to be causing that odour eg Irrigation, pit one or pit two, flushing happening etc.

25. As a result of this it was proposed by the WRC Resource Officer that a Site Response Plan for Odour would be drafted in consultation with WFL and adopted. The Site Response Plan for Odour was finalised in April 2017 and a copy was provided to WFL by WRC (Jennifer Matthys). (**2017 Odour Plan**). A copy of the 2017 Odour Plan (as received by WFL) is at page 135 of the Section 42A Report.

26. The 2017 Odour Response Plan that was developed with WFL differs from that annexed to the Section 42A Report. The following differences are noted:

    a. Determination of response actions – clause 1 – the 2017 Odour Plan simply noted that attendance was not required if the odour was no longer occurring. The Updated odour Plan does expand on this, with attendance not being required if the complainant is "merely reporting the odour for our stats". Attendance is noted as not being "crucial".

    b. Determination of response actions – clause 2 – the Updated Odour Plan advises staff they are not required

to attend if the complaint is after 10pm – "its up to you". This was not in the 2017 Odour Plan. As a number of complaints had come late at night, WFL felt it was important for WRC staff to attend whenever possible. This change wasn't discussed with WFL.

c. On-site inspection – clause 5 – the steps to be taken by WRC have changed. The requirement in the 2017 Odour Plan to investigate the piggery property and note down anything that could be causing odour has been removed and replaced with an instruction not to do this as "*Jennifer has been doing pro-active visits and the sources of odour are well understood*". The last pro-active visit was in March 2018. No proactive visits have been undertaken since. Since March 2018 WFL has undertaken further mitigation which, we believe, has further reduced the potential for odour on site and beyond the boundary.

d. There is also a significant change in the background section. In the 2017 Odour Plan, Jennifer Matthys comments that

> *Mrs Smith experiences odour from the site on a regular basis, particularly during the evening and seldom during the day. She has complained three times (at the time of writing this response plan) since the submission period closed, despite the fact that she will be heard at the hearing, and despite the fact that she had had a tour of the site with the applicant and WRC staff, with discussions about the odour. It appears that she has decided to complain regularly to "up the anti" but also, I imagine, she would like to have her complaints verified by WRC staff".*

e. The amended Odour Response Plan has replaced this section as follows:

> *Prior to the hearing we need to have her [Mrs Smith's] complaints assessed by WRC staff. I have done a comprehensive odour assessment recently and I will be doing at least two more. I have found distinct odour next door at the neighhbours driveway 39 Kairangi Road, so I have no reason to suspect that Mrs Smith is imagining it or exaggerating*

27. WFL has never received a copy of the amended Odour Plan that is attached to the s42A report. The first time I saw this was when I read the Section 42A Report. The 2017 Odour Plan was written with input and feedback from WFL. I am not sure why we weren't asked for feedback when the amended Odour Plan was created.

28. To my knowledge, WRC has only responded on one occasion to a complaint. This was the visit by Novalea Crowe and Robert Isaac on 16 February 2018. The other two proactive visits undertaken by Jennifer Matthys were carried out the day after complaints were received. The last proactive visit was undertaken by Jennifer Matthys on 8 March 2018.

29. Despite the 2017 Odour Plan and the amended Plan asking staff to take a statement from the complainant, I don't believe this has ever occurred. I have never received a copy of a statement taken by WRC relating to a complaint by Mrs Smith or any of the other people that she has said also experienced odour. I don't know why that hasn't happened.

30. WFL has arranged for staff or principals to follow up on complaints when it became apparent that there was no follow-

up by WRC. Information about those follow-up attendances are in the evidence of Martin Ellis, Clive Andersen and Martin Dysarht. It had always been important to WFL that the Plan be followed closely, as follow-up checks on any odour complaints by someone independent (WRC staff) should provide information about events complained of. The verification process is seen as important by WFL.

Investment and Upgrades 2016 – present

31. Since the Application was notified, WFL has undertaken a number of upgrades and improvements intended to address the allegation that Mrs Smith is experiencing significant odour at her property. These steps have included:

a. Installation of new ventilation (to remove end of sheds vents and install roof vents);

b. Installation of a new transformer to the ROR Facility to match with new ventilation arrangements;

c. Installation of a new fresh water bore and associated infrastructure to allow sufficient fresh water for twice daily hosing, previously recycled water was used;

d. Increase in hosing of the sheds to twice daily;

e. Exclusion of meat and bone meal from the pigs diets to decrease the potential for odour from a meat based feed ingredient and purchase of a new soya auger to enable the new feed to be delivered;

f. Changes to the time that pigs were fed to try and avoid this occurring in the early evening when odour complaints seemed to be prevalent, the assumption being that the animals may smell more when active;

g. Purchase and installation of two ozone filtration systems in association with the trialling of ozone as an odour mitigation measure (the first ozone filtration system failed).

h. WFL has also engaged experts to investigate whether the use of Vegetative Barriers would be a viable option to address any perceived odour effects beyond the boundary of the ROR Facility.

i. Trialled twice daily flushing with recycled water to see if it made a difference.

32. Only some of these upgrades are referred to in the Section 42A Report.

33. WRC has been kept advised of upgrades and improvements as they have been undertaken. For example, I sent fortnightly updates to WRC regarding process and results of the ozone trial. I also updated WRC staff on the additional mitigation undertaken by WFL at a meeting with David Stagg, Marius Rademeyer and Jennifer Matthys on 27 July 2018.

Engagement of Other Experts

34. In addition to the physical works that have been undertaken, WFL has engaged with external experts and consultants to try and ascertain whether there are odour effects beyond the boundary of the ROR Facility and, if there is odour, what the possible causes may be. This is in addition to engaging the services of Environmental Management Consultants and Tonkin and Taylor to prepare Reports and provide information for the Application process.

35. These additional experts include:

a. <u>Permathene Earth Solutions</u>

Permathene completed an inspection of the floating pond cover on Pond 1 at the ROR Facility. This was required as a result of a suggestion from WRC that the cover was leaking and that this may account for odour. The Report concluded that the cover was not leaking. A copy of the Report from Permathene is attached

b. <u>Dr Marc Dresser, Beca Consultants</u>

Beca Consultants were engaged after a Report from the WRC Resource Officer dated 6 December 2017 suggested that the anaerobic ponds at the ROR Facility were seeping through a bank bordering a farm drain. Dr Dresser carried out a scene investigation and took a number of samples from the drains. The Beca Report concluded that the ponds were not leaking; that the source of odour was an accumulation of material related to the compost and runoff from the neighbouring goat compost storage area in the neighbouring drain; and that any odour from this source was not significant. A copy of the Beca Report is attached. The neighbour's drain was subsequently cleared.

c. <u>QEC Limited</u>

QEC Limited carried out five proactive odour assessments between 5 September 2018 and 18 October 2018, one of which has been treated as less reliable, undertaken in weather conditions inconsistent with the conditions when odour complaints have been made. They have provided separate Briefs of Evidence setting out their findings.

36. The Brief of Evidence of <u>MARTIN ELLIS</u> covers in more detail the expenditure that WFL has incurred in respect of the additional works and experts.

Further consultation with neighbours

37. As part of the Consent renewal Application process, WFL consulted with affected neighbours as required by WRC.

38. When the initial consultation was done, Mrs Smith filed a submission in opposition. Although the neighbouring goat farm manager (Tony Fischer) did not provide written consent to the application he did not subsequently file a submission in opposition.

39. WFL consulted with Mr Fischer to identify and address his concerns. Mr Fischer indicated in discussions with me that his concerns were largely addressed by the changes WFL made to the ventilation and flushing routines. This was also confirmed in an email from Mr Rademeyer to David Ray on 16 February 2017. A copy of that email is attached to my Statement of Evidence

40. Unfortunately Mr Fischer passed away in December 2017.

41. As it has now been nearly 2 ½ years since the initial application was notified, I recently contacted the neighbours to see if there had been any change in their position.

42. Some neighbours have provided further confirmation of their approval of the application. I have not heard from some neighbours and have not directly followed up those particular neighbours as I didn't want to hound them, particularly when the only complainant in the last three years has been Mrs Smith and/or her family members.

43. WFL is proactive in communicating with neighbours about any operational aspects that may impact on the potential for odour beyond the boundary of the ROR Facility. Our current consent

conditions require us to communicate with neighbours when we are shifting compost from the site. Attached to my Statement of Evidence is the last email that was sent in this regard.

44. All of the neighbours to the ROR Facility (including Mrs Smith) have my direct cell phone number. Mrs Smith has on occasion sent me text messages directly. I am confident that the other neighbours would contact me directly if they are experiencing any odour issues.

Additional Mitigation

Vegetative Buffers

45. In discussions with WRC, WFL has given consideration to the installation of Vegetative Barriers (**VEB**) and the covering of the sump as possible additional mitigation.

46. It is my view that while these could be included in the form of consent conditions, they are unlikely to provide any significant benefits.

47. VEB were first mentioned as a potential mitigation measure in discussions with WRC in July 2018. Subsequent to that meeting WFL undertook research to identify if VEB had been used to mitigate piggery odour and, if so, how effective that had been. It did not appear that ozone had been used with any success to treat piggery odours within New Zealand.

48. The research undertaken by WFL suggests that VEB provide largely visual mitigation (which may have a psychological effect on perceived odour). Copies of the research relied upon by WFL to reach this conclusion are attached to my Statement of Evidence.

Ozone Trials

49. WFL has also undertaken trials with the use of ozone as an odour mitigation measure. Again, the first time we became aware of ozone as a potential mitigation measure was during discussions with WRC in July 2018, WRC suggested that WFL investigate ozone. Subsequent to that meeting WFL undertook research to see if ozone had been as a mitigation measure for piggery odour. As a result of that research WFL purchased machinery and installed the necessary infrastructure to enable ozone to be trialled.

50. Unfortunately, the first ozone unit that was supplied failed. WFL subsequently purchased and installed a second ozone unit. There was some intermittent success with the second ozone machine but this was short-lived and inconsistent.

51. Unfortunately the technology is largely untested in the field of piggery odour in New Zealand. As a result WFL found that the machinery required worked only intermittently and produced inconsistent results overall. I am reluctant to continue to incur the costs of trying to source operative machinery, given the issues we have had with this in the past.

Covering of effluent receiving sumps

52. The covering of the two effluent receiving sumps (Pit 1 and Pit 2) will have an effect on the cumulative odour caused by the operation. This point has been made by Dr Dresser and Jayne Metcalfe. The hesitation has been around the practicality of covering the sumps and the resulting treatment of the trapped air. It had been hoped that the ozone air and water treatment trial would have provided an option in this area. We believe that we can enclose the sumps, and this would have a beneficial effect.

Additional Mitigation and Changes to Operations – summary

53. In summary, WFL has undertaken significant operational and infrastructure changes in the last two years to address odour effects. I consider that these measures have had an effect on odour from the ROR Facility. This view is based, in part, on the fact that the number of complaints from Mrs Smith in the last six months have decreased, and when there have been complaints these have been of a lesser intensity rating (a 3-4) than in the past (a 5-6).

54. WFL has been, and remains committed to, working with our neighbours and the WRC to address any issues that may arise as a result of the ROR facility. We have been proactive in utilising new technologies and spending capital to keep our unit modern and minimising any impact on the receiving environment. We are seeking a consent renewal to continue our business of farming. We have been able to work with neighbours in that past (Tony Fischer and Amber Griffiths) Unfortunately I have come to the conclusion (based on my own discussions with the Opposing Submitter, and the information she has provided to WRC) that there is nothing short of shifting the ROR facility that WFL could do to address the perceived odour effects for Mrs Smith.

Response to s42A Report

1. The following paragraphs contain my responses to a number of matters that are raised in the s42A Report. The cross references are to the pages and section numbers used in that report.

2. Page 75, section 13.2. The final paragraph on page 75 states that "the assessment in this report shows that the piggery has in the past resulted in objectionable odour that caused adverse

effects beyond the boundary of the site. The adverse effects that the odour caused include that at times at a neighbouring property had to be shut and people had to remain indoors to escape the odour". I do not believe that the assessment shows that the piggery has resulted in objectionable odour that caused adverse effects beyond the boundary of the site. The report is largely a "desktop study" of various reports produced by other parties. The only odour experiences and assessments that have been available to the writers of the report were the following:

3. Marius Rademeyer was involved in odour sampling/assessment on 29 September 2016. Mr Rademeyer reported his experience/assessment of odour as being 0 ("no odour").

4. Jennifer Matthys was involved in making several odour assessments. She accompanied Mr Rademeyer to do an assessment on 29 September 2016. At that time she recorded an odour of between 0 – 1 during her ten minute assessment.

5. Jennifer Matthys assessment on 5 December 2017 recorded piggery odour at the driveway of 39 Kairangi Road – this was rated a 3/6. No piggery odour was recorded at the driveway of 37 Kairangi Road (the Smith Property) but there was a strong bovine odour (rated a 4/6) along the driveway of the Smith property. Intermittent piggery odour was experienced (rated a 1/6 to 2/6) along Kairangi Road.

6. Jennifer Matthys reported odour effects beyond the piggery boundary in her assessments carried out on 8 March 2018. This assessment is the subject of criticism of Leigh-Anne Peake in her evidence.

7. Ms Matthys also experienced fleeting odour to a level 3 strength in 20 November 2018, although no formal odour assessment was undertaken at that time.

8. Jayne Metcalfe was involved in a site visit on 20 November 2018. Although no formal odour assessment was carried out at that time, she reported fleeting odour at the Smith property during the site visit.

9. Except for those personal experiences of odour, which do not indicated frequent odour at a significant level, the writers of the s42A report are reliant on the complaints made by Mrs Smith, none of which have been verified.

10. The only time when WRC officers followed up to investigate any of the 32 complaints made by Mrs Smith was the site visit on 19 February 2018 by Novalea Crowe and Robert Issac. Their record of that visit reports a distinct pig odour at Kairangi Road that one of the officers rated at a "3". That was the only report of off-site odour during any follow-up visit by WRC officers or contractors.

11. Section 13.2 of the report states as a matter of fact that the adverse effects caused by the odour include that *at times windows at a neighbouring property had to be shut and people had to remain indoors to escape the odour.* If correctly reported, that statement should record that the complainant has asserted that the odour caused a need to shut windows and for people to remain indoors. It is also stated that *outdoor activities, family functions and social gatherings also had to curtailed.* Rather than reporting this as a matter of confirmed fact, the report should, at most, record that this was the complainant's statement.

12. Page 76, paragraph 2. This paragraph contains a statement that *there is considerable uncertainty whether the measures implemented by WFL will be successful in avoiding adverse effect beyond the boundary of the site.* That paragraph relies on the fact of there being a number of odour complaints lodged between March – June 2018 *when the mitigation measures were implemented.*

The reasoning recorded in that paragraph is inaccurate and confused. Further changes to equipment and operations were implemented by WFL after June 2018. These included further changes to feed composition, the time of feeding, and continued experimentation with the use of ozone.

13. Since those changes were implemented, there has been a very low level of complaint, which lifted very recently as we approach the hearing time. Mrs Smith made the following complaints since 1 July 2018:

(a) 30 July 2018 – 11.25pm - rating from Mrs Smith – 5/6;
(b) 31 July 2018 – Experienced 8.30pm – reported 10.30pm - rating from Mrs Smith – 3/6;
(c) 12 August 2018 - occurred between 12 – 12.30 pm – reported 4.01pm - rating from Mrs Smith 2-4/6;
(d) 25 November 2018 - rated 6/6 by Mrs Smith – lasted ½ hour – experienced 5.30pm - reported 9.30pm – duration – ½ hour.
(e) 27 November 2018 - rated 2/6 by son (Terry) – reported by Mrs Smith who was off site at the time. Ten minute duration.
(f) 28 November 2018 – reported 11.00am, rated 3/6 by Mrs Smith.
(g) 28 November 2018 – reported 8.22pm by Mrs Smith, experienced by boarders (Mrs Smith not home at the time). No rating given.

14. There was a definite drop off in the rate of complaint when those latest measures were implemented.

15. The s42A report does not contain any mention of the fact that there was no complaint whatsoever about WFL's operations from any source, including the Smith household, from 2012 until March 2017, shortly after the application was notified. The only changes to the piggery operation (since that period of 5 years without complaint) have been positive changes that will have reduced any odour effects. It seems to me to be unbalanced to ignore the five year absence of complaints prior to the application being notified, then the series of complaints from just one source after the application was notified.

16. The s42A report also fails to take any substantial account of the total absence of complaint from any of the Roto-o-Rangi community members, nor any mention of 14 of the 16 neighbours consulted about the application actually gave their written approvals. I do not see how any report on odour effects could ignore that situation.

17. Page 56 second bullet point. The writers of the s42A report criticise the timing of the odour assessments carried out by QEC consultants. The report states that Jayne Metcalfe does not agree with the conclusions drawn from the proactive assessments for a number of reasons, including, surprisingly, that *the majority of the T & T and QEC Limited assessments haven't been undertaken at a time of year or time of day when complaints have previously been received*. The report states that it is *unlikely that these assessments represent worse case conditions.*

    I am very surprised that there is any criticism of the timing of the QEC assessments, as the timing was specified very clearly

by WRC in discussions with WFL representatives. I discussed the most appropriate times for the QEC assessments with Jennifer Matthys prior to the QEC work being done. Ms Matthys was very strong in her view that the assessments should be undertaken early or late in the day, at times when wind conditions were still or very nearly still, and when any breeze is from the southerly quarter. QEC had to be very selective about the times when they undertook their assessments and they did undertake them in those conditions. QEC have reported that those conditions did not present themselves in the evenings, so the assessments were undertaken in the mornings.

18. There is criticism about the time of year when the assessments were undertaken. It is not possible during the period September – November to undertake assessments that represent summer conditions. It should be noted that there were no complaints whatsoever, from Mrs Smith or other neighbours, during the whole of the summer of 2016/2017, or any of the previous summer periods. Mrs Smith's complaints commenced in March 2017 and continued on a regular but unpredictable basis through until July 2018 when the number of complaints reduced.

19. The only consistent factor about the timing of Mrs Smith's complaints was the wind conditions i.e. when the wind was still or very light from the southerly quarter. That is entirely predictable, given the location of the Smith dwelling to the north/north west of the piggery buildings.

20. The s42A report recommends a number of additional operational and equipment changes to be incorporated in consent conditions, but at the same time recommends only a 5 year duration of the consent. Given the consistent acceptance of the company's operations within the local community, the

single source of complaint, the absence of verification of any complaints, and the recent introduction of further mitigations voluntarily by WFL, the suggested further upgrades **and** 5 year term are not a justified response.

21. I note that a 15 year consent duration is not an unusual duration for a renewal of an existing activity of this type, in the absence of verified adverse effects beyond the boundary. I understand that the consent conditions can, and usually do, include opportunities for periodic review of consent conditions. In the present situation, I see no reason why the existing activity should not be authorised to continue for a 15 year term, but with review opportunities with realistic intervals. Legal counsel for WFL will expand on this option.

Consent conditions recommended in the s42A report

Air discharge consent

1. The following paragraphs of my evidence address some of the suggested conditions of resource consent that are contained in the s42A report.

2. Condition 3 It would not be practical to arrange for a dedicated 24 hour phone number to be available that will be answered personally at all times of day and night. Hopefully that is not the expectation. Provision should also be made for substitution of an email address for notification where that it is agreed to by a property owner listed in this condition.

3. Condition 5 I do not understand why a minimum of 3 weeks advance written notice should be given for handling of solid piggery waste material. I would expect that a week's notice would be more than adequate.

4. <u>Condition 6</u> I believe that a period of 2 months would be required for production of an updated Site Management Plan. There will need to be outside involvement and possibly some discussion with WRC officers.

5. <u>Condition 10</u> The proposed biogas flare reignition system is unnecessary and would be a waste of resources. A better alternative would be to include provision for consideration of the benefits of a reiginition system in the mitigation strategy described in condition 12.

6. <u>Condition 11</u> The covering of pit 1 and pit 2 and venting to a biofilter will be a substantial cost and will cause some operational difficulties into the future, but is an option that can be implemented by the consent holder. It is not offered as a condition because WFL does not believe that further mitigation is shown to be necessary. However if the Commissioners believe it is necessary to implement further mitigations, covering the pits is a costly but viable option.

7. <u>Condition 12</u> Two months is too short for such a strategy to be developed and finalized. The condition should specify at least a 3 month period for this.

8. <u>Condition 16</u> The cost of a compliant meteorological station is still uncertain at this site. Expert advice is being requested at present and if one is required, may be better located on nearby land less affected by trees and buildings. I also understand that the standard cited in the advice note may have been superseded.

Waste water irrigation consent

9. Condition 7 The specified period should be 1 September to 31 December to match the shorter rotation period for grazing and grass growth.

10. Condition 10 Investment in optimisation of the wastewater management system is a further cost that will reduce the justification for a 5 year consent duration. This is another reason why a 15 year term for the consent is appropriate.

11. Condition 18 The requirement for sampling and analysis of treatment pond water should only be necessary during periods when irrigation is occurring. There is no point incurring the additional cost of sampling and testing at other times.

12. Paragraph 20 The groundwater samples should be taken in July and December each year to coincide with the monitoring requirements for WFL's Pirongia facility, maximising efficiency without reducing effectiveness of the monitoring.

Dated: 5 December 2018

A B Ground

Annexures to Statement of evidence of Anthony Bini Ground

1. Pond Cover Inspection Report, Permathene Earth Solutions.
2. Beca Report (Dr Marc Dresser) - 20 December 2017
3. Beca Report (Dr Marc Dresser) - 7 February 2018
4. Email Marius Rademeyer to David Ray - 16 February 2017
5. Updated neighbour consultation – July 2018
6. Email – Bindi Ground to residents – 14 August 2018
7. Vegetative Environmental Buffer research

1.Pond Cover Inspection Report, Permathene Earth Solutions.

PERMATHENE
Earth Solutions

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29/6/17

Attn: Bindi Ground
Roto-o-Rangi Piggery
30 Kairangi Road
Roto-o-Rangi
RD3
Cambridge

Dear Bindi,

At 8.30am yesterday morning I inspected the floating cover that we installed on your property in July, 2007.
I am pleased to say that I found no signs of stretching or any other cause for concern.
As expected, the .75mm Permaliner Membrane is showing no signs of deterioration and there is no brittleness that could possibly be associated with UV breakdown.

Best regards,

Chris Young
Manager Geosynthetics.

2. Beca Report (Dr Marc Dresser) 20 December 2017

Level 2 Waitomo House
6 Garden Place, Hamilton 3240, New Zealand
T: +64 7 838 3828 // F: +64 7 838 3808
E: info@beca.com // www.beca.com

20 December 2017

Attention: Bindi Ground

Dear Bindi

Thank you for meeting me on site on 15th December at 9.30am. Detailed below are my observations and notes from the site visit, and my comments.

Background

- Site visit occurred on 15/12/17 between 0930hrs and 1100 hrs
- Dr Marc Dresser, Technical Director, Beca, was accompanied by Mr Bindi Ground, Director, Waratah Farms Ltd.
- Biosecurity protocols and Health & Safety systems were in place and followed before, during and after the visit.
- A site walkover was conducted, with aspects of the effluent system explained and demonstrated by Bindi Ground.
- Photographs were taken and the effluent system visually inspected.
- Further information relating to the farm was provided by Bindi Ground via email, including the WRC site report file note 60-24-79A dated 6 December 2017

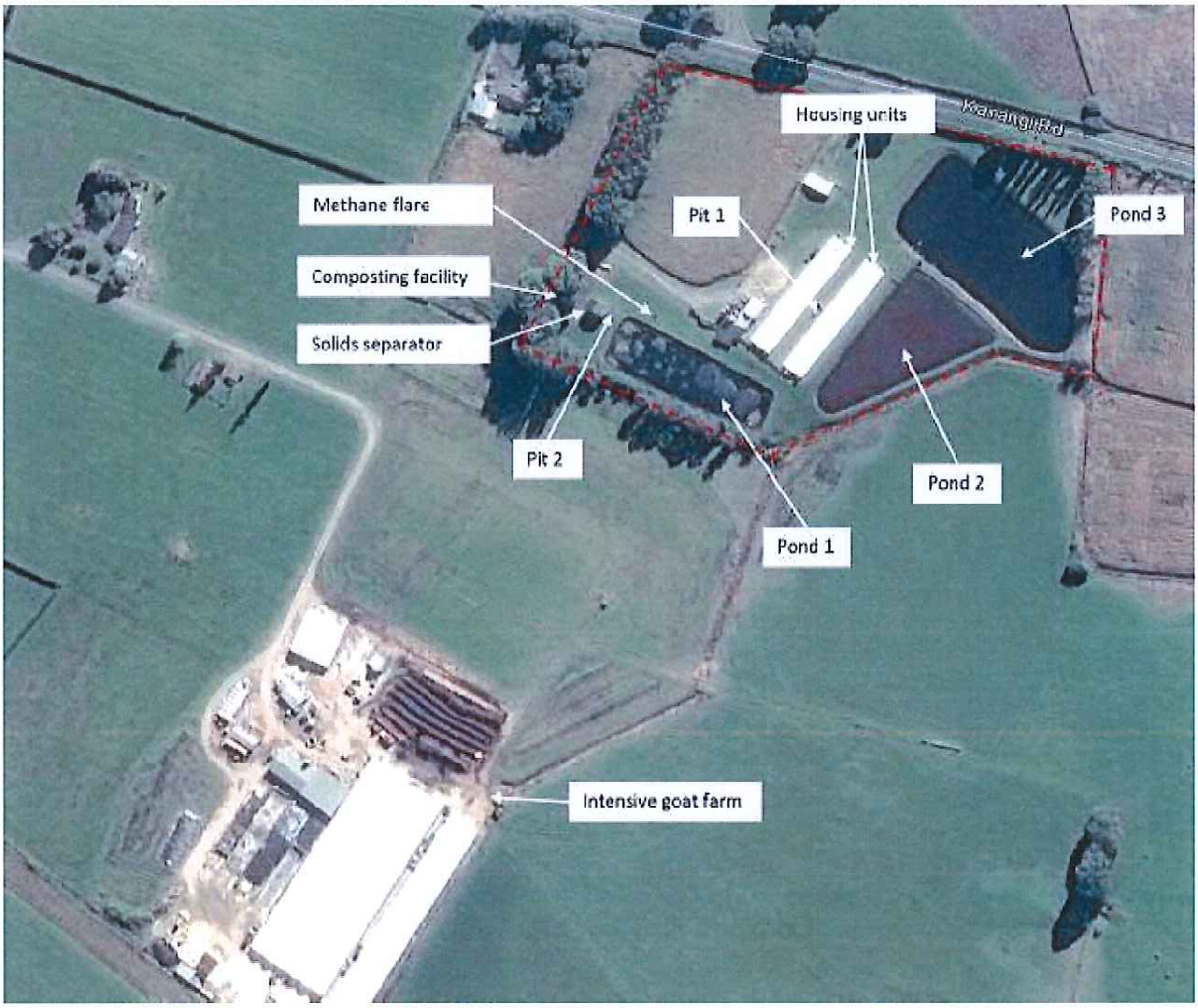

Figure 1. Aerial view of Waratah Piggery.

Effluent system description

The effluent system comprises a recycled flood wash system that enters a concrete sump, known as Pit 1, via 2 submerged outlets which reduce atomisation. This sump is located in-between the 2 housing units. Effluent is stirred and a level controlled pump directs the effluent to a second sump, known as Pit 2. Here the liquid is again stirred and pumped up to a screw press style solids separator that operates automatically based on a signal from the supply pump.

Figure 2. Pit 1, collection sump located between housing units.

Figure 3. Pit 2, collection sump and stirrer.

Figure 4. Solid separator unit

The solids fall into a storage bunker located below the solid separator platform, where they are stored and subsequently cleared approximately 3 times per year. The liquid, under gravity, enters a clay lined pond, Pond 1, which has been converted to a low pressure covered pond by NIWA scientists. The purpose of this cover, a loosely sealed HDPE lid, is to allow collection of the methane gas that is produced from anaerobic digestion. This methane is then flared off as and when required through a manual flare, which reduces the odour produced from this primary biological treatment process. There was no odour detected from this pond during the site visit.

Figure 5. Solids bunker

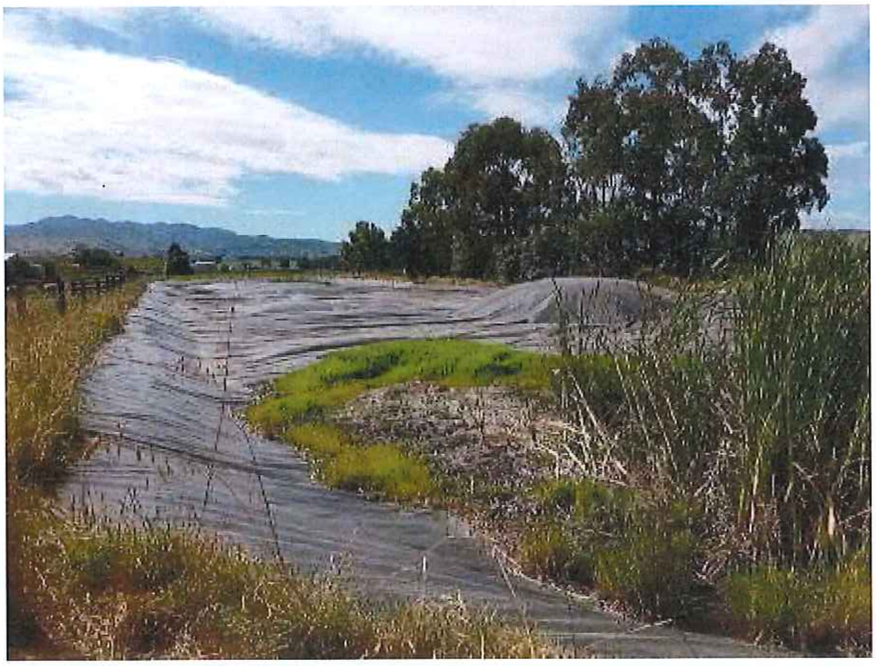

Figure 6. Pond 1, covered pond for methane collection

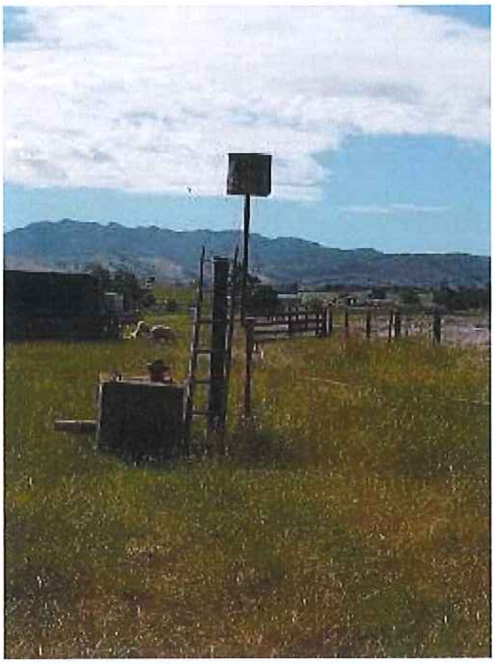

Figure 7. Methane gas flare.

The liquid then goes through a transfer sump, to Pond 2, an aerobic treatment pond. This pond is also clay lined however it is not covered. Stormwater collected on the farm is added to the effluent system through pond 2, except in the event of excess stormwater, when the excess is diverted through to the stream via a diverter valve. There was minimal odour detected from this pond during the site visit.

A pump transfers this liquid to a third and final clay lined pond, a clarifying pond, from where it is then pumped to an in paddock irrigation system. There was no odour detected from this final pond during the site visit. Bindi reported that there was no odour during irrigation.

Figure 8. Pond 2

Figure 9. Pond 3

In addition to the effluent system, there is a carcase composting area that is used for the disposal of dead animals. This consists of 2 bunkers, located close to the sold separation storage bunker.

Figure 10. Carcase composting bunkers.

During the site visit, the weather conditions were observed to be clear skies, with the external temperature around 25 degrees and a light South-westerly breeze.

Comments on site visit

Whilst undertaking the site visit, it was obvious that at certain points around the site there was a slight detectable odour, although nothing presented as offensive. There was no odour detectable from any of the drains that bound the Southern and Eastern sides of the site, nor from the groundwater holes that had been dug by Bindi Ground into the base of the pond side slopes and extended below drain water level.

During operation of the flush wash system, a stronger odour was given off from the Pit 1, and this appeared to be amplified by the wind tunnel effect created between the two long buildings, which caused a stronger breeze and creating a chimney effect over the sump. The stirrer in this pit activates 3 minutes before the pump turns on, which was believed to be when the sump reached 50% capacity. There was also a similar odour given off from Pit 2, as this was stirred to enable the solids to be pumped to the solids separator. The stirrer in Pit 2 is operational only when the pump is operational.

It was noted that the drains around the outside of the property were heavily weeded, and the water in these drains appeared stagnant due to minimal flow / movement.

Water within the drain was observed to be clear and no unusual algal growths etc were found. Upstream, towards the composting piles on the goat farm, excessive amounts of duckweed could be seen.

Access was made to the drain in an area to the west of the Waratah farms boundary and this also had excessive vegetative growth and similar water clarity. This Southern side of the property is bounded by an intensive goat farm, with what appeared to be barn scrapings piled in multiple heaps close to the drain. Irrigation of goat shed effluent was reported to occur at various times. This was not investigated further.

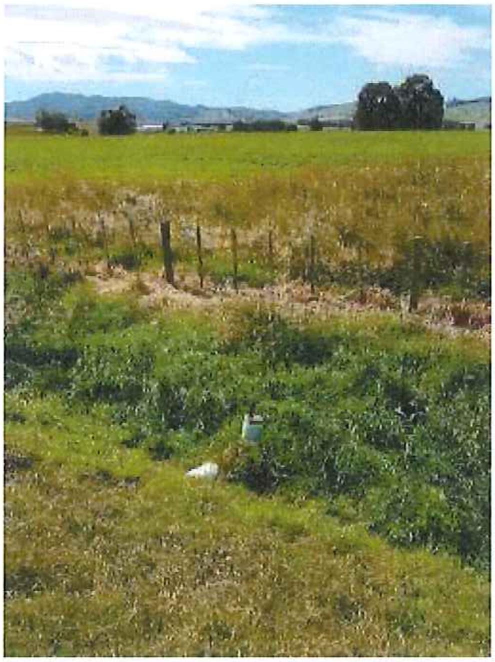

Figure 11. Photo of drain on property boundary, and winter stormwater bypass.

Figure 12. Photo of drain upstream of property boundary.

Figure 13. Photo of drain coming from neighbouring property.

Suggested way forward

Bindi informed me that there had been an odour complaint, and subsequent monitoring by WRC, as described in file note 60-27-79A, had detected a pungent odour reportedly emanating from one of the drains to the South of the property. This was described as extremely strong 6/6 intensity and produced gagging response in WRC staff member.

This observation is not consistent with the site visit undertaken on 15 December 2017, where no excessive odour was detected, and there was no obvious cause that would likely give rise to odour coming from the drains around the property.

Therefore, in order to determine possible sources of the reported odour and then, once found, attempt to mitigate it, I consider there are 5 potential sources.

1) Odour from operations occurring outside the property boundary
2) Odour from stagnant and rotting drain vegetation
3) Odour from sumps whilst filling, being stirred and pumped
4) Odour from ponds due to biological activity
5) Odour from carcase composting operations

Therefore, I recommend further in-depth investigations into implementing the following procedures.

1) Clear the drains on the boundary of weeds and rotting vegetative material, and ensure the drain water is flowing appropriately. The drain is shown in Figure 14.
    a. This will allow you to monitor the water in the drain at strategic points which will demonstrate if there are excess nutrients entering from a number of sources
        i. At a point up flow of the eastern property boundary
        ii. At the confluence of the neighbouring drain and the property boundary, to the south of Pond 2
        iii. At the exit of the drain located East of Pond 3.
    b. This will also remove the decomposing vegetative matter from the stagnant stream
        i. It is recommended to transport the excavated material off site as this could cause its own odour nuisance. The freshly excavated drain could also cause an odour issue for a short while, and, if the wind is blowing in a certain direction, may cause the neighbouring property some odour concerns. Warning them that the excavation is to occur, in an attempt to discover if there is an issue, would be advisable.

Figure 14. Aerial view showing the drain that will require cleaning.

2) If elevated nutrient levels are also being detected in other locations, then it would be prudent to check for potential sources of odour outside the site boundary.

3) If, after a suitable period of time, nominally 4 weeks, there remains an odour concern, and elevated nutrient levels are being detected only in the down flow location in the drain, undertake concurrent pond drop tests on each pond to determine if the seepage rates from the ponds are within specifications.

4) Consider isolating and capturing the gases being vented from the two sumps and investigate if gasses are being released from pond 1 to 2 transfer sump.

    a. This would entail a complex logistical operation, and specific management plans for the operation and maintenance of the plant contained within the sumps, as the toxic and corrosive nature of the enclosed environment is a health and safety hazard and could also cause premature equipment failure.

    b. It was reported to Beca that he majority of odour complaints have been received outside farm working hours, when the flood wash system and thus transfer sump stirrers and pumps are not operational, thus it is unlikely that these items could cause an issue.

5) Consider further material to increase the burial depth for the composting operation and the addition of an odour neutraliser if applicable.

    a. The double bunker composting facility was not odorous on the day of the site visit, however it may not always be the case under different conditions. Having an excess of composting material depth would ensure that this was not the source of any potential odour problem.

Storage

The ponds were described as being clay lined, however this could not be confirmed on the day of the site visit. The clay lining material is required to meet the required sealing standard of 1×10^{-9} m/s permeability rate and be constructed in an appropriate manner. If these ponds have been in-situ for a number of years, and operational, it is entirely possible that the sludge layer in the pond is performing the sealing function, thus extreme care must be exercised when emptying the ponds, particularly if a full scrape is required, so as not to disturb this sealing layer.

If the ponds are leaking, then in order to continue the farming operations a replacement storage system will need to be installed and this could be in the form of a tank or an appropriately sealed in-ground pond.

The volume of liquid produced per day was reported as just under 90 m^3/day. This volume will be used for design purposes.

If it is assumed that a maximum of 90 day storage is required, and all excess stormwater is diverted directly to the drain, this would then give a total required storage volume of 8,000 m^3.

One reputable supplier of above ground tanks is Tasman Tanks. They have over 300 tanks in the Waikato and, with the installations I have worked on and seen in the past, performed good work. Tasman Tanks have

a maximum tanks size of 6,000 m^3, which will allow for 60 days storage. The cost to supply and install this tank is approximately $190,000.

If 8,000 m^3 is required, they will supply and install two 4,000 m^3 tanks for $145,000 each.

Additional ground work is required for these and not included in this price. This ground work would include excavation of a circular ring, 2 m wide, to the solid subbase, backfilled with gravel, and blinded with sand so the ring of the tank sits in the middle of this.

A modicum of pipework will also need to be installed to hook into the existing system.

Maguire drainage contractors are industry qualified and reputable designers, suppliers and installers of effluent ponds with whom I have worked extensively with in the past. A pond with approximately 8,050 m^3 of storage would be 55 m x 55 m x 4 m with a 2:1 batter. Excavation, under drainage and venting and supply/install of a synthetic liner for a pond this size would cost approximately $100,000

A pond with approximately 4,000 m^3 of storage would be 35 m x 55 m x 4.5 m with a 2:1 batter. Excavation, under drainage and venting and supply/install of a synthetic liner for a pond this size would cost approximately $75,000.

No price for pipework or additional infrastructure has been allowed for. A pond of this size would also require fencing.

I trust this information is useful, and I have captured the discussion we had regarding the system operation.

If I can be of any assistance please do get in touch. Thank you once gain for the opportunity to assist you and I look forward to hearing from you.

Yours sincerely

Marc Dresser
Principal Environmental Scientist

on behalf of
Beca Limited
Direct Dial: +647 960 2345
Email: marc.dresser@beca.com

3. Beca Report (Dr Marc Dresser)
7 February 2018

Beca

Level 2 Waitomo House
6 Garden Place, Hamilton 3240, New Zealand
T: +64 7 838 3828 // F: +64 7 838 3808
E: info@beca.com // www.beca.com

7 February 2018

Attention: Bindi Ground

Dear Bindi

Report on testing

Many thanks for the opportunity to undertake this work for you. Please find below my report on the site visits and sampling we undertook.

Background.

Beca were contacted by Bindi Ground, Waratah Farms, to provide technical input with regard a letter from WRC suggesting a leaking pond.

Dr Marc Dresser, Technical Director and Principal Environmental Scientist with Beca, undertook multiple site visits to the Roto-o-rangi piggery over a number of weeks.

- 15/12/2017 - To determine the site layout and to determine if objectionable odour could be detected. This was also used to map out sampling locations and protocol, ensuring H&S was not compromised.
- 17/12/2017 - Immediately after the drain clearing had taken place to determine if objectionable odour had been released due to the disturbance of the ditch material. The spoil had been carted away in order to eliminate any possible odour issues. No odour was detected on site at this time.
- 22/12/2017 - To determine if objectionable odour could be detected. None was.
- 7/1/2018 - First round of sampling, which was to give indication of any contamination issues in ditch, this occurred after the drain had been cleared for a number of weeks.
- 17/1/2018 - Second round of sampling, following 1 month after drain clearing had occurred, to allow any disturbed sediment to settle and to implement a refined testing method.

An initial report dated 20 December 2017 was written (Beca reference #4285700) which indicated 2 specific immediate actions:

- Clean the drain to allow sampling to take place
- Sample drain water and analyse to check for source of contamination coming from outside property boundary

The drain was cleaned by excavator on 17 December 2017, and a site visit was undertaken immediately afterwards to determine if any odour was being released due to the cleaning. The excavated material had been disposed of offsite, and there was no odour detectable.

Following the approach recommended in the first Beca report (Report dated 20 December 2017 (Beca reference #4285700)), the first sampling occurred on 7 January 2018 at 3 locations:

- Upper (a point on the up-drain boundary)
- Mid (a point approximately 2 m down-drain of the confluence of the Goat Farm ditch and the boundary drain)
- Lower (a point on the down-drain boundary)

These points are shown in Figure 1.

The second round of sampling occurred at on 17 December 2018 at 4 discrete locations:

- Upper (a point on the up-drain boundary)
- Goat (a point approximately 10 m up-ditch towards the goat farm)
- Mid (a point approximately 2 m down-drain of the confluence of the Goat Farm ditch and the boundary drain)
- Lower (a point on the down-drain boundary)

These points are also shown in Figure 1. The Goat Farm ditch location was added for the second set of sampling to give clarity as to the effect of the mixing of the Goat farm ditch water on overall drain water composition.

Figure 1. Site map and sampling locations, showing the direction of flow in the boundary drain and the Goat Farm ditch.

The samples were taken using a cleaned glass jug, rinsed in the sample water, and decanted into sample containers. They were taken to Hill Laboratories in Hamilton for testing.

The results were then analysed and reported upon.

Observations

During the course of the multiple site visits it became apparent that at no time were any odours detected on site that would register as "Extremely Strong", as indicated in the Waikato Regional Council File Note #60 24 79A, dated 6 December 2017. Occasional "wafts" of pig shed odour were detectable, registering no more than 3 or 4 out of 6, and are totally expected to be of this level when walking through a piggery. It must be noted that at no time during the multiple site visits was there a period with no wind.

Results

The first set of samples showed that the boundary drain water was becoming significantly contaminated in between the Upper and Mid sampling section. These results are given in Figure 2 below.

		Upper 07-Jan-2018	Mid 07-Jan-2018	Lower 07-Jan-2018
Total Potassium	g/m3	10.3	24	30
Total Ammoniacal-N	g/m3	0.195	8.7	11.9
Total Kjeldahl Nitrogen (TKN)	g/m3	0.76	8.5	14.5
Total Phosphorus	g/m3	0.035	0.55	0.69
Escherichia coli	MPN / 100mL	1,081	11,200	3,650

Figure 2. Photo showing results of first sampling.

In order to determine if this contamination was due to a source external to, or internal to, the piggery, a second set of sampling that included the Goat Farm ditch sample location was undertaken.

During collection of the second set of samples, there was a marked visual difference between the liquid collected in the drain at the Upper sampling point and that from the Goat sampling location. The water in the drain from the Upper sampling location, was clear. The water from the goat farm ditch, sampling location Goat, was black in colour and gave off a pungent odour. Sample location Mid is 2 meters after the Goat Farm ditch water enters the main boundary drain. Here, the drain water was a light tea colour, and continued as such until it exited the property on the Eastern boundary at sampling location Lower. A photograph showing these samples is provided in Figure 3.

Figure 3. Photograph showing the samples collected for the second set of sampling. In order from left is Upper, Goat, Mid, Lower sampling locations.

The results of the second set of sampling, which demonstrated that there was significant contamination entering the drain from the Goat Farm ditch and being mixed into the relatively clean water coming from the Upper sample location and running along the southern boundary of the pig farm, are given in Figure 4.

		Upper 17-Jan-2018	Goat 17-Jan-2018	Mid 17-Jan-2018	Lower 17-Jan-2018
Total Potassium	g/m3	10.6	37	20	32
Total Ammoniacal-N	g/m3	0.112	1.16	6.5	17.1
Total Kjeldahl Nitrogen (TKN)	g/m3	0.79	520	8.3	20
Total Phosphorus	g/m3	0.051	26	0.32	0.79
Escherichia coli	MPN / 100mL	520	1,515	4,880	1,201

Figure 4. Results from second set of sampling

The second set of results for Mid sample location are somewhat confusing. Further testing is required for absolute clarity, but, following extensive discussion within Beca, it is my opinion that the elevated levels are due to sampling occurring in the direction of flow and not counter flow, as would be the norm, in order to prevent stirring up sediment and contaminating the down-drain sample. In addition, the Mid sampling location may not be far enough down drain to enable complete mixing of the liquid entering from the Goat Farm ditch.

Discussion

The first set of sampling indicated that there was an increase in contamination from Upper to Mid sampling locations. In order to further understand the process, the second set of sampling replicated the first set of sampling, and also included the Goat Farm ditch. This sampling demonstrated the likely cause of the problem. The black colour of the Goat Farm ditch water is indicative of high oxygen demand, causing low dissolved oxygen concentrations. This in turn produces sulphides (which also give rise to the black discolouration) and an excess of hydrogen sulphide (H2S). The distinctive H2S odour was immediately apparent upon sampling the Goat Farm ditch, however none was apparent at any of the other sampling locations on the boundary drain.

Conclusion

From this testing, and from observations during the site visits, it is the Goat Farm ditch that I consider to be the likely source of the odour that WRC staff discovered on this corner of the property during their proactive monitoring, highlighted in File Note #60 24 79A, dated 6 December 2017. This is the exact location where the Goat Farm ditch merges with the main boundary drain. This ditch and the main boundary drain are below surrounding ground level, and when there is little to no wind, there is likely minimal removal of odour from the ditch. The H2S will then "pool" on the surface and migrate along the surface of the water, being the lowest point in the drain.

Recommendation

The knowledge gained from the testing and site visits, leads to my current recommendation that no further action is required on the Waratah Farms piggery, as the testing indicates the likely source of odour is the Goat Farm ditch, and as such, based on the evidence gained during this work, it is not deemed necessary to proceed further with the investigative steps as outlined in the initial Beca report dated 20 December 2017 (Beca reference #4285700).

Yours sincerely

Dr Marc Dresser
Principal Environmental Scientist

on behalf of
Beca Limited
Direct Dial: +647 960 2345
Email: marc.dresser@beca.com

4. Email Marius Rademeyer to David Ray
16 February 2017

Sue Garmonsway

From:	Sue Garmonsway
Sent:	Sunday, 2 December 2018 1:08 p.m.
To:	Sue Garmonsway
Subject:	FW: WARATAH FAMRS - ROTO O RANGI

From: Marius Rademeyer [mailto:roadhouse@clear.net.nz]
Sent: Thursday, 16 February 2017 11:22 AM
To: David Ray <david.ray@mitchelldaysh.co.nz>
Cc: Jennifer Matthys <Jennifer.Matthys@waikatoregion.govt.nz>
Subject: WARATAH FAMRS - ROTO O RANGI

Hi David,
Further to the above application, I am writing to confirm that WRC has received submissions from Oakwood Farm Trust owner of the neighbouring property at 37 Kairangi Road, and Terry & Janet Smith occupiers of the dwelling on that property.
I Have spoken to Tony Fischer, occupier of the neighbouring property to the south, who was also served notice. Tony advised me during our phone conversation that he received the notice but that he is satisfied with progress to mitigate off-site odour effects. Therefore, he did not submit in opposition to the application.
I have contacted the Smiths with a view to meeting with them to clarify their submissions. At this stage, my understanding is that they wish to be heard.
Please can you advise if you want WRC to arrange for a hearing without delay, or if you want WRC to facilitate formal or informal pre-hearing discussions with the Smiths? If so please advise alternative dates/ times that will suit you. I can then endeavour to facilitate those discussions.
I note that if you want to delay a formal hearing, then we will also require you to confirm your approval to place the application on hold (s37) pending the outcome of discussions.
I am hoping to meet with the Smiths tomorrow or Saturday. Therefore, I will appreciate an early response form you if at all possible, in order that I can update the Smith on the next steps.
Kind regards,
Marius

MARIUS RADEMEYER RESOURCE MANAGEMENT CONSULTANCY LTD
58 Broadway, P.O.Box 272-1374 Papakura, 2252, Auckland, **T** (09) 292-2511, **M** 021 114 6290

5. Updated neighbour consultation – July 2018

Roto-O-Rangi Piggery Resource consent renewal.
Follow up consultation. July 2018

Consulted Party Details

Name : Bryce Mead

Residential address : 84 Kairangi Rd
RD3 Cambridge

Email address : Brycedmead@gmail.com

Phone numbers : Home : 078271802

Mobile : 0273244828

Business : 078271802

I have been asked to provide any updated views on the proposal for Waratah Farms to renew its existing resource consent for the Roto-o-Rangi Piggery at 32 Kairangi Road.
The intent of the update is to reaffirm the support I have given in April 2016.
Any additional comments are welcome

Consulted party view on proposal (additional comments)

☑ I / We give our continued support

☑ I / We have no changes to our previous consultation

Signature : BDMead

Printed Name : BRYCE MEAD 25/7/18.

Roto-O-Rangi Piggery Resource consent renewal.
Follow up consultation. July 2018

Consulted Party Details

Name : JEFF GERRAND

Residential address : 794 ROTO-O-RANGI RD
RD3
CAMBRIDGE

Email address : j.gerrard 56 @ gmail.com.

Phone numbers : Home : —

Mobile : 0274-924-094

Business : —

I have been asked to provide any updated views on the proposal for Waratah Farms to renew its existing resource consent for the Roto-o-Rangi Piggery at 32 Kairangi Road.
The intent of the update is to reaffirm the support I have given in April 2016.
Any additional comments are welcome

Consulted party view on proposal (additional comments)

✓ I / We give our continued support

✓ I / We have no changes to our previous consultation

Signature : [signature] 15/8/18

Printed Name : JEFF GERRAND

Roto-O-Rangi Piggery Resource consent renewal.
Follow up consultation. July 2018

Consulted Party Details

Name : Alice Mottershead

Residential address : 17 Kairangi Road
RD3
Cambridge

Email address :

Phone numbers : Home : 078271778
Mobile : 0272346344
Business :

I have been asked to provide any updated views on the proposal for Waratah Farms to renew its existing resource consent for the Roto-o-Rangi Piggery at 32 Kairangi Road.
The intent of the update is to reaffirm the support I have given in April 2016.
Any additional comments are welcome

Consulted party view on proposal (additional comments)

✓ I / We give our continued support

✓ I / We have no changes to our previous consultation

Signature : EA Mottershead 15-8-18

Printed Name : EA Mottershead

6. Email – Bindi Ground to residents 14 August 2018

Sue Garmonsway

From:	Bindi Ground <bindi@Waratahfarms.co.nz>
Sent:	Tuesday, 14 August 2018 11:34 a.m.
To:	mark.alice@hotmail.com; principal@rotoorangi.school.nz; rotofarms@xtra.co.nz; Janet Smith; jcknowles@xtra.co.nz
Cc:	Jennifer.Matthys@waikatoregion.govt.nz; 'Roto-O-Rangi Piggeries'; Marius Rademeyer; Clive Andersen
Subject:	Compost load out

Hi All.

As per our resource consent I am writing to advise that we are planning on taking a load out from our compost bunkers at Roto-o-Rangi piggery during the next fortnight.
I expect that the process will take less than two hours in duration.

We continue to make some management and equipment changes at the farm in response to comments received during the ongoing consultation of our resource consent renewal, and believe that the results of these changes will continue to improve the operation.

Should you have any feedback about our farm, good or bad, it is helpful for us to know – please drop me a line. My contact email is bindi@waratahfarms.co.nz or 021 74 95 91. The feedback is helpful because we can understand how we are performing.

Kind regards and looking forward to any feedback,

Bindi Ground
Waratah Farms
Ormsby Road
R D 3 OTOROHANGA, NZ
ph + 64 7 873 7752
fax + 64 7 873 8222

7. Vegetative Environmental Buffer research

Agroforest Syst (2007) 69:45–65
DOI 10.1007/s10457-006-9017-6

Mitigating swine odor with strategically designed shelterbelt systems: a review

John Tyndall · Joe Colletti

Received: 13 March 2006 / Accepted: 1 August 2006 / Published online: 22 September 2006

Abstract Recent reports clearly indicate that odor emitted from concentrated livestock production facilities in the Midwest of the US is a significant social problem that negatively impacts rural and state economies, human health, and the quality of rural life. A potential incremental approach to dealing with livestock odor is the use of shelterbelts arranged in strategic designs near and within livestock facilities. This review outlines the various ways that shelterbelts can be effective technology which bio-physically mitigates odor thereby reducing social conflict from odor nuisance. The biophysical potential of shelterbelts to mitigate livestock odor arises from the tree/shrub impacts on the central characteristics and physical behavior of livestock odor. As the majority of odors generated in animal facilities that are detectable at appreciable distances travel as particulates, there is compelling evidence that shelterbelts can ameliorate livestock odor by impeding the movement of these particulates. Because the odor source is near the ground and the tendency of livestock odor is to travel along the ground, shelterbelts of modest heights (i.e. 20–30 ft) may be ideal for odor interception, disruption, and dilution. Shelterbelts can be adapted to fit almost any production situation. Depending on shelterbelt health, these trees can provide long term, year round odor interception, with increasing effectiveness over time. Additionally, more is becoming known about how landscape aesthetics affect how people might perceive livestock odor, suggesting that landscape elements such as shelterbelts can lead to aesthetic improvements and perhaps more positive opinions of livestock odor and the farm systems that create them.

Keywords Air quality · Agricultural pollution · Odor mitigation · Swine · Vegetative buffers

Introduction

The Natural Resource Conservation Service of the USA defines air quality as a measure of the concentration of particulates and gases relative to an accepted standard that limits the use of the air for a designated purpose at a specific location (Vining and Allen 1993). Unfortunately for many people living, working, enjoying, or passing through parts of rural America, the quality of the air is often below accepted standards (Huang and Miller 2006). Recent reports clearly indicate that odor emitted from concentrated livestock production facilities in the Midwest of the US,

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particularly from pork production, is a significant social problem that negatively impacts rural and state economies, human health, and the quality of rural life (Iowa CAFO Air Quality Study 2002; Wing and Wolf 2000; Thu and Durrenberger 1998). Whereas livestock derived odors are ubiquitous with animal agriculture, four factors are thought to cause an increase in odor nuisance and a need for additional technological and management creativity. First, larger-scale livestock confinement production has led to increased concentrations of manure being stored and utilized in relatively small geographic locations. Second, urban/suburban expansion into the agricultural landscape has put many more people with limited agricultural experience into closer proximity to livestock production. Third, the current livestock odor problem is characterized by high concentrations of odorous emissions that travel across highly modified landscapes relatively devoid of any significant natural barriers that can impede, alter, absorb, or dissipate the odor plumes prior to contact with people (e.g. Iowa has about 93% of its natural landscape converted to fairly homogeneous agricultural uses). Fourth, market economics and regulatory policy of livestock production create limited producer incentives to control water and air pollution beyond minimum regulatory requirements—to do more may put producers at a financial disadvantage. Livestock production, communities, and the environment in which people live, work and enjoy life will continue to be at risk if creative and effective solutions are not forthcoming.

A potential incremental approach to dealing with livestock odor is the use of shelterbelts (trees and shrubs) arranged in strategic designs near and within livestock facilities. This review outlines the various ways that shelterbelts can be an effective technology which bio-physically mitigates odor in a socio-economically responsible way thereby reducing social conflict from odor nnisance (Lin et al. 2006; Midwest Plan Service 2002; Tyndall and Colletti 2001). Several sources (Koelsch 1999; WED 1999; National Pork Producer Council 1995; Lorimor 1998; OCTF 1998; Jacobson et al. 1998) list shelterbelts as odor control devices, but provide little physical, biological, or economic quantification as to effectiveness. The National Center for Manure and Animal Waste Management listed the lack of quantification regarding the impact of vegetative barriers on livestock production emissions as a "major research gap" (National Center MAWM 2001). Still, the USDA's National Animal Health Monitoring System Swine 2000 report noted that 33% of respondents across 17 states use shelterbelts/windbreaks specifically for air quality management (Vansickle 2002). A recent Iowa swine producer survey indicates that 38% of the respondents ($n = 562$) use shelterbelts for odor mitigation pnrposes and 64% of that group are satisfied with their effectiveness and management—only 0.9% were unsatisfied with the practice (Lorimor and Kliebenstein 2004).

This review will focus only on swine odor mitigation, as swine production has historically been associated with the most frequent odor nuisance complaints (Hardwick 1985). However it should be noted that the use of shelterbelts for odor mitigation is theoretically amenable to all livestock and poultry species.

Defining shelterbelts and swine odor

Shelterbelts

Shelterbelts are vegetation systems that typically use trees and shrubs arranged in row or group configurations to redirect wind and reduce wind speeds, thereby modifying environmental conditions within the upwind and downwind sheltered zones. Wind flow modification is useful in controlling wind erosion, controlling blowing snow, increasing crop yields, protecting farm buildings and other structures, protecting livestock, improving working conditions in the field, or any combination of these effects (Brandle et al. 2004). Trees and shrubs can also provide visnal diversity within agricultural landscapes, improve biodiversity, provide wildlife habitat and can improve the private recreation potential of many farms (Brandle et al. 2004; Ronneberg 1992).

The magnitude of wind dynamic and microclimate changes will vary within and between shelterbelt systems depending upon the internal, external, and managerial characteristics of the

system (J. Brandle pers. comm. 1999). The internal and external structures of a shelterbelt are very important. In terms of the internal structure, porosity is the most commonly used descriptor. It is a simple ratio of perforated area to total area (Heisler and DeWalle 1988). Shelterbelts with a porosity of 40–60% provide the greatest reduction in wind speed over the greatest distance (Brandle and Finch 1991). External structnre can be described as the height, width, and number of rows, species composition, length, orientation, continuity, and overall design of plantings or natural configurations. Management characteristics can include: the goals of the shelterbelt (e.g. crop protection/enhancement, wildlife habitat, etc.); species selection, planting technique and planting design; manipulation of porosity; and maintenance (J. Brandle pers. comm. 1999).

Constituents of swine odor

To have a better understanding of the shelterbelt—livestock odor dynamics, an examination of the physico-chemical characteristics of livestock odor is a good place to start. Swine manure odor is a product of a complex interaction and intermingling of individual odorous and non-odorous components that are produced during anaerobic decomposition of animal manure (Bottcher 2001; Zahn et al. 1997; Melvin 1996). Anaerobic decomposition of animal manure involves a complex series of digestive reactions by diverse populations of bacteria that metabolize the nutrients contained within the manure and subsequently convert these chemicals to various odorous compounds (Williams 1996). Researchers have identified upwards of 330 specific chemicals and compounds in animal manure odor that are end products and intermediates of the anaerobic decomposition process (Schiffman et al. 2001; Zahn et al. 1997). In the US more than 75% of the swine production systems handle manure anaerobically (Zahn et al. 1997). Included in this collection of odorous compounds and chemicals are a few key gases. Gases refer to the specific gaseous compounds that are produced and emitted from a manure source—primarily ammonia (NH_3), hydrogen sulfide (H_2S), methane (CH_4), and carbon dioxide (CO_2). Some gases, particularly highly volatile compounds like ammonia and methane, have potentially chronic effects associated with long-term environmental degradation (i.e. acid rain and other NO_x related problems, eutrophication) rather than short-term odor nuisance (Jacobson 1997). Collectively, the chemicals that make up swine odor are referred to as volatile organic compounds (VOCs).

Of particular importance, the majority of odorous chemicals and compounds are easily absorbed onto, concentrated by, and carried on aerosols (particulates) generated in animal facilities (such as animal houses and manure storage) and from land application (Bottcher 2001; Hammond and Smith 1981). An aerosol is a suspension of solid or liquid particles in a gas with particle size ranging from 0.002 μm to more than 100 μm, this includes such things as dust, clouds, fumes, mist, fog, smog, smoke and sprays (Hinds 1999). Depending on ambient weather conditions, odorous particulates have been known to travel upwards of two miles from their source (Hammond et al. 1981). Thernilius (1997), Laird (1997), and Hammond and Smith (1981) all conclude that by removing and/or controlling these particulates, animal houses, lagoons, and feedlots may become less odorous. Eby and Willson (1969) report that most of the odor from poultry houses can be eliminated by removal of air borne dust. Hartung (1986) concluded that up to 65% reductions in odor emissions are possible by filtering air dust from the animal houses' exhaust systems. However, the complex relationship between VOCs and particulate matter and the association between particulate reduction and odor reduction are far from conclusive and are subjects of continuing research (Cai et al. 2006; Bottcher 2001).

Shelterbelt and swine odor interactions: odor mitigation

Many odor control management technologies are available. They generally fall into one of three strategic categories. The first deals with the prevention of odor and involves technologies such as manure and feed additives. The second strategy attempts to capture and destroy odors before they are released into the atmosphere and involve

techniques such as chemical scrubbers and biofilters. The third technique uses innovations that attempt to disperse and/or dilute odors before they can accumulate and become a nuisance to neighboring areas and involve manipulating air movement using obstructions made of both constructed materials (e.g. screening) and living barriers of trees and shrubs (Schmidt and Jacobson 1995).

The potential of shelterbelts to mitigate livestock odor arises from the tree/shrub impacts on the central characteristics and physical behavior of livestock odor. These characteristics are:

- most livestock odor sources are at ground level;
- there is often limited odor plume rise due to common weather conditions (i.e. temperature iuversions) and limited mechanical landscape turbulence (Takle 1983; Takle et al. 1976);
- odor plnmes have spatial and temporal variability (Guo et al. 2001; Zhu et al. 2000);
- odor plumes may be very extensive covering large land areas (Smith 1993);
- there is often a close proximity of people to odor sources;
- the odors generated in animal facilities that are intense and detectable at appreciable distances often concentrate and travel on particulates (Cai et al. 2006; Bottcher 2001; Hammond et al. 1981);
- there appears to be a major socio-psychological component to the perception of odor being a nuisance (Mikesell et al. 2001; Kreis 1978).

Because the odor source is near the ground and the tendency of the plume is to travel along the gronnd, shelterbelts of even modest heights (i.e. 20–40 ft) may be ideal for plume interception, disruption, and dilution (Lin et al. 2006; Bottcher 2001; Heisler and DeWalle 1988; Laird 1997; Thernelius 1997; Takle 1983). Shelterbelts can be adapted to fit the production situation and expected/experienced odor plume shape and timing. Depending on the shelterbelt design and tree/shrub species used, it can deal with the temporal changes to provide long term, year round plume interception, with increasing effectiveness over time. More is also becoming known about how landscape aesthetics affect how people might perceive livestock odor, suggesting that landscape elements such as shelterbelts can lead to improvements and perhaps more positive opinions of livestock odor and the farm systems that create them (Mikesell et al. 2001; Kreis 1978).

It should be emphasized that shelterbelts are amenable to use with the three main sources of livestock odor: animal buildings, manure storage systems, and agricultural land that has manure applied. Most other odor mitigation technology is very often source specific and not adaptable throughout the farm. Shelterbelts can be used throughout the entire farm and agricultural landscape. It is a technology that is not limited to producer use only. In fact, properly designed shelterbelts, may be the only odor technological approach that cau be effectively used by the public, as well as producers.

Based on evidence available in research literature, there are five primary, interacting, ways that shelterbelts can mitigate livestock odors by

- physical interception and capture of dust and other aerosols as well as gases by trees and shrubs;
- dilution and dispersion of downwind concentratious of odor;
- land deposition of dust and other aerosol from reduced wind speeds;
- acting as a biological sink for the chemical coustituents of odor after interception;
- enhancing the aesthetics of pork production sites and rural landscapes.

Physical interception of dust, gases and other aerosols

Swine confinement buildings are generally ventilated in one of three primary ways: ventilation by way of uatural, open-air methods and by way of mechanical ventilation, or a combination of the two-hybrid systems. Regardless of the ventilation process utilized, this exhaust air contains significant quantities of odorous dust particles and gases. This air is in most cases exhausted without prior treatment. Once outside the confinement, depending on the current climatic conditions, these "plumes" can travel significant distances.

Vegetation can and does filter airstreams of particulates. As air moves across vegetative

surfaces, leaves and other aerial plant surfaces remove some of the dust, gas, and microbial constituents of airstreams. It is also generally accepted that trees and other woody vegetation (i.e. shrubs) are among the most efficient natural filtering structures in a landscape in part due to the very large total surface area of leafy plants (Bolund and Hunhammer 1999).

Direct filtering occurs when particles are removed from air streams due to interception by and deposition onto plant surfaces. Small, turbulent eddy currents occur when laminar airflow is disrupted by aerodynamically rough surfaces such as leaves and branches (Beckett et al. 1998, 2000a, b). These eddy currents that form in turbulent airflows around plant surfaces reduce the resistance of the protective boundary layer of these surfaces allowing much of the particulate load to be impacted (lodged) onto plant surfaces. And once impacted, it often takes very high winds for particles to become re-suspended (Ould-Dada and Baghini 2001; Beckett et al. 1998). Interception and impaction by tree laminar (leaf) surfaces typically involves particulates with diameters between 0.1 μm and 10 μm (the so called PM_{10} range) (Beckett et al. 2000b). For particles of dimensions 1–5 μm, interception by fine hairs on leaf surfaces and non-laminar surfaces (stems, petioles, bark) may be the most important retentive mechanism (Smith 1984). In a study of aerial dust in commercial swine finishing houses, it was noted that 93.3% of the particles sampled were 5.2 μm and smaller (Stroik and Heber 1986). Also, particles from swine facilities are ofteu irregular in shape, generally classified as flakes, fibers, spheres or cubes (Dawson 1990), and as noted by Freer-Smith et al. (1997) such shapes are advantageous for particulate retention on leaf surfaces. Quantification of this process, however, has been limited.

Recent wind tunnel experiments and field studies have qnantified the capture efficiency (ratio of particulates hitting and being retained by tree surfaces to the amount of particulates in the air stream) of several different tree species as well as under conditions of different total particulate loads (Beckett et al. 2000a). Beckett et al. (2000b) exposed five tree species—Corsican pine (*Pinus nigra* var. *maritima*Aiton), Leyland cypress (× *Cupressocyparis lelyandii* Dallimore & Jackson), hedge maple (*Acer campestre*L.), Swedish whitebeam (*Sorbus intermedia* L.), and hybrid eastern poplar (*Populus deltoides* × *trichocarpa* Beaubre)—to 1 μm diameter droplets of NaCl over a range of air speeds (from 0.7 ms^{-1} to 10 ms^{-1}) within a wind tunnel. At 10 ms^{-1} they found the particle trapping efficiency of *Corsican pine* (2.8%) and *Leyland cypress* (1.22 %) to be significantly greater than that of *Swedish white-beam* (0.21%), *hybrid eastern poplar* (0.12 %), and *hedge maple* (0.06%). Such results seem to confirm greater capture efficiency for species with more complex shoot structures, and with small but complex surface area (e.g. conifer needles) or hairier leaves (e.g. *whitebeam*). They also indicated a functional relationship between trapping efficiency and windspeed—that is the greater the particle inertia as it encounters a solid object, the greater likelihood of impaction onto that surface.

In a parallel study, Beckett et al. (2000c) examined the actual accumulations (weight) of particles (PM10, PM2.5, and soluble ions—coarse, fine, and ultra fine grain particles) within four of the same tree species as above in urban settings in the UK—a fifth species, Common Whitebeam (*Sorbus aria* L.), was also examined . They found that all five tree species captured the three size ranges of particulates with similar efficiency at both urban sites studied (one a small urban park, the other an agricultural research site on the campus of the University of Sussex). That is, the same pattern of particulate capture can be seen for each particle size range at each site. And just as with the wind tunnel simulations, Corsican pine was by far the most efficient particulate filter with Leyland cypress ranked second. Among the broadleaf species observed, the Common Whitebeam accumulated a significant amount of the coarse fraction particulates, which may be explained by this species' rough and hairy abaxial (lower) leaf surfaces (Beckett et al. 2000c). In contrast, poplar, with comparatively smooth and leathery leaves, was the least effective particle collector.

Ucar and Hall (2001) reviewed research of shelterbelts mitigating pesticide drift and concluded that the spray droplet capture efficiency of tree species is among the most important

variables (along with toxicity tolerance and micro-climate suitability) when developing a drift-mitigating strategy. They also noted the general superiority of conifers for particulate capture and suggest that because conifers are "in leaf" year round they may also be more effective temporally. This is an important factor with regard to odor because even though odor nuisance increases in warmer weather, odor events do happen year-round. Nevertheless, studies have shown that non-laminar (stems, petioles, bark) particulate capture can be significant. For example, Ucar and Hall (1998) cite a study by Porskamp et al. (1994) that observed alder (*Alnus* spp.) windbreaks reducing pesticide drift up to 90% when in leaf, and still up to 70% when leaves were absent. Wind tunnel tests have shown non-laminar particulate capture contributing upwards of 37% of the total particulate load (particle size = 2.75 μm) to European beech (*Fagus sylvatica* L.) trees, and upwards of 47% of the total load (particle size = 5.0 μm) to White poplar (*Populus alba* L. trees (Little 1977).

Another factor influencing particle capture is a trees' roughness on a larger scale as defined by the overall canopy structure of individual trees or grouping of trees. A highly complex canopy (i.e. the pinnate structure of ash *Fraxinus* spp.) creates more opportunity for wind obstrnction in the through-flow and therefore more internal turbulence (Beckett et al. 2000a). Interestingly it was noted, that younger, smaller trees of species that are efficient particle filters are also highly effective at removing particulates due to their greater foliage densities compared to much larger, mature specimens (Beckett et al. 2000a).

It is difficult to get an understanding of just how much particulate matter is accumulated. Some studies indicate actual amounts such as Steubing and Klee (1970), who measured the considerable filtering capacity of Mugo pine (*Pinus mugo* Turra) along the roadsides in Frankfurt, Germany. These researchers found that Mugo pine can have a capture effect of at least up to 0.18 mg cm^{-2} (1,800 mg m^{-2}) of dust on leaf surfaces (Farmer 1993), or Beckett et al. (2000b) who noted particulate weights of 488 mg m^{-2} and a total foliar surface area (ab- and ad-axial surfaces) of 341 m^2 on a single juvenile Enropean linden tree (*Tilia* × *europaea* L.) within a shelterbelt in Fulmer, East Sussex, UK.

To assess the importance of these capture quantities, an example from Takai et al. (1998) assumes that the inhalable dust emission rate is 88 g h^{-1} for a mechanically ventilated hog farm with 500 pig fatteners, or an emission rate of roughly 2100 g of inhalable particulates per day. A single, 20 ft European linden tree may at least have the capacity of holding about 166 g of particulates at any time in dry weather (note that this includes only insoluble particles). This also does not include particulates captured by any of the woody parts of the tree (stems and bole). Linden shelterbelts placed within and around this hypothetical farm, depending on overall length and number of rows could have anywhere from 100 to 400 trees (or even more) with a potential total particulate load of around 16,000–66,400 g of particulates. However, some important questions still remain such as the load limit in which particnlate capture efficiency becomes significantly reduced, the maximum duration of particulate holding, and the ultimate fate of the particulate matter held by the vegetation.

It must also be emphasized that the calculation of actual capacity, or total particulate loads within individual trees or grouping of trees is confounded by the ambient conditions of each site. Precipitation, which can effectively wash both soluble and insoluble particulates from tree surfaces (Beckett et al. 2000c), ambient humidity, diurnal weather patterns, variable wind speeds and wind direction, topography, the complex daily variability in emissions of the various particulate sources, and even the positioning of the plant material (natural vs. designed planting) collectively create an ecosystem context that make published total particulate loads site-specific and of limited generalizability, except to the extent that they can show that the particulate capture capacity exists and, in some cases, is likely to be substantial.

Perhaps additional filtration evidence can be found in overall patterns of particulate deposition. The total particulate capture of trees is dependent not only on the species-specific morphological capacity for particulate capture, but

also upon the particle loads in the airstreams. That is, the higher the particulate load in the wind stream, the more particulates are found to be captured and held by these plants. Freer-Smith et al. (1997), show a filtering effect within a small urban woodlot near a major highway in Surrey, UK, since the number of particles counted on leaf surfaces decreased significantly as distance from the highway (the particulate source) increased. This result, however could be partially explained by dispersion of the particulate stream as well as by particulate capture. Still, this capture pattern was also evident with the filtering of coal-mine dust within a 15 m-wide mixed-age (24–50-year-old trees) greenbelt consisting mostly of European White Birch (*Betula pendula* Roth.) in Kansk, Siberia (Spitsyna and Skripal'shchikova 1991). Both suggest that the airstream is becoming "cleaner" as it travels through the trees. For information regarding total particulate capture, Beckett et al. (1998) provide a more extensive review, particularly with reference to urban trees.

Based on the literature there are some general conclusions that can be made regarding the particulate filtering capacity of trees (Beckett et al. 2000a, b, c; Spitsyna and Skripal'shchikova 1991; Smith 1984):

- There is a high correlation (i.e. Pearson r values from 0.7 ± 0.19 to 0.98 ± 0.02) between leaf surface area and the quantity of dust accumulation.
- The greater the surface roughness of the leaf, the greater the particulate capture efficiency for particles 5 μm and less. Surface roughness increases with the presence of leaf hairs and pronounced veination.
- Smaller leaves are generally more efficient than larger leaves in collecting particulates.
- Leaves with complex shapes and large circumference-to-area ratios (i.e. conifers) appear to capture particulates most efficiently.
- Conifers are generally more efficient in capturing particulates than broadleaf species.
- Non-laminar surfaces (petioles, stems, bark) also accumulate significant amounts of particulates in the PM_{10}range.
- The more irregular in shape the particulates are, the greater the capture and retention on tree surfaces.

Dilution and dispersion of downwiud concentrations of odor

The conditions leading to pollutant trapping by the atmosphere are well known (Takle 1983; Takle et al. 1976). Low wind velocity, radiational inversions and lack of physical landscape features that create turbulence all contribute to pollutants being trapped at ground level (Jacobson et al. 2001; Guo et al. 2001; Takle et al. 1976). Odor has a tendency to be most severe during stable, night-time conditions with low to moderate wind speeds, at which times odors emitted near the surface will not diffuse upward but remain uear the surface and travel by way of near laminar flow that will meander over the terrain (OCTF 1998; SOTF 1995; Takle undated). Most odor events are recorded between 5 AM and 7 AM and between 7 PM and 10 PM, both relatively high residential activity hours and stable atmospheric conditions (Jacobson et al. 2001). Air temperature is also a major factor. At higher temperatures, the conditions for anaerobic decomposition can improve and greater volatility of odorous compounds may occur (NPPC 1995; SOTF 1995). When these weather conditions occur singly or simultaneously, it has been noted that odor can be transported over distances greater than two miles (NPPC 1995). Shelterbelt systems may be of value in dealing with these situations.

Shelterbelts have the ability to lift part of the odor plume into the lower atmosphere aiding in the dilution and dispersion process. When wind approaches a row of trees, a portion of the air stream will pass through the vegetation, some will pass around it, with the remaining wind being lifted up aud over the vegetation. The lifting aspect will begin at some distance on the windward side, typically a distance equal to 2–5 times the height (referred to as 2–5 H) of the shelterbelt (McNaughton 1988). As studies in the distribution of windblown pollution indicate, the properties of the underlying surface (terrain) are important in deflecting the airstream or in modifying the rate of mixing and consequent dilutiou of the material carried with it (Pasquill 1974). Within the near vicinity of shelterbelts, heat, vapors, CO_2 and other scalar quantities

(including odor plumes) are transported along streamlines by the prevailing winds and only across streamlines by mechanical turbulence (McNaughton 1988). McNaughton (1988) further notes that as the air streams top the obstacle, the stream is redirected, becomes compressed and increases in speed. This is commonly referred to as wind shear. This affected zone above the shelterbelts has been noted at heights of 1.5 H (that is 1.5 times the height of the barrier) to 1.7 H. Therefore, for a shelterbelt that is about 20 ft tall, this effected zone may extend roughly 30–34 ft above ground level. This zone then downtnrns to follow the air stream downwind and acts as a source of turbulent kinetic energy. Thus shelterbelt height is a significant variable: the taller the barrier the higher air will be pushed into the lower atmosphere. It should be noted, however, that this dynamic has yet to be quantified.

Both field and wind tunnel studies that have examined the dynamics of shelterbelts cite a somewhat triangular "quiet" zone (zone of low speed, providing maximnm wind protection) that extends from the top of the shelterbelt down to a distance of about 8 H. Immediately above this quiet zone the longitudinal turbulent fluctuations are more energetic and larger in scale (Cleugh 1998). It is within this turbulent zone that much of the dilution of the odor plume into other air layers may take place (Fig. 1 below is a schematic of these processes). This dilution effect comes not only from that part of the odor plume which is mixing with other "higher-off-the-ground" air layers but also from a slower release of odorous particulates and gases into the airstreams that continue downwind. Therefore, the concentration of odorants within the plume that does continue downwind is reduced. Based on compnter simulation stndies, the plume also appears to become more uniform in terms of concentration, which is beneficial with regards to how the human olfactory system processes exposure to odors (Lammers 2002). High odorant variability within an exposure often leads to higher perceptions of an odor event being considered offensive (P. Lammers pers. comm. 2002).

Recent wind tnnnel and field studies performed by North Carolina State University personnel have shown that artificial wind break walls deflect building exhaust air so that air flows higher above the ground or the surface of downwind lagoons improving potential dilution of odors to the point of noticeable odor reduction downwind (OCTF 1998; Bottcher et al. 1999). By examining the behavior of smoke emissions, researchers have observed enhanced vertical mixing of swine building exhaust plumes due to the presence of artificial, non-porous windbreak walls (Bottcher et al. 2000, 2001).

Odor plume modeling has also indicated this vertical mixing in simulations. Using three-dimensional fluid dynamic algorithms with simultaneous diffusion calculations, Lammers et al. (2001) observed that an odor emission from a livestock building wonld experience an elevated mainstream that is distributed by turbulent eddies in the lee of a solid flow barrier such as an adjacent building. The impact of a diffuser type barrier such as a shelterbelt with an unspecified level of porosity shows a slightly different plume pattern in that there is still an elevated mainstream but the dispersion is more uniform, and therefore,

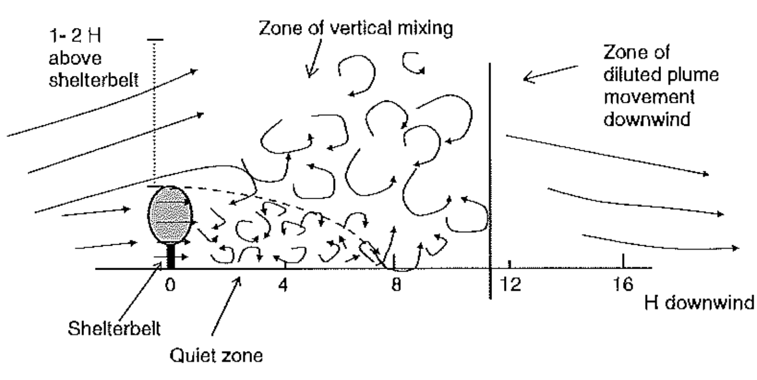

Fig. 1 Schematic representation of turbulence and zone of potential odor dilution. Adapted from McNaughton (1988). The term "H" means "multiplication by height of shelterbelt"

diluted in the downwind stream (Lammers et al. 2001; P.S. Lammers pers. comm. 2002).

Lammers et al. (2001) note that shelterbelts could become a temporary zone of increased odor trapping and perhaps zones of increased on-site odor (e.g. concentrated odor). However, it is not yet known if there are any on-farm implications because of this. Bottcher et al. (2001) warns that smoke simulations indicate that dilution benefits are reduced during periods of stable wind flows.

Buildings are not the only odor source that can benefit from air stream manipulation by shelterbelts. Anaerobic manure lagoons and other uncovered manure storage facilities are also major sources of swine odor. Liu et al. (1996) numerically simulated the effects of tall barriers around manure lagoons and predicted reductions in downwind malodorous lagoon emissions of 26–92% for a range of barrier distance to height ratio from 8 to 0.6. This reduction is largely due to the prevention of particulates (generated elsewhere on the site) from passing over the lagoon surface. Thereby limiting the concentration of odorous VOCs convecting off of the lagoon surface onto ambient particulates and then subsequently moving downwind.

In a recent Canadian pilot study, Lin et al. (2006) used a mobile odor generator to simulate swine odor and quantify the odor dispersion effects of various configurations of field shelterbelts (e.g. differing species, optical porosity, distance from odor source). Two single row deciduons and two single row conifer shelterbelts where compared to a control site that lacked landscape vegetation. Using trained odor panelists (individuals trained in differentiating odor intensity) in the field there were recorded reductions in odor concentration with downwind distance from the source. The reductions are believed to be caused by the presence of the tree row leading to enhanced odor dispersion in the field. In general, Lin et al. (2006) concluded that: (1) windbreaks of low optical porosity ($\approx$35%; optical porosity being a two dimensional measure of porosity) showed a more pronounced odor reduction effect; (2) a conifer tree row (species not defined) at 15 m from the odor source showed greater odor dispersion than a deciduous tree row (*Populus* spp.) at the same distance; (3) a tree row located closer to the odor source recorded more odor dispersion than one located further downwind (15 m vs. 60 m). See Lin et al. (2006) for details regarding analytical protocols and full results.

Land deposition of dust and other aerosol due to reduced wind speeds

Much progress has been made in understanding turbulent transport of air over, around, and through windbreak structures as well as quantifying wind speed alterations (Wang and Takle 1995; Zhang et al. 1993; McNaughton 1988; Heisler and DeWalle 1988; Kort 1988). Measured reductions in wind speed on the lee (downwind) side of a shelterbelt have been varied, with reductions being recorded as far as 50 H of the shelterbelt (Heisler and DeWalle 1988). Measurable wind speed reductions to about 30 H are more typical (Cleugh 1998). The air turbulence changes and wind speed reduction creates situations where wind borne particles can be deposited at much shorter downwind distances than would occur without the shelterbelt. For example, a barrier effect has been noted in the hedgerow systems in Britain as downwind spatial deposition patterns of various propagules (e.g. seeds, pollen, or spores) have been identified (Burel 1996). Ucar and Hall (1998), investigating windbreaks and agrochemical drift mitigation, discussed the exponential trends of drifted spray deposits. They suggest that even a simple vegetative barrier such as a single row of trees would reduce potential chemical drift significantly due to reduced wind speed, though they pointed out that that does not mean reduction to significant levels in all cases. Ucar and Hall (2001) also conclude that pesticide drift reduction offered by shelterbelts evidently arises from two main causes. The first cause is the shelterbelt induced reduction of wind speed over and around the targeted crops; the second cause is due to interception of fugitive pesticide aerosols within the shelterbelt itself.

Laird (1997) and Thernelius (1997) both modeled the potential of windbreaks to deal with odor carrying particulates using an open circuit wind tunuel and a small-scale model of an open-air ventilated hog confinement building and a

simulated shelterbelt. The hog house particulate matter was simulated with highly ground walnut shells positioned within the model hog house. Digital imaging was used to examine the brightness of the wind tunnel floor as a measure of dust deposition behavior. Multiple scenarios were tested examining differences in particle deposition due to the number of parallel shelterbelts of various heights as well as different wind speeds and angles. The objective was to minimize the total particulate mass that leaves the farm boundaries. Table 1 below displays some results of modeled particulate reduction due to shelterbelts.

Based on the results, wind velocity, angle of wind, and the height of the shelterbelts are important variables, with wind velocity being the most important. Successful reduction in mass transport far downstream ranged from 35% to 56%, with the conclusion that this reduction would provide a substantial reduction in the effects of offensive odors in surrounding areas (Laird 1997). Both researchers, however, noted that in order for the information they gathered to be useful in full-scale applications, it remains necessary to perform field-testing. Vegetation type was not a variable nor was windbreak porosity, which has been noted as possibly the most influential factor in reducing wind speed (Ucar and Hall 1998; Brandle and Finch 1991; Heisler and Dewalle 1988). Dust interception by the vegetative barriers was loosely considered as it was noted that "part" of the total dust mass was retained by the model shelterbelts.

Acting as a sink for the chemical constituents of the odorous pollution

Not much is knowu about the ability of trees and other plants to ameliorate odor by way of intake or absorption of odorous chemicals or the managerial use of vegetation for this purpose. There is, however, indirect evidence that suggests this is possible. In the last few decades there has been tremendous interest in the ability of plauts to remove various pollutants from the air, and several reviews have addressed the capability of plants to act as a sink for air contaminants (Kwiecien 1997; Smith 1984; Benuett aud Hill 1973; Hill 1971).

Aerosol chemicals can enter the plant in three ways: (1) gaseous diffusion through open stomata, (2) if chemicals are soluble, they can enter through the stomata in dissolved form, and (3) chemicals can be adsorbed onto and absorbed into plant tissues (Landolt and Keller 1985; Smith 1984). The rate of pollutant transfer is regulated by a series of resistances (Saxe 1990; Smith 1984). It has beeu emphasized that other than pollutant concentration and exposure time, stomatal resistance is the most important factor determining the uptake of pollutants by plants (Landolt and Keller 1985). Diffusion through open stomata is considered the route of least resistance. This is regulated first by the plant surface boundary layer (the perfectly still layer of air surrounding all surfaces) and then by the concentration gradient between the ambient air and the sorptive surfaces of a plant's interior (Kimmins 1997; Treshow and

Table 1 Downwind particulate reduction associated with different wind parameters as modeled in a wind tunnel using a simulated 3 row shelterbelt

Wind speed(m/s)	Angle of wind (°) (oblique to the shelterbelt)	Height of shelterbelt (m)	Distance from building(m)	Percent of particulates lost without shelterbelt	Percent of particulates lost with shelterbelt	Percent change in particulate retention with shelterbelt
4	0	5.00	19.11	57.4	29.1	50.7
4	30	5.00	19.11	75.3	32.8	43.6
5	15	3.75	19.11	80.0	51.7	64.6
6	0	5.00	19.11	81.9	49.3	60.2
6	30	5.00	19.11	96.4	63.0	65.4

Shelterbelt heights and distance from building translated from 1:50 scale. The percentage of particulates lost with or with out shelterbelts means the percentage of on-farm particulates that are blown off the farm and, theoretically, "downwind"

Source: Laird (1997) and Thernelius (1997)

Anderson 1989). Diffusability and solubility of pollutants are the main factors that affect the rate of boundary layer penetration.

Once the boundary layer is penetrated and contact is made with the leaf surface, a pollutant may enter by two routes: absorbed by way of passive diffusion through the stomata (if soluble, pollutants will often enter in solution) or absorbed through the tissues (Waring and Schlesinger 1985). One study of interest examined different sorption rates of snlfur dioxide and ozone between conifers and deciduous trees during a fumigation study and determined that sorption rates were higher in conifers (Elkiey et al. 1982).

A waxy, lipophilic cuticle resists adsorption of pollutants into plant tissues. The cuticle does offer significant resistance to the movement of water and solutes but it is not impermeable, as evidenced by the fact that most agricnltural chemicals are applied as foliar sprays and many of those chemicals, such as herbicides and systematic insecticides, must penetrate the cuticle to be effective (Schonherr and Riederer 1989). Interestingly, lipophilic substances (i.e. organic fatty compounds) actively accumulate in lipids on plant surfaces (the cuticle is composed of cutin, which is a lipid-based polymer) (Taiz and Zeiger 1991). The leaves of trees are highly lipophilic and due to lipophilic affinity, they are excellent accumulators of lipophilic foreign substances snch as VOCs (Reischl et al. 1987, 1989). For example, as measured in field experiments, nitrogen based chemicals and compounds have shown high affinities for leaf cuticles and other plant surfaces (Asman et al. 1998). This affinity of nitrogen-based chemicals to leaf cuticles is enhanced with increased relative humidity and decreased vapor pressures (Asman et al. 1998). Both typically occur within the leeward quiet zone of shelterbelts. Depending on the porosity of the shelterbelt, relative humidity is typically 2–4% higher and temperature is several degrees higher in sheltered areas than in open areas (Brandle and Finch 1991). Asman et al. (1998) suggested that reductions in NH_x might be achieved indirectly by modifying local scale atmospheric transport and because a relatively large percentage of the emission is dry deposited close to the sonrce, benefits might be achieved by planting a managed farm woodland system around known sources to increase dry deposition and reduce deposition to more critical areas downwind.

Research also suggests that trees can be used as bio-indicators for pollution emission location and prediction (Reischl et al. 1987, 1989; Gaggi et al. 1985). Reischl et al. (1989), using gas chromatography tests, recorded accumulations of chlorinated hydrocarbons (anthropogenic VOCs) in the foliage of 15-year-old Norway spruce (*Picea abies*). Foliage samples were taken at different locations in the proximity of different pollntion centers such as an industrial area, an urban area, and a hazardous waste landfill and were then compared to samples from a "clean air" site (an area of considerable distance from a pollution source). The study fonnd much higher concentrations of pollutants from the samples located in the polluted areas as compared to the levels recorded for the clean area.

Another potential air pollution sink exists on and within the microorganisms that coexist on plant surfaces. The surfaces of plants, depending on such factors as plant species, humidity, temperature, season, leaf age and health are usnally covered with micro-organisms of all kinds; various forms of fungi, bacteria, and yeasts dominate (Schreiber and Schonherr 1993; Dickinson and Preece 1976; Preece and Dickinson 1971). In an early review, Smith (1976) hypothesized that since epiphytic organisms have been exposed to many compounds now considered as pollutants for millennia and that this exposure occurs at the atmospheric–plant interface, these microbes may behave as sinks for certain particulates and gaseons pollntants. Schreiber and Schonherr (1992, 1993) determined that microorganisms often influence and affect the quantification of foliage uptake of chemicals to the point where care must be made to separate the mechanism during related research.

It is known that many different microorganisms are capable of metabolizing and/or breaking down chemical pollutants such as anthropogenic VOCs (Baker and Herson 1994; Muller 1992; Fry et al. 1992) and this process is used in many different types of bioremediation techniques (Baker and Herson 1994). It is not, however, currently

known how effective epiphytic microorganisms are at metabolizing and/or degrading odorous VOCs or if such a process could be effective in mitigating ambient and downwind odorous conditions.

Smith (1984) and Abbasi and Khan (2000) listed some generalizations regarding gaseous/aerosol pollutant interception and/or nptake into plants that can be made based on controlled experiments and with seedlings. Among the most important were:

- Plant uptake rates increase as solubility of the pollutant in water increases. Ammonia in particular is highly soluble in water.
- When the plant surfaces are wet, the pollutant removal rate may increase up to 10-fold. When conditions are damp, the entire aerial plant surface is available for uptake.
- Moisture stress and limitations on solar radiation act to limit stomatal openings and can hinder pollutant uptake significantly.
- Pollutants are absorbed most efficiently by plant foliage near the canopy surface, where light-mediated metabolic and pollutant diffusivity rates are greatest.
- Because numerous forces and conditions regulate the rate of pollutant uptake, the rate of removal under field conditions will be highly variable.
- However, the rate of pollutant removal can increase linearly as the concentration of the pollutant increases.

Aesthetics

Socio-psychological factors play a role in livestock odor being perceived as a nuisance. Researchers have documented that perceptions of odor differ from individual to individual and are characterized by personal preferences, experiences, opinions, imagination, cultural associations, visual images, and variability in our olfactory systems (Distel and Hudson 2001; Williams 1996). In an early review regarding the minimization of livestock odor impacts, Kreis (1978) made several observations in this regard. It is explained that avoiding nnisance complaints is difficult, in part, because of interactions of the social and psychological background and the individual preferences. Kreis (1978) points out that psychologists have stressed that *a priori* bias either positive or negative towards an odor source often inflnences emotional responses to that odor source. It is further suggested that additional "aesthetic insult" from that odor source, be it other pollutants (such as water pollution), or other more cosmetic factors such as yard disorderliness or objectionable architecture may negate many odor amelioration attempts. Additionally, visual cnes have been noted to be associated with higher incidences of odor nuisance complaints (Kreis 1978 citing Eugene 1971 and Waller 1970).

Mikesell et al. (2001) interviewed all the neighbors within a variable radius (≤ 1 mile) of seven large swine farms in Pennsylvania and recorded an inverse relationship between the "attractiveness" of a farm and reported negative odor intensity ratings. That is, those farms that appeared to be more subjectively attractive were perceived to be less odorous. However, quantification of actual odor emission rates at each farm was not attempted, and the characteristics of what constitutes "attractiveness" were not defined.

The specific aesthetic appeal of shelterbelts within agricultural landscapes has been examined. Cook and Cable (1995) find by way of a photo elicitation (slide show) survey of Kansas State University undergraduates that photos of Great Plains shelterbelts (both single belts and systems) rate very high on scenic quality indices whereas open and barren agricnltural landscapes rate very low on scenic quality indices. They conclude that (1) shelterbelts add quite positively to the scenic beauty of Great Plains landscapes and (2) that observer background characteristics appear to have little to do with scenic quality evaluations of shelterbelt landscapes, therefore suggesting a loosely generalizable appreciation of the landscape aesthetics of shelterbelts. Also, Ronneberg (1992) listed improved aesthetics as a major benefit of general shelterbelt use, stating that studies have shown "Visual diversity...(is) preferred to open landscape".

Kliebenstein and Hurley (1999) conducted a general public survey regarding environmental impacts and other farm issues, and found that

68% ($n = 329$) of the respondents agreed that "filtration" (iu a general sense) of swine building air for odor reduction is somewhat to very acceptable. There was also a general high social approval of technology that is considered "natural" (which it could be argued includes shelterbelts), as opposed to technology which is mechanical or chemical in nature.

Professionals involved with livestock agriculture generally accept that a well-landscaped operation, which is visually pleasing or screened from view by landscaping is much more acceptable to the public than one which is not (Lorimor 1998; NPPC 1995; Melvin 1996). It is this notion of visual screening that has made landscaping and shelterbelts a common suggestion from agricultural engineers with regard to minimizing odor problems. If it is made known to neighbors and local communities that a shelterbelt is being used as a pollution (air or water) control tool, it may serve as very visible proof that a livestock producer is making an extra effort to control odor.

General shelterbelt design considerations

Shelterbelts designed for the purpose of particulate capture and plume dilution/dispersion can be located on the production site wherever particulate emissions occur. Main on-site locations of particulate emissions are swine buildings, agricultural fields that receive land applications of manure, heavily used roads, and any outdoor animal systems (i.e. feedlots or hauling lots). For plantings near buildings it was noted that they should extend high enough to fully intercept the plumes of airflow issuing from the fans (e.g. 4 m high for typical buildings) (Bottcher et al. 2000). Care must also be taken so as not to compromise building ventilation. If naturally ventilated, trees and/or shrubs must not impede necessary wind patterns. For mechanically ventilated buildings, vegetation must not be close enough to impede ventilation intakes and outlets or maintenance alleys. Based on examinations of artificial windbreak walls (Ford and Riskowski 2003; Bottcher et al. 2000), a distance of at least four fan diameters downwind from the fans are sufficient to prevent back pressures, however the eventual crown width of the tree species must be factored in. Thus some suggest that shelterhelts should be located at a minimum distance of five times the diameter of the fans (Malone and Abbot-Donnelly 2001). If shelterbelts are to be planted near or around manure lagoons or earthen manure pits, the rooting habits of the tree species used should be known to prevent tree roots from compromising the protective lining of the lagoon that prevents leaching of pollutants into the soil and gronnd water sources.

In general, care always needs to be taken when vegetation is planted to avoid creating any negative on-farm situations. The mature size of vegetation must be known so that trees and/or shrubs will not grow to become hazards. If used near roads or feedlots, trees should not be planted in ways that impede sight lines and create snow deposition problems in the wintertime. Likewise, if planted as a perimeter around agricultural fields, expected snow deposition patterns are critical so as to prevent excessive moisture problems in the spring and/or as a benefit to possibly enhance moisture in dryer areas.

Shelterbelt structure is of prime concern when it comes to particulate interception. Aspects such as height, length, width, and porosity (density) all have important implications. For interception, shelterbelt height is important to the degree that the odor plume is intercepted as much as possible. A shelterbelt that is shorter than the plume will only intercept that portion that comes into contact with the trees. Because the odor source is near the ground and due to typical weather patterns in agricultural areas, the tendency of the plume is to travel along the ground with limited rising and mixing (Takle 1983), therefore shelterbelts of even modest heights (i.e. 15–30 ft) may provide adequate plume interception. Shelterbelt length needs to be considered with regard to the width of the plume, again for proper plume interception. An initial rule of thumb may be to size the shelterbelt length at least as wide as the width of a building ventilation system, the width of a manure lagoon, or the width of an agriculture field that has received a manure application. Odor plumes start out at least as wide as the emission source and may expand with distance downwind

from that source depending on ambieut weather and laudscape conditions.

Shelterbelt porosity is also of siguificant concern for particulate capture as there needs to be adequate air flow through a shelterbelt so that particulates have an opportunity to make contact with tree surfaces and create instances of internal turbulence. A shelterbelt that is too dense simply pushes most of the wind up and over and particulate capture efficiency diminishes significantly (Ucar and Hall 2001). Total deposition of particulates to a shelterbelt is determined by a trade-off between enough porosity promoting throughflow of particulate-laden airstreams and enough density to promote particulate contact with tree surfaces, implying there exists an optimum value for porosity (Raupach et al. 2001). Dorr et al. (1998) (as cited in Ucar and Hall 2001) suggested a theoretical optimum porosity of 40–50% for capturing windborne pesticide droplets. It was also suggested by Dorr et al. (1998) that a system of shelterbelts consisting of multiple rows of belts with this level of porosity, provide increased surface area for particulate capture. Thus the widths of the shelterbelt and the number of rows involved are important factors for particulate interception and capture.

With regard to promoting odor plume dilution, species considerations for this particular dynamic can be different than those of particulate capture. Here height and overall shelterbelt porosity is of critical concern. Some species, which may not be the best for particulate capture, may be more appropriate here. Species such as *Populus* grow quite quickly (1–4 ft per year has been observed in the Midwest US), and may be used as nurse trees—trees that can provide early height while other slower growing species (i.e. conifers) take more time. As shelterbelt porosities of $< 40\%$ may be needed to achieve desired turbulence, the overall crowning habit of species should be understood, as some species maintain a fuller crown even as they grow taller. There is also limited empirical evidence that suggests a wedge-shaped belt (e.g. multiple rows of different heights), with shortest row facing into the prevailing wind, can "ramp" (push) airstreams higher into the atmosphere (J. Brandle pers. comm. 1999).

Generic shelterbelt system demonstration

Below is basic diagram of a shelterbelt design associated with a hypothetical hoop house swine production facility. The shelterbelt design shown is very generic. This generic design provides "buffering" around the major sources of livestock odor for a hoop house of this design located in ceutral Iowa. The design can easily be adapted to fit other livestock confinement and /or feedlot systems. The wind in Iowa primarily comes from the south, southwest, and southeast during the summer months and the north and west during the winter. The orieutation of shelterbelts reflects this. Also note that there are uo trees or shrubs located on southern eud of this facility. This facility would be naturally ventilated and there is a need to limit the risk of negatively impacting the necessary flow of cooling winds into the buildings open southern walls.

Shelterbelt impact on odor perception

The primary goal of odor mitigation is to *minimize* perceived odors, not necessarily eliminate them. Williams (1996) and Melvin (1996) suggest that the achievement of this goal cau be measured by reductions in: (1) odor concentrations reachiug populated areas, (2) the number of people affected by objectionable odors, (3) the duration of exposure to odors, and (4) the number of occurreuces of odor events. Legally defined separation distances aid in the dispersion of odors. In Iowa, for example, this distance is between 1,250 and 3,000 ft depending on the size of the facility and number of animals (Lorimor 1999). Because most of these distances are determined based on protection of water sources, the distauce is often not euough to reduce odor concentrations to levels that eliminate odor nuisance. As the evidence above suggests, shelterbelts have the ability to reduce odor concentrations significantly at or very near the source, which greatly euhances the effectiveness of that separation distauce. Appropriate shelterbelt designs, through the combined effects of each dynamic—particulate capture, plume dilution, particulate drop out, aud biological attraction of odorous chemicals to

vegetation—should be able to decrease the concentration levels of odor plumes leaving production sites and, therefore, contribute incrementally to the physical decrease of odorous chemicals moviug through an airshed. This, in combination with legal separation distances should significantly limit odor plumes reaching populated areas, reduce the total number of people affected downwind, reduce the duration of exposure to odors, and allow for reductions in the number of occurrences of odor events. And any aesthetic landscape improvements may contribute to a more positive response to odor that does reach critical receptors—people.

However, key to that assessment is the notion of 'appropriate'. If a shelterbelt is planted withont the consideration of ecological, biochemical, and engineering principles and knowledge, shelterbelts can be inefficiently utilized or worse they could be ineffective (Khan and Abbasi 2001). Ucar and Hall (2001) also stress that existing shelterbelts and other vegetation may work quite well for their original purpose (i.e. erosion control, crop/animal protection, riparian buffer zones), but in establishing shelterbelts for other goals (snch as odor mitigation) careful design is imperative. Moreover, as shelterbelts likely provide site specific incremental mitigation benefits, they should not be considered as outright substitutes for separation distance or used in decisions regarding the setting of legal distances. They also should not be considered as an alternative to standard best management practices (Ucar and Hall 2001). Ideally shelterbelts are to be used with other proven odor mitigating technologies and/or suitable manure management practices for the additive benefits of incremental odor amelioration.

Overall discussion on shelterbelts as technology

Despite the promise of shelterbelts as a beneficial technology there are some potential drawbacks that are common to tree based technologies. There is the time needed for the vegetation to grow. This is a difficult technological drawback when dealing with acute odor problems and retrofitting plant material is the management option. It is likely that trees need to be at least 3–5 years old before any noticeable benefits occur (thongh aesthetically, benefits may occur sooner). Shelterbelts also have space needs. Some livestock systems are more space limited than others. And several rows of trees throughout a production site can add up to hundreds of trees. Fnrthermore, facility land space may be limited because of maintenance and access roads. Trees need to be located so as to not hinder the use of those roads. Of particular concern is that for optimal use some shelterbelts may best be planted on land that is not part of the production site, particularly around fields where manure is spread. This may require coordination across property ownerships and the planting of trees on edges of active agricultural land. Government assistance programs such as the Conservation Reserve Program (CRP) and Environmental Quality Incentives Program (EQIP) may provide some financial support but multiple landowner coordination is often difficult to manage.

Knowledge of tree growth and maintenance to maximize tree health and prevent unnecessary tree mortality (e.g. avoiding certain herbicides, proper mowing procedures, and providing suitable moisture levels) is reqnired. Many land management professionals typically have expertise in trees/forestry or in farm systems but rarely expertise in both (Schaefer 1989). Such situations have led to on-farm failures of tree systems.

There are also time reqnirements for maintenance that may include: mowing, spraying, irrigation, and occasional tree replacement—5% to 10% tree mortality is common over the first 10 years for many otherwise healthy shelterbelts (G. Horvath pers. comm. 2002). Some concern has been expressed regarding the notion that shelterbelts may provide habitat for on-farm pests such as rats and other mammals as well as undesirable insects. Research on this topic is limited. But there has been very little evidence that this has been a serious problem with crop field shelterbelts. Undoubtedly more research is needed to fully answer this question.

Because empirical evidence is lacking it is difficult to assess the effectiveness of this technology at this point. However it is likely that there is a continuum of effectiveness. The lower the overall level of odorous emissions emanating from a

production site, the more effectual shelterbelts are likely to be. It is likely that there is a threshold at which shelterbelts (and other technologies) are simply overwhelmed and a nuisance situation may continue to exist. Field and laboratory tests are needed for a better understanding of this threshold.

There are some very real barriers to appropriately using shelterbelts within and near livestock production sites. Though shelterbelts are comparatively inexpensive to establish and maintain as an odor control technology, they do represent a cost to livestock producers both up front (i.e. site preparation, plant stock, and shelterbelt establishment) and over time (i.e. management). Recent research, however, has shown that total costs are significantly below what swine producers have been reported to be willing to pay for odor control. For example an economic analysis of the shelterbelt design shown in Fig. 2 revealed total costs to be between \$0.45 and \$0.59/per pig (marketed) *below* producer willingness to pay for odor control (Tyndall 2003; USDA 1996).

It is known that livestock odor has site-specific idiosyncrasies in its biophysical behavior and also idiosyncrasies in the social reaction to it, yet many current advances in odor mitigation seem to ignore this fact. Odor nuisance complaints are on the rise in the Midwest of the US, so it seems clear that there is something missing in management approaches currently used. Indeed, Person et al. (1995) call attention to this by suggesting the status quo in managing odor nuisance is not at all adequate in the face of the changes in livestock agriculture. Furthermore they state that the "appropriateness of recommendations for new technology and management practices will depend upon their being simultaneously compatible in an extensive interactive system that functions

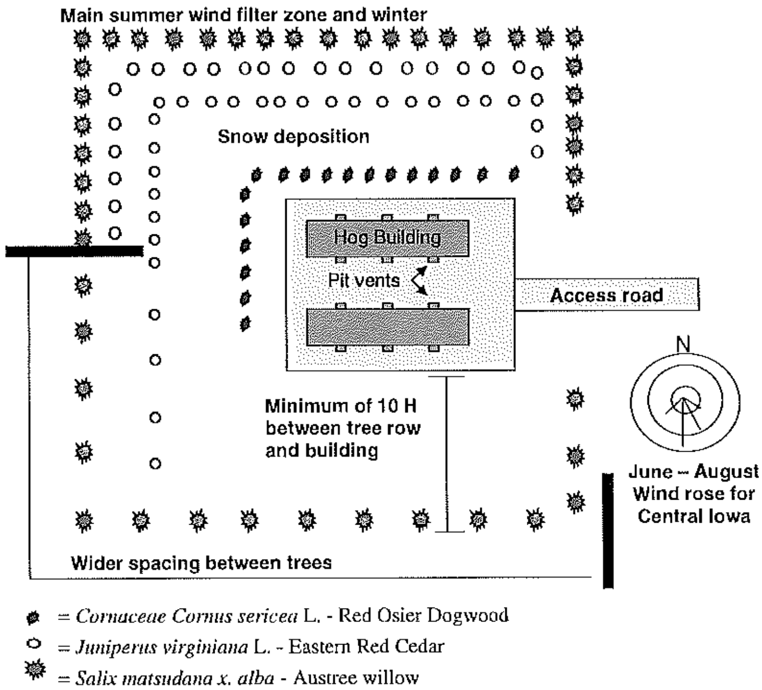

Fig. 2 Diagram of a shelterbelt system planted around a hypothetical naturally ventilated (side curtain) 2,100 head wean to finish hog facility. Planting orientation is guided by the summer wind patterns for Central Iowa—predominant summer winds originate from south to slightly south-east. Plantings to the south and south-west/east show wider spacing between trees and a minimum distance of 10 H from tree row to buildings; this is to allow for adequate summer wind to vent the buildings. The shelterbelts along the north-west and north show three rows and tighter spacing (8–10′ between trees; 12 ft between rows) to provide a zone of filtering surface area and turbulence to aid in dilution of odor plume. Three species are shown here for visual and biodiversity

in a community, natural (resource), economic, (and environmental) context all of which are tightly coupled" (Person et al. 1995).

It is for these reasons that there is a distinct advantage in the use of shelterbelts in that there is evidence that they are quite adaptable to the ecosystem and production variability of livestock production sites and production regions. There is also information that the presence of trees in agricultural landscapes has socio-aesthetic advantages that most other odor mitigation technology lacks completely. Shelterbelts are also a technology that can be considered production technology neutral, in that producers who raise hogs in a variety of facilities—confinement, modified confinement, hoop house, pasture—can plant designed shelterbelt systems. Shelterbelt systems are also a size neutral odor mitigation technology. Shelterbelts, very uniquely, offer a technology that both producers and rural residents and communities can appropriately use, suggesting "user neutrality". Further, as opposed to other odor mitigating technologies that typically depreciate over time, shelterbelts may be the only odor control technology that theoretically increases in effectiveness over time. As with other tree based technologies used in agriculture, the effectiveness of shelterbelts in mitigating odor comes from providing complex ecological infrastructure within an otherwise ecologically simplified system (Schultz et al. 2000). As the trees grow larger, and more morphologically complex their ability to mitigate odors should become increasingly efficient. Of course, this implied improvement over time is contingent upon the long term health and maintenance of the shelterbelt systems and the continuance of hog production best management practices.

Conclusion

Clearly, the published information on the ability of shelterbelts to mitigate on-and off-farm livestock odor is limited and further bio-physical, economic, and social qualification and quantification of this technology is needed. Yet the existing evidence indicates that shelterbelts, when planted in strategic designs (e.g. on-farm location, species selection), can help incrementally to reduce odor pollution. There are several key studies currently underway that will begin to answer questions of quantification, design, and producer and societal acceptance (Adrizal et al. 2006; Malone et al. 2006; Colletti et al. 2006). In the mean time it seems prudent to approach the design of shelterbelts for odor mitigation from a "prevent hazards" point if view and plant in a way so as to not cause snow deposition problems and/or impediment to needed natural wind flow.

It has been said that the sustainability of industries within agriculture will be shaped by its collective ability to improve environmental impact technologies (Kliebenstein 1998). This review suggests that shelterbelts can make an incremental, yet likely beneficial, contribution to that end.

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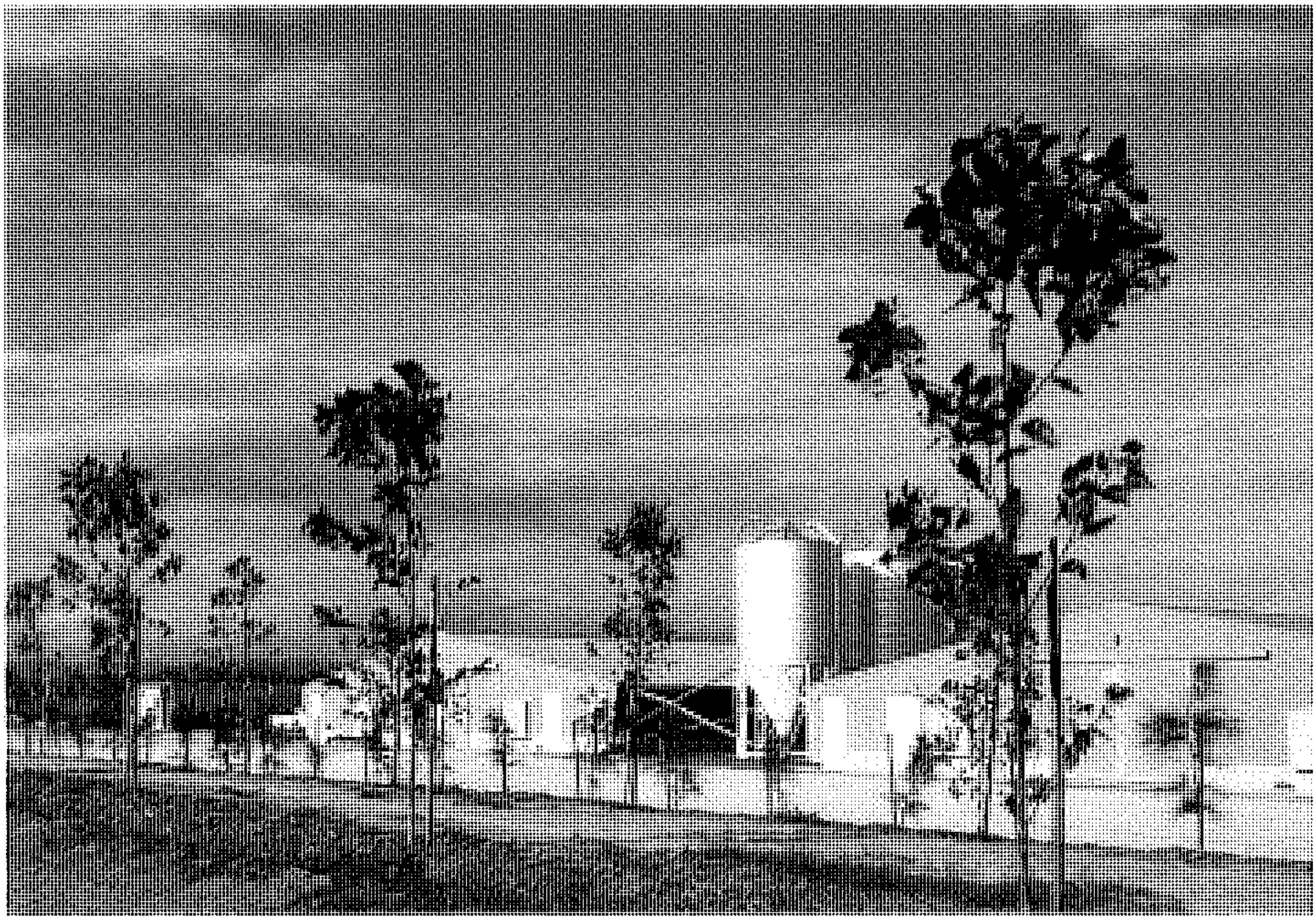
Vegetative environmental buffers for meat chicken farms – Literature review



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Vegetative environmental buffers for meat chicken farms

Literature Review

by E.N. Bielefeld, E.J. McGahan and P.J. Watts

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Foreword

The RIRDC Chicken Meat Program has been funding research for a number of years aimed at exploring available options and developing tools to assist growers to manage dust and odour impacts. This research has included the development of odour and dust measurement techniques, the assessment of odour and dust control technologies and separation distance modelling. The establishment of vegetative screens (or vegetative environmental buffers (VEBs)) to mitigate shed emissions from meat chicken farms is another dust and odour mitigation option worth further investigation, as it has proven to be a viable and successful option in the USA.

The importance of this report is that it reviews the best available literature on quantifying emissions from meat chicken sheds, the effectiveness of VEBs in mitigating emissions from these facilities, and establishes design principles for designing and establishing successful VEBs for meat chicken farms. This information has been used to develop producer guidelines for vegetative buffers on Australian meat chicken farms.

The project was funded by the RIRDC Chicken Meat Program, from producer levies matched by Australian Government funds.

This report is an addition to RIRDC's diverse range of over 2,000 research publications and it forms part of our Chicken Meat R&D program, which aims to stimulate and promote R&D that will deliver a profitable, productive, sustainable Australian chicken meat industry that provides quality wholesome food to the nation.

Most of RIRDC's publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

Craig Burns
Managing Director
Rural Industries Research and Development Corporation

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What the report is about

This report reviews the best available literature on quantifying meat chicken shed emissions, the effectiveness of VEBs in mitigating emissions from livestock facilities and establishing design principles for designing and establishing successful VEBs for meat chicken farms. This information has been used to develop producer guidelines for vegetative buffers on Australian meat chicken. The guide can be accessed at https://rirdc.infoservices.com.au/items/14-063.

Who is the report targeted at?

The primary target for this report is meat chicken producers.

Background

Vegetative environmental buffers (VEBs) are a dense vegetative filter created by planting multiple-rows of suitable grasses, shrubs and trees immediately down-wind of livestock buildings to promote the interception of particulates and odours from the fan exhaust plume (Parker *et al.* 2011). The term 'vegetative environmental buffers', was coined by researchers in the USA to distinguish standard shelterbelts/windbreaks from applications of vegetation specifically designed with a design emphasis on air quality improvements (Malone 2004). VEBs have been planted on USA meat chicken farms in the past decade as a tool to foster good relations with neighbours, maximise environmental stewardship, support farm biosecurity and enhance the aesthetic value of properties (Scott 2007) by primarily reducing dust and odour emissions from the farm and the subsequent potential for off-site impacts, and by providing a visual screen.

Ongoing research conducted in Australia has been aimed at exploring available options and developing tools to assist the grower to manage dust and odour impacts. VEBs are a dust and odour mitigation strategy and worthy of further investigation in Australia due to its proven success in the USA.

Aims/objectives

The primary objective of this project is to produce guidelines aimed at assisting Australian meat chicken farmers in adopting VEBs to reduce dust and odour impacts and improve farm visual amenity. These guidelines are based on the outcomes of a literature review and contain information for designing, establishing and maintaining VEBs on meat chicken farms for nine climate zones in Australia. This literature review attempts to quantify emissions from Australian meat chicken sheds as well as investigate the effectiveness of VEBs that have been trialled in the USA to reduce shed emissions.

Results/key findings

From the research on VEBs in the USA, some general design and management guidelines for establishing VEBs on meat chicken farms are apparent and are directly transferrable to designing VEBs for Australian farms. These are outlined below:

- VEBs should not be planted any closer than about ten times the fan diameter from the exhaust fan end of the shed to prevent the buffer impeding fan efficiency. This distance needs to be increased for sheds with multiple fans but the modification of this formula, if there is one, is not clear from the literature.

- VEBs should be planted a minimum of 25 m from the fans to prevent plants being desiccated at high wind speeds.

- A minimum of three staggered rows of plants are desirable with the row adjacent to the fans being a waxy-leaved evergreen shrub for Australian conditions versus a deciduous tree/shrub; the inner row/s deciduous trees and the outer rows evergreen trees to provide a windbreak.

- Evergreens with waxy leaves are preferred for the inner row (closest to the exhaust fans) as this row endures most of the dust emissions, which over time build up on the trees vegetation affecting their health. Evergreens with waxy leaves tend to withstand high particulate loads best as the waxy coating on the leaves allows dust to be washed off when it rains.

- Two staggered rows of evergreen trees, or a combination of windbreak type trees, are recommended for other screen zones e.g. where the primary purpose of the screen is to provide a windbreak, shade or visual screen. The density of planting should correspond with prevailing seasonal winds from each direction.

- Leaves with a complex shape and large surface area (e.g. conifers) appear to be the most effective for capturing particulates.

- The windward side should contain evergreen species that maintain lower branches close to the ground. Otherwise, it may be necessary to interplant with evergreen shrubs to compensate for the low-level opening.

- The spacing between tree rows and between adjacent trees in a row will be determined by tree species, objectives of the planting, farm situation and, if mowing between rows, the width of mowing equipment.

- Planting strips of tall-growing grass close to the fans, between the VEB and the fans, may also be beneficial.

- A VEB with a curved design is preferable than one with square corners.

Recommendations

Research conducted in the USA has developed some general design and management guidelines for establishing VEBs on meat chicken farms. Many of these design principles are directly transferrable to designing VEBs for Australian farms. However, there are several key differences between the USA and Australia that need to be addressed when preparing producer guidelines for Australian conditions.

Shed exhaust fans in the USA are rarely used in winter due to the cold climate, and conversely, snow is not an issue for Australian conditions. In most regions of Australia, shed exhaust fans are used all-year-round, due to the warmer climate. Therefore, planting deciduous trees/shrubs in the inner row of the VEB may not be practical in Australia as the VEB will still have to capture dust emissions during winter. Evergreens with waxy leaves would provide a better alternative.

In Australia, the risk of fire from planting trees close to buildings is an issue. Establishment of VEBs near meat chicken sheds could increase this risk if the species that make up the VEB have features that make them highly flammable (high volatile oil content, dead wood or twiggy material, heavy litter falls in summer, open-work canopies of hanging foliage and fine leaves). If the VEB consists of species that have features that make them fire-retardant (foliage has high salt and moisture content, soft leaves, low volatile oil content, smooth non-peeling bark and high leaf density), the VEB could have the opposite effect and could protect meat chicken sheds from an advancing fire. The traits of many native species in Australia fall into the fire accelerant category. Hence, many natives may not be suitable to include in VEBs, even if they meet other criteria for ideal plants for VEBs. Non-native species that have been identified as being highly successful at capturing particulates in the USA (e.g. conifers) also fall into the 'highly flammable category'. Depending on the fire risk of an individual farm, it still may be advantageous to plant some of these 'flammable' species if the risk is relatively

low and the remainder of the VEB has species that are fire retardant. This issue will need further investigation in Australian conditions.

The ideal distance between shed exhaust fans and VEBs to prevent backpressure on the fans and plant desiccation from high winds still needs to be clarified for sheds with multiple fans in a row and rows of multiple fans. This distance may need to be greater than the ten times the fan diameter, which is the minimum distance recommended in the USA to prevent fan back-pressure. Clarification of this issue may require discussions with key researchers in the USA who have been designing VEBs as well as researchers in Australia who have a strong background in Australian ventilation systems. There is a possibility that trials in Australia may need to be conducted before a recommended distance formula can be developed.

This literature review has identified some key plant characteristics that are required for establishing successful VEBs in the USA as well as some key characteristics that will need to be included for VEBs in Australia (e.g. to reduce fire risk). A producer guideline listing suitable species for each meat chicken region of Australia has been developed (https://rirdc.infoservices.com.au/items/14-063).

1. Introduction

The RIRDC Chicken Meat Program has been funding research for a number of years aimed at exploring available options and developing tools to assist growers to manage dust and odour impacts. This research has included the development of odour and dust measurement techniques, the assessment of odour and dust control technologies and separation distance modelling. The establishment of vegetative screens (or vegetative environmental buffers) to mitigate shed emissions from meat chicken farms is another dust and odour mitigation option worth further investigation, as it has proven to be a viable and successful option in the USA.

Vegetative environmental buffers (VEBs) are a dense vegetative filter created by planting multiple-rows of suitable trees and shrubs immediately down-wind of livestock buildings to promote the interception of particulates and odours from fan exhaust plumes (Parker *et al.* 2011). The term 'vegetative environmental buffers' was coined by researchers in the USA to distinguish standard shelterbelts/windbreaks from applications of vegetation specifically designed with a design emphasis on air quality improvements (Malone 2004). VEBs are designed to foster good relations with neighbours, maximise environmental stewardship, support farm biosecurity and enhance the aesthetic value of properties. A VEB consisting of multiple rows of different species of trees and/or shrubs, that is properly installed and maintained, is able to achieve all of the objectives listed above and to minimise the impact of any tree losses (Scott 2007).

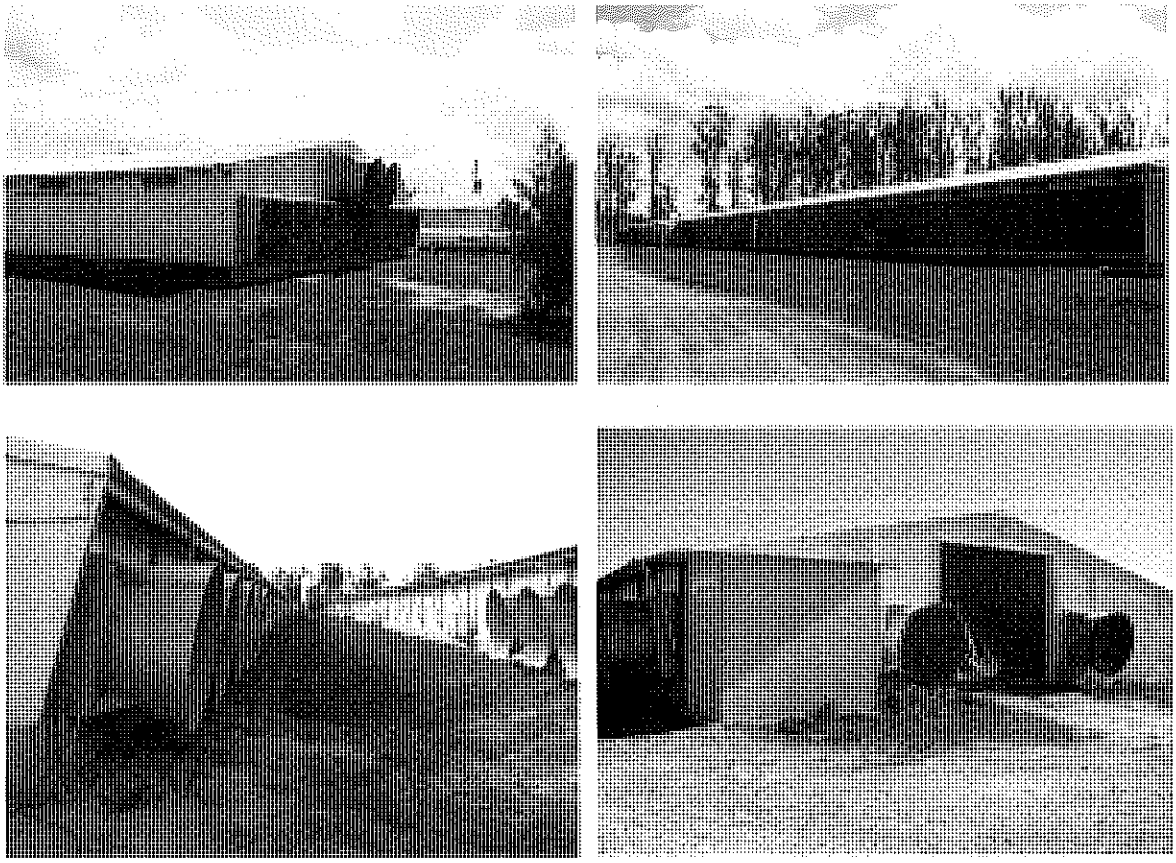
VEBs are similar to shelterbelts and windbreaks which are "vegetation systems that use trees and shrubs arranged in a row or group configurations to redirect wind and reduce wind speeds, thereby modifying environmental conditions within the upwind and down-wind sheltered zones" (Tyndall and Colletti 2007). Shelterbelts and windbreaks are not specifically designed to capture particulates and gaseous emissions from livestock facilities and usually consist of only one or two rows of trees/shrubs. The emphasis of this review will be on VEBs as their design can apply the same general principles to create a buffer that primarily functions as a shelterbelt/windbreak.

The primary objective of this project is to produce guidelines that will assist Australian meat chicken farmers in establishing VEBs to reduce dust and odour impacts and improve farm visual amenity. These guidelines have been based on the outcomes of this literature review and contain information for designing, establishing and maintaining VEBs in nine climate zones in Australia. Thirteen production localities have been identified as being the regions where the majority of chicken meat is produced in Australia. These thirteen production localities are situated within nine climate zones. The production localities include three in Queensland including the outer suburbs of Brisbane, Esk and Mareeba (Atherton Tablelands); five in NSW including Sydney, outer-Sydney, Casino, Griffith and Tamworth; two in Victoria including Bendigo and the Mornington Peninsula; as well as outer-Adelaide in South Australia; outer-Perth in Western Australia and outer-Hobart in Tasmania. In order to successfully design VEBs for each of these localities, local climate and topographic features has been characterised to assist in the selection of a list of plant species that may be suitable for establishing VEBs.

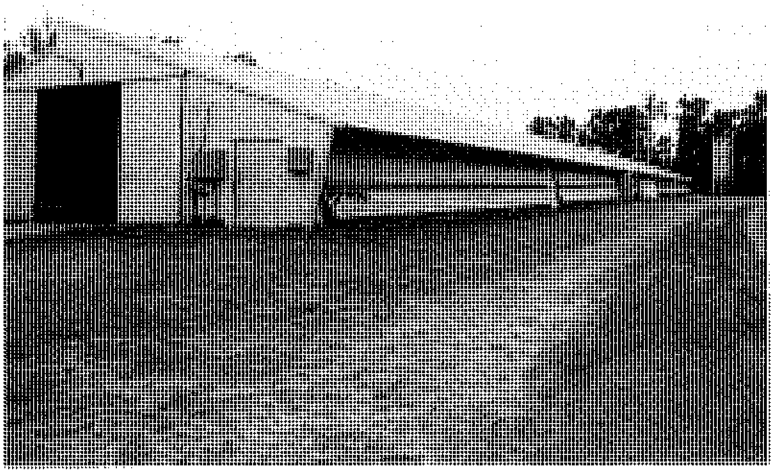
This report reviews the best available literature on quantifying emissions from meat chicken sheds, the effectiveness of VEBs in mitigating emissions from livestock facilities and establishing design principles for designing and establishing successful VEBs for meat chicken farms. This information has been used to develop producer guidelines for vegetative buffers on Australian meat chicken farms.

2. Shed Ventilation Systems in Australia

The Australian chicken meat industry is dominated by large-scale, intensive productive facilities. Most meat chicken growers have either built modern tunnel ventilated sheds, with electronically controlled mechanical ventilation systems, or have converted naturally ventilated sheds to tunnel ventilation (Photograph 1). Tunnel ventilated sheds are typically long and narrow, and capable of holding 30,000 to 60,000 birds. There are often three to ten sheds on one grow-out farm. Tunnel ventilated sheds have exhaust fans at one end of the shed. These fans draw in air from the other end or sides of the shed through a series of vents or cooling pads in the shed walls. The air passes over the birds in the shed and is exhausted out other end of the shed at high speeds. This creates a longitudinal airflow that is effective at regulating perceived temperature (Figure 1). The system is controlled automatically, with several temperature sensors in the shed monitoring the heating and cooling settings which are adjusted as often as every three minutes. There are still some traditional 'naturally ventilated' sheds in operation (Photograph 2). These sheds have open sides with ventilation controlled by raising/lowering curtains or panels running along the side of the shed, or by a vent opening at the top of the shed (Figure 2). Ceiling fans are often installed to encourage air flow and water misting systems (foggers) cool birds by evaporative cooling in very hot conditions (ACMF 2011b). This report predominantly focuses on VEBs suitable for tunnel ventilated sheds, as this is the most common production system in Australia.



Photograph 1. Typical modern tunnel ventilated meat chicken sheds in Australia



Photograph 2. Typical naturally ventilated sheds in Australia

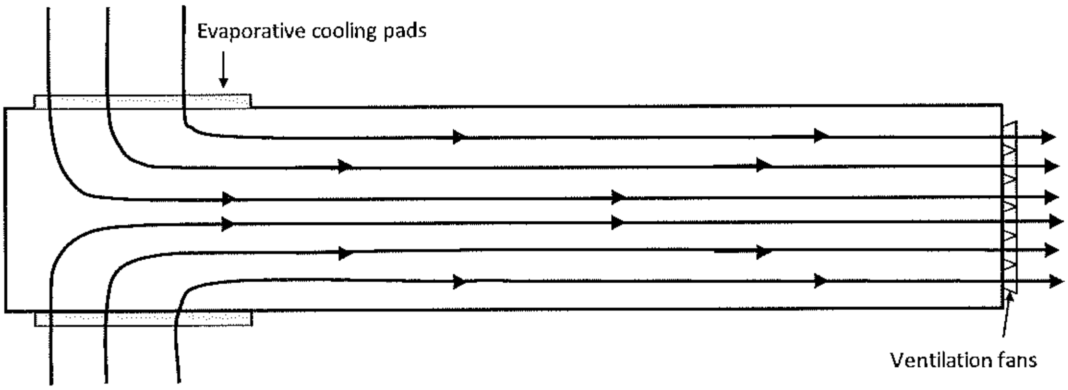


Figure 1. Diagram of airflow through typical tunnel ventilated shed

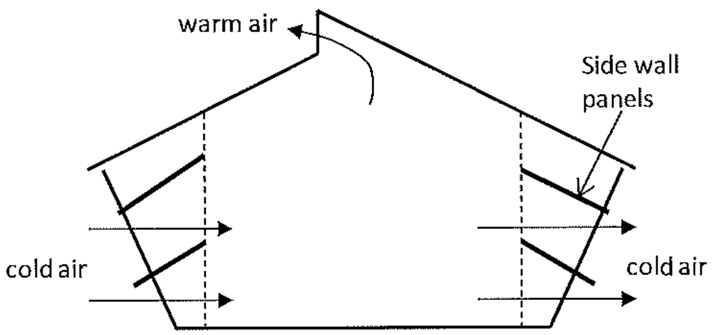


Figure 2. Diagram of airflow through typical naturally ventilated shed

3. Air Quality and Biosecurity Issues Associated with Meat Chicken Farms

Characteristics of dust from meat chicken farms

Meat chicken sheds can emit dust (particulate matter) and chemical (nitrous oxide, ammonia, methane, hydrogen sulphide, volatile organic compounds) emissions into the atmosphere. The main source of these emissions is chicken litter. Litter is made up of bird faecal material and bedding material (e.g. wood shavings, sawdust, rice hulls). Dust within a shed also originates from the feed, skin and feathers (i.e. dander) of the chickens themselves.

Dust (particulate matter) size and impacts

Dust emissions (particulate matter, PM) from meat chicken sheds, particularly tunnel ventilated sheds, can potentially have negative health and environmental impacts (Modini *et al.* 2010). Particulate matter is categorised by size, due to the different health effects from particles of different diameters. Airborne particles less than 100 μm aerodynamic equivalent diameter are referred to as total suspended particulate matter (TSP). Particles less than 10 μm are inhalable particles. Inhalable particles are grouped into coarse particles (2.5–10 μm) and fine particles (<2.5 μm). Coarse particles or inhalable particles (PM_{10}) tend to be deposited in the upper respiratory tract, while fine particles or respirable particles ($PM_{2.5}$) can be deposited in the smallest airways (alveoli) in the lung. Particles produced from gas-to-particle conversion generally fall into the $PM_{2.5}$ category (Blackall *et al.* 2010).

Potential health impacts on humans due to dust from meat chicken farms are associated with inhalable particles (<10 μm), which can be trapped in the nose and throat and swallowed. TSP (10-100 μm) is typically associated with adverse aesthetic issues rather than adverse health effects. These particles tend to settle on surfaces causing soiling and discolouration. PM_{10} particles are associated with increases in respiratory problems including asthma, bronchitis, and emphysema. The specific effects depend on the inhaled particles size, chemical composition, concentration and the presence of other pollutants. There is some evidence that, within the PM_{10} fraction, particles of $PM_{2.5}$ and $PM_{1.0}$ might be more deleterious to health than other size fractions as they can be inhaled more deeply (Blackall *et al.* 2010) and can remain suspended in the atmosphere for long periods of time (~days) and can travel a large distance from their source (Modini *et al.* 2010).

In terms of an environmental effect, particulate matter can:

- impair visibility and reduce solar radiation (very small particles can remain suspended in the air for long periods of time, and can effectively scatter light);
- corrode metals and masonry;
- coat buildings, structures and vehicles with dust that requires cleaning; and
- coat the leaf surface of plants, which may inhibit their growth (Blackall *et al.* 2010).

Emitted particles can deposit on surfaces either by gravity or by interception due to air movements, or they can be transported down-wind from the source. The travel distance of PM depends on:

- physical properties (aerodynamic particle size, which is related to diameter, shape and density);
- availability of surfaces to intercept PM;

- meteorological conditions, such as temperature and humidity, which can affect particle size concentration; and
- wind speed and turbulence (atmospheric stability).

There is also a relationship between dust and odour emissions. Odour producing chemicals and micro-organisms can adhere to dust particles that are emitted from sheds (reviewed in Dunlop 2009). Lacey *et al.* (2004) reviewed the literature available on the relationship between dust and odour emissions and found contradictory evidence. Studies in pig facilities have shown that a number of odorants can be carried on dust particles but a study that reduced dust emissions inside a meat-chicken house with electrostatic precipitation found no significant difference in odour concentrations. The authors of that review suggested that it is likely that a significant number of odorants attach to dust particles, but if dust levels are reduced, there are still enough other odorants in the air to maintain threshold odour concentrations.

Quantifying dust emissions from Australian meat chicken farms.

The most comprehensive studies that have measured dust emissions from tunnel ventilated sheds in Australia are Blackall *et al.* (2010) and Modini *et al.* (2010). Australian production practices are different from overseas countries mainly due to the hot climate. International studies on dust emissions from all types of meat chicken sheds (Europe and USA) have been reviewed and summarised by Blackall *et al.* (2010). The literature reports a range of 0.02–81.33 mg/m^3 for inhalable dust and 0.04–9.7 mg/m^3 for respirable dust. The main factors identified which affect emissions include shed type, bedding materials, bird age, activity and density, litter moisture and season (Takai *et al.* 1998 cited in Blackall *et al.* 2010). The primary study, which is somewhat comparable to Australian production systems, is Redwine *et al.* (2002), which measured dust and ammonia concentrations inside four tunnel ventilated sheds in Texas, USA over a sixmonth period. They reported shed emissions as a product of the measured concentration of the contaminant in the sheds and the measured ventilation rate. Their findings are summarised below:

- TSP concentrations inside sheds ranged from 7.387–11.387 mg/m^3.
- Mass medium diameter (MMD) of TSP samples ranged from 24–26.7 µm aerodynamic equivalent diameter. The MMD increased with bird age.
- The mass fraction of PM_{10} sized particles in the TSP samples inside the shed ranged between 2.72%–8.40% (mean 5.94%).
- Shed ventilation rates were between 0.58 and 89 m^3/s.
- TSP emission rates ranged from 7.0–1673 g/hr.
- PM_{10} emission rates ranged from 0.58–99 g/hr.

Blackall *et al.* (2010) measured dust concentrations inside tunnel ventilated meat chicken sheds with single-use litter and dust emissions from the sheds of one Queensland property. Their main findings are detailed below and in Table 1 and Table 2:

- Dust emissions from empty sheds with fresh litter are initially high when the ventilation system is first turned on, but decline to background levels within 1.5 hrs. Biological particles are only a small fraction of total particles and are the same as background levels.
- Particle concentrations in shed emissions decrease slightly with increased ventilation rate, but total particle emissions per shed increase with increasing ventilation rates and are dependent on bird age.

- Peak particle emissions were detected for birds of 4–5 weeks of age, rather than for oldest birds. This could be due to the older and larger birds being less active and creating less dust and /or due the effect on increased litter moisture limiting the generation of dust.

- The majority of the particle mass emitted was larger than 2.5 μm (respirable particles) and in the range of 2.5-10 μm (inhalable particles).

- PM_{10} dust emissions were around 7.6 g/hr/500 kg of bird mass before the first thin-out which dropped to 2.8 g/hr/500 kg of bird mass after thinning.

Table 1. Dust emissions from a Queensland meat chicken farm (Blackall *et al.* 2010)

Feature	Bird age (days)	Emission rates	
		PM_{10}	$PM_{2.5}$
Particle mass concentrations (mg/m³)	19	1.16	
	28	1.57	
	45	0.88	
Particle mass emission rates (mg/s)	19	76.3	
	28	156.4	
	45	73.8	
Particle mass emission rates per kg of bird mass (mg/s/kg)	19	4.19×10^{-3}	1.3×10^{-3}
	28	4.3×10^{-3}	0.072×10^{-3}
	45	2.82×10^{-3}	0.91×10^{-3}
Particle mass emission rates per 500 kg of bird mass and during 1 hr (g/hr/500 kg of bird mass)	19	7.54	2.34
	28	7.74	0.13
	45	5.08	1.64

Table 2. Particle and bacteria number concentrations and emissions from meat chicken shed (Blackall *et al.* 2010)

Type of Particles	Bird age, Days	Particles concentration, # x 10^6/m³ or CFU x 10^6/m³			Particle emission rates, # x 10^{10}/h or CFU x 10^{10}/h
		Mean	Std	Range	Mean
Total	0	2.2	0.1	1.9 – 2.4	
	19	19	8.1	11 – 45	210
	28	45	19	17 – 90	85
	45	21	5.1	13 – 38	150
Biological	0	1.7	0.1	1.4 – 1.9	
	19	15	6.9	9 – 38	150
	28	33	15	12 – 70	67
	45	16	4.4	11 – 30	65
Bacteria	0				
	19	0.56	0.22	0.39 – 0.97	2.7
	28	2.4	1.2	1.5 – 4.6	0.75
	45	1.6	1.1	0.14 – 3.1	1.2

Modini *et al.* (2010) measured dust emissions from one tunnel ventilated meat chicken shed in south-east Queensland to compare emissions from single-use litter (first batch) and partially-reused litter (second batch). Measurements were taken throughout the growing cycle from 14 to 55 days. Their paper only reports the averages of all dust concentrations, emission rates and CMD measurements

from each production cycle. Table 3 summarises the average results obtained for dust concentrations and emission rates for different sized particles. They concluded that the average concentration and emission rate of dust from partially reused litter was higher than fresh (single-use) litter. Standard deviations suggest that, apart from dust emissions and concentrations for $PM_{0.5-20}$, there was no significant difference between fresh and partially recycled litter. The authors did note that ventilation and litter moisture conditions were different between the two batches, which could have affected the results. Average ventilation rate for the fresh litter batch was 83.3 (± 19.9) m^3/s and 67.0 (± 13.4) m^3/s for the partially recycled litter batch. Average moisture content of the litter was 29.7 (±4.9)% and 26.7 (±2.1)% for the fresh and reused litter batches respectively.

Table 3. Average dust concentrations and emission rates from a single tunnel ventilated shed in south-east Queensland using fresh or partial reused litter (adapted from Modini *et al.* 2010)

Dust variable	Fresh litter	Partially reused
Ave dust emission rate - Particle no. (particles/s/kg LW)	1.2×10^{-4}	3.2×10^{-4}
Ave dust emission rate - PM_{10} (mg/s/kg LW)	4.7×10^{-4}	6.2×10^{-4}
Ave dust emission rate - $PM_{2.5}$ (mg/s/kg LW)	1.1×10^{-4}	1.3×10^{-4}
Ave dust concentration - PM_{10} (mg/m^3)	0.28	0.45
Ave dust concentration - $PM_{2.5}$ (mg/m^3)	0.063	0.095
Ave dust concentration - $PM_{0.5-20}$ (particles/m^3)	7.6×10^{6}	2.4×10^{7}
Ave dust emission rate - PM_{10} (mg/s/1,000 birds placed)	0.56	0.82
Ave dust emission rate – $PM_{2.5}$ (mg/s/1,000 birds placed)	0.13	0.17
Ave dust emission rate - $PM_{0.5-20}$ (particles/s/1,000 birds placed)	1.6×10^{7}	4.0×10^{7}

Dust emissions from meat chicken sheds are usually estimated using well-established emission factor equations and dispersion models to estimate concentrations. These models are not particularly accurate. In practice, dispersion modelling using estimated dust emissions shows that 60% of predicted values are within ±40% of measured annual concentration for estimates made over many sources and over a long period of time (Blackall *et al.* 2010).

Pathogens contained in dust

Meat chicken farms are a potential source of a range of pathogens. The main sources of pathogens are chicken faeces or infected birds. The mere presence of microorganisms does not mean that infection will occur in humans. The organisms need to be of a type that will infect humans (zoonotic pathogens).

Chicken litter may contain pathogens that have the potential to be harmful to both humans and meat chickens. Pathogens that are present in Australian chickens and are of public and environmental concern has been covered in detail by Blackall *et al.* (2010) and Runge *et al.* (2007). The Australian chicken meat industry is currently free of avian influenza. Other pathogens of potential concern are summarised in Table 4.

Table 4. Summary of pathogens potentially present on Australian meat-chicken farms

Pathogen Type	Pathogen	Description
Bacterial	*Campylobacter jejuni/coli*	Common in chickens. Evidence of poultry to human transmission. *Campylobacter jejuni* is a microaerophilic organism, which means it has a requirement for reduced levels of oxygen for survival. It is a relatively fragile and sensitive to environmental stresses. Can survive on pasture spread with spent litter for 10-20 days.
Bacterial	*Clostridium perfringens,*	Common in general environment including chicken sheds. Considered low risk pathogen to humans as there is no strong link of human infections to meat chicken products or litter. Spore forming organism with capacity to survive for long periods in environment.
Bacterial	*Clostridium. Botulinum (type C & D)*	Common in general environment. Type C & D affect other animals but not humans. Survival is indefinite due to production of spores.
Bacterial	*Cryptosporidium baileyi*	Non pathogenic to humans.
Bacterial	*Escherichia coli*	Common but most chicken serotypes are pathogenic for birds only and not important causes of infections in other animals or humans.
Bacterial	*Erysipelothrix rhusiopathiae*	Uncommon. Can survive on pasture for 14 days.
Bacterial	*Listeria monocytogenes*	Rare. Outbreaks are sporadic in meat chickens and rarely reported in Australia. Can survive in soil 300-700 days.
Bacterial	*Marcobacterium*	Rare in Australia.
Bacterial	*Salmonella spp.*	Infections due to Salmonella are not a common cause of disease in Australian meat chickens. Poultry *Salmonella* serovars are not common to serovars affecting humans. Can survive up to 53 days on pasture.
Bacterial	*Staphylococcus aureus*	Infections are common in meat chickens. Approx 50% meat chicken isolates. Relatively resistant organism.
Bacterial	*Yersinia pseudotuberculosis*	Rare. Low risk
Viral	*Rotavirus*	Transmission of avian rotaviruses is rare and there is no known public health significance.
Viral	Newcastle disease virus (NDV)	Widely present in poultry but most strains are of low pathogenicity and clinical disease is not common. Clinical signs and severity in poultry vary but can result in mortality. Human infections are from direct contact with infected birds result in headache and flu-like symptoms which may develop into eye infection. Transmission is by infected bird faeces and secretions and possibly windborne particles to a lesser extent (Animal Health Australia 2010).

Source: summary of reviews by Blackall *et al.* (2010) and Runge *et al.* (2007)

The concentration of any pathogen cannot be assumed to be the same in chicken litter as in the concentration in the dust inside a meat chicken shed. As previously mentioned, chicken litter is made up of bird faecal material and bedding material (e.g. wood shavings, sawdust, rice hulls) whereas dust within a shed originates from a number of other sources, including feed, skin and feathers (i.e. dander).

Transmission of zoonotic pathogens from meat chickens to humans may occur via the food chain, from processed meat or from food crops fertilised with chicken litter, from direct contact with infected

birds, or from oral transmission of chicken faeces or chicken litter. Meat chickens may also be carriers of some zoonotic diseases while not necessarily being affected by the disease. The simple presence of a pathogen does not necessarily mean that infection will result. The pathogen must be present at high enough numbers to ensure that an infection will result. *(This is quantified as the infectious dose, ID_{50} – the number of organisms needed to ensure that 50% of the exposed population are infected.)* The infectious dose for selected pathogens is in Table 5.

Table 5. The infectious dose for selected pathogens (Runge *et al.* 2007)

Pathogen	ID_{50}
Campylobacter jejuni	900
Cryptosporidium parvum	150
Listeria spp.	2,100,000
Salmonella spp.	100,000

In Australia, there has been little research to measure pathogens levels in spent litter. The type and viability of pathogens in spent litter is dependent on the spent litter age, pH, bird age, diet, temperature, humidity and management practices (Nicholas *et al.* 2007b).

Chinivasagam *et al.* (2010) reported on the presence and level of food-borne pathogens in chicken litter at the end of a cycle of birds, where the maximum possible concentration of pathogens would be found, for 28 farms in Queensland, New South Wales and Victoria. **The pathogens investigated were *Camplyobacter, Listeria* and *Salmonella*, as well as the indicator organism *E. coli*.**

- *E. coli* levels varied from 1.2 x 10^7 to 1.0 x 10^2 colony forming units (CFU)/g. As poultry *E. coli* isolates are not of the type that infect humans, these levels of *E. coli* are of no public health significance.

- *Salmonella* levels were below the detection limit of 3 Most Probable Number (MPN)/g in 8 of the 28 samples studied.

- a) 252 *Salmonella* isolates serotyped showed that, in 11 litter samples, all were found to be *S. enterica* serovar Sofia. b) In 9 litter samples, *S. enterica* isolates other than serovar *Sofia* were present.

- c) Thus, 19 of the 28 litter samples contained no detectable levels of pathogenic *Salmonella*. In the remaining nine samples, pathogenic *Salmonella* ranged from 0.9–230 MPN/g.

- *Campylobacter jejuni/coli* was detected in ten samples. In seven of these, the level of *Campylobacter* was below 100 MPN/g.

- *Listeria spp* were absent in all samples.

There was no difference in the rate of positive samples for either *Campylobacter* or *Salmonella* between single-use and re-used litters. *Salmonella* is recognised to be a good survivor in the environment and, although it was found in the majority of litter samples, it was only at low levels in both single and reused litter. There is evidence that *Campylobacter* has a poor survival capacity in litter in the absence of the chicken. *Campylobacter* was detected in only one of six re-used litters tested, whereas in 22 of the single-use litters, nine were positive for *Campylobacter*. However, the levels detected for both litter types were low. In conclusion, the study showed that pathogen survival was not influenced by litter type, source material or physical characteristics.

Chinivasagam *et al.* (2009) investigated the food-borne pathogen risk of the partial reuse of chicken litter in south-east Queensland. Used litter was treated by pushing into heaps and partially composting

before respreading at the grower end of the shed. The main findings of the study are summarised below:

- *Campylobacter* was present on all occasions at high levels (10^4–10^6 MPN/g) in the litter (at the latter stages of the chicken cycle) before the piling process, while *Salmonella* was present on most occasions before the piling process but at lower levels (10^3–10^4 MPN/g).

- *Salmonella* and *Campylobacter* levels decreased through the pile-up process with none of these organisms being present on days 4–6 following pile formation, the final days of the pile. *Campylobacter* demonstrated a 6-log reduction. However, *E. coli* (an indicator organism) was present during the last day of the pile (during both cycles) on the first farm but was not detected on the second farm. This could possibly be linked because these particular piles had a generally lower temperature profile than that other piles examined in the study.

- Both *Clostridium perfringens* and *Bacillus*, spore forming organisms, were not impacted by the pile-up process.

- Outcomes suggest that the pile-up process has the potential to deal with the key pathogens (*Salmonella* and *Campylobacter*) within 4–6 days of forming the pile.

- This study confirmed that the partial composting practices on both farms achieved effective pathogen destruction. However, these outcomes need to be supported by good in-shed management processes.

Some research has been carried out in Australia on the risk of infection from applying spent litter to crops. Craddock and Hollit (2010) analysed 60 samples of grain harvested from plots spread with 2.5 t/ha of spent litter prior to sowing and found no significant difference in concentrations of *Salmonella, E. coli* and anaerobic spores to grain harvested from plots with no spent litter applied.

Wilkinson *et al.* (2003) conducted a study to evaluate the food safety risks with the use of spent litter in vegetable production in the Melbourne area. They concluded that:

- Low *E. coli* levels and no *Campylobacter* were detected on any crops at harvest.

- *E. coli* counts and the detection of *Salmonella* were variable in spent litter deliveries.

- *Salmonella enteric* serova Sofia was detected on a coriander crop that had been side-dressed 18 days prior to harvest. However, research suggests that this serova is non-pathogenic for humans and chickens.

Risk of transfer of pathogens in dust from meat chicken farms

There is a potential for a range of pathogens to be present inside meat chicken sheds and therefore could be found in dust emitted from sheds. However, the survival of pathogens emitted as aerosols in the external environment is influenced by a number of factors including dehydration, desiccation and solar radiation, temperature and humidity. Quoted survival rates of pathogens in other mediums (e.g. soil and on pasture) are not the same as survival rates in the air.

For an infection to occur, pathogens need to be present at high enough numbers (Table 5) and need be inhaled and ingested (i.e. small enough particle size). Few studies in Australia have measured pathogens levels and dust emissions inside and outside meat chicken sheds.

Blackall *et al.* (2010) examined dust emissions and pathogen levels of a selection of indicator pathogens from four meat chicken farms in south-east Queensland with typical tunnel ventilated sheds. Their study measured levels of four groups of pathogens including *Salmonella* spp., *Campylobacter jejuni/coli* and *E. coli* (traditional indicator species) which are normal inhabitants of the

gastrointestinal tract of chickens and can be transferred via faeces. It is worth noting that other research has shown that many *Salmonella* and *E. coli* isolates from chickens are unlikely to cause disease in humans (Table 4). Harmless species of *Staphylococcus*, i.e. not *S. aureus*, were also identified as suitable indicator species. *Staphylococcus spp.* are associated with poultry dander.

Blackall *et al.* (2010) found that for the litter inside the sheds:

- *Salmonella* was only present intermittently, not present at all farms, and present at low maximum levels of 1,000–230,000 organisms/g.
- *Campylobacter* was only detected late in the production cycle of the litter in high levels (10^3–10^7 MPN/g litter).
- Levels of *E. coli* in the litter increased to 10^8 /g of litter within 5 days of bird placement on new litter to around 10^7 MPN/g of litter and decreased to around 10^5–10^7 MPN/g of litter at the end of the batch.
- Measured levels of *staphylococci* in the litter ranged from 10^{10}–10^{12} MPN/g of litter on one farm and 10^8–10^{10} MPN/g of litter on another farm.

For aerosols inside the sheds,

- *Salmonella* was absent unless higher concentrations in litter were measured (above 10^4–10^5 organisms / grams of litter). Levels measured ranged from 0.33–4.4 organisms/m^3.
- *Campylobacter* was only detected once and at a low level (0.22 MPN/m^3). This is likely due to it being sensitive to the drying process.
- Levels of *E. coli* ranged from 1,000–100,000 organisms/m^3.
- Levels of staphylococci ranged from 10^5–10^6 organisms/m^3.

In the external environment,

- *Salmonella* was only rarely detected in the external aerosol environment and at low levels that posed no significant risk to human health.
- *Campylobacter jejuni/coli* was never detected outside the sheds which is likely due to its fragile nature in the external environment.
- *E. coli* was present outside the sheds but levels dropped away at distances beyond 20 m from the fans.
- Throughout the production cycle, internal airborne levels of staphylococci increased throughout the production cycles from background levels and ranged from 10^1 to 10^6 /m^3. External levels followed same trend as internal levels but were lower. At one site that featured open topography in front of the sheds, staphylococci could be detected at elevated levels close to the shed and returned to background levels at 400 m from the shed.
- *Salmonella*, *E. coli* and staphylococci were also detected in settled dust (large particle size) outside the sheds.

The authors concluded that there is a strong link between levels of pathogens measured in litter, in aerosols inside the shed, and in aerosols outside the sheds. However, the levels of pathogens measured outside the sheds were low. Concentrations of pathogens in the litter and internal shed air are influenced by the age of birds in the shed and the stage of the production cycle. Management practices

that reduce levels of pathogens in spent litter inside the shed will therefore further reduce already low levels outside the sheds.

In conclusion, there is a correlation between the concentration of some pathogens in aerosols inside the shed to levels found in the external environment. This suggests that some indicator pathogens (i.e. *E. coli*, *Salmonella* and *Staphylococcus spp*, can survive in the air (as dust) and be transported over a short distance. The distance travelled depends on the environmental factors that inhibit the survival of the organism and the terrain of the landscape. However, levels recorded in the external environment are low and do not appear to be of great concern for human or animal health. These results are also supported by literature from other intensive livestock industries, namely beef feedlots.

Beef feedlot manure in Australia has been shown to contain 10^{10} culturable bacteria per gram dry weight or at least 1% of the total mass of this material. Wilson *et al.* (2002) examined the dust immediately upwind and down-wind from a feedlot on four days in spring during warm weather (< 30 °C). Gram negative pathogenic bacteria (*Salmonella spp* and *Escherichia coli O157:H7*) were detected (only non-pathogenic gram positive bacteria were found) down-wind of the feedlot, indicating relatively poor survival or at least non-culturability. Canadian research (CABIDF 2004) also pointed to limited travel down-wind of total bacteria from two feedlots in Alberta, Canada. Total bacteria levels at 0.5 km to 1.0 km down-wind fell to levels detected upwind from the feedlots.

Odour emissions from meat chicken farms

Potential sources of odour

The main potential sources of odour from meat-chicken farms are litter, body odour from birds, dead birds (if not quickly removed and disposed of), stockpiled or composting litter (mechanical disturbance of the compost heap) and litter spread on land. Most meat chicken farms efficiently remove spent birds and do not stockpile or compost spent litter on-site. Hence, the major source of odour is from the litter inside meat chicken sheds.

Odours generated from litter are a result of the biodegradation of manure that can take place under aerobic or anaerobic conditions. Gaseous odorous compounds that have been absorbed into litter or from the body of the birds transfer into the shed air at rates depending on the velocity of the air passing across the surface of the litter and the birds. Turbulent mixing within the shed continues this process. The processes of the generation, transfer and transport of odour occur simultaneously and limit each other's reaction rate. Water acts as a catalyst to all of these processes (Jiang and Sands 2000).

Jiang and Sands (2000) provide the following description of the biochemical processes that occur in litter of varying moisture contents:

> "At or near the litter surface, the presence of oxygen from the air creates aerobic conditions under which uric acid, proteins and animal fats are biodegraded. The aerobic processes produce nitrogen-containing odorants such as ammonia, amines, indole, skatole and volatile fatty acids. Aerobic conditions also enable, sulfide-containing compounds such as methionine, to oxidise microbially into sulfur containing odorants such as hydrogen sulfide, dimethyl disulfide, and dimethyl trisulfide.
>
> Within the litter and in pads of caked manure on poorly managed farms, oxygen supply is limited and anaerobic conditions may occur. Under anaerobic conditions, sulfur-containing compounds are biodegraded into thiols, volatile organic sulfides and mercaptans. Anaerobic processes may be limited by reducing the litters moisture content and by increasing the exposure of the litter to air (oxygen) by reducing stocking rates to facilitate bird movements. It may also be limited by feeding balanced complete rations with sulfur compounds of high biological availability particularly early in the growth cycle of a batch."

Odour generation processes tend to accelerate with increasing bird age as manure accumulates more quickly in the litter. Harvesting birds during the batch reduces the bird density in the sheds, temporally

providing greater exposure of the litter to air, increased velocity of air over the litter surface and facilitating bird movement and scratching. However, towards the end of the batch, the remaining birds' excretion rates increase and the air exposure and bird movement and scratching will be reduced. This results in a plateau of maximum odour concentrations in the shed during the last weeks of a batch (Jiang and Sands 2000).

Measurement and prediction of odour emissions

There have been only a few published studies in Australia that have attempted to quantity odour emissions from meat chicken sheds (Dunlop *et al.* 2010, Simons 2010). These have been summarised in Table 6. Overseas studies are less relevant for comparison due to different shed designs, management and climatic conditions. There have also been a number of odour emission measurements conducted on meat chicken sheds in Australia as a part of the planning approval process or compliance auditing. These emissions are not published in the scientific literature.

Dunlop *et al* (2011) measured odour emissions at tunnel ventilated broiler farms over several production cycles in Queensland and Victoria. Odour emissions were examined for both single use and partially reused litter. The experiment found that there were no significant differences between odour emission rates per 1,000 birds placed in the shed at the start of the batch or per kg of liveweight. Measurements for odour emissions ranged between 337 - 2,939 ou/s per 1,000 birds placed in the shed at the start of the batch and between 0.53 - 2.12 ou/s per kg of liveweight respectively. This research found similar emission rates to those previously reported in the literature.

Dunlop *et al.* (2010) have recently measured odour emissions from nine tunnel ventilated sheds in south-eastern Qld. At eight farms, odour emissions measured just before first pick-up (around Day 35 of batch) using dynamic olfactometry (to AS/NZS 4323.3:2001). Odour emission rates ranged from 330 – 2,960 ou/s per 1,000 birds and from 0.19 – 2.12 ou/s/kg. At one farm, odour emission rates were measured over two batches at approximately weekly intervals using dynamic olfactometry. This showed that odour emission rates increased with live bird weight until first pick-up (Day 35-36), followed by an immediate decrease, then a gradual increase until the end of the batch. At this farm, an artificial olfaction system (a portable odour assessment instrument that uses a non-specific gas sensor array combined with a signal processing system to detect odour) was used to demonstrate that odour emission rates generally increased with bird liveweight and fluctuated diurnally. The diurnal pattern featured a short period of peak emissions, generally in afternoon, and minimum odour emission rates in the night and early morning. This research found similar emission rates to those previously reported in the literature and are summarised in Table 6.

Simons (2010) surveyed ten farms in Victoria to assess litter conditions and odour emissions, and selected four farms to trial odour control technologies. All sheds were tunnel ventilated, had evaporative cooling systems and had computerised ventilation systems. Odour emissions were measured at the end of the batch of birds (26-36 days) for a two year period. Two laboratories analysed the odour emissions and, although there was some discrepancy between some individual results, overall the results from both were within the expectations of the Australian Standard for olfactometry testing (*AS 4323.3-2001 Stationary Source Emissions Part 3: Determination of odour concentration* by dynamic olfactometry). Laboratory 1 data for odour and emissions ranged from 0.4– 3.5 million ou.m^3/min for 98% of the measurements (excluding outliers). Laboratory 2 reported odour emission results ranging from 0.5 – 3.7 million ou.m^3/min for 97% of the measurements (excluding outliers). The overall mean odour emission rate was 1,700,000 ou.m^3/min (400,000 -3,500,000 ou.m^3/min) or 730 ou.m^3/sec/1,000 bird placed (146 – 2,053 ou.m^3/sec/1,000 bird placed). The study correlated factors influencing shed odour emissions from litter including ventilation rates, litter type, shed ammonia levels, age of birds at testing, litter moisture, litter pH, bird stocking rate and temperature. Key observations included:

- Odour concentrations decreased with increasing shed ventilation rates.
- Odour emission rates increased with increasing shed ventilation rates.

- Litter conditions such as litter moisture and litter pH were not simple indicators of total odour emissions as measured by olfactometry.
- Ammonia concentration was a contributing factor to odour emission rates.
- Odour emission rate was a factor of increasing bird age.
- Farm identity and ambient weather conditions were contributing factors to odour emission rates.
- Whilst olfactometry provides a measure of the total odour emissions from a shed, it does not differentiate between the different odorants that are being produced by aerobic or anaerobic conditions.

Table 6. Odour emissions from meat chicken sheds in Australia

Reference	Location	Bird age (days)	Ventilation system	Density (birds/m²)	Litter management	Odonr emissions	
						(ou/s per 1,000 birds)	(ou/s/kg)
Dunlop *et al.* (2011)	VIC/Qld		tunnel		Single and partial rense	337-2939	0.53-2.12
Dunlop *et al.* (2010)	SE Qld		tunnel	18.4 (16–20.2)	Single and partial reuse	330-2960	0.19-2.12
Simons (2010)	Vic	26-36	tunnel	23-38	Single use	146-2053	0.08-1.15 and 0.16-1.32 *

*Two laboratories were used and produced slightly different results.

In 1998, Jiang and Sands (2000) measured odour concentrations inside natural and tunnel ventilated sheds of two New South Wales and two Victorian farms. Table 7 presents the results for farms with sheds for which ventilation rates were calculated. At Farm NA and NB, litter moisture and ammonia concentrations were also measured.

Table 7. Odour concentrations inside sheds and estimated emissions (adapted from Jiang and Sands 2000)

Farm	Location	Bird age (days)	Ventilation system	Density (birds/m²)	Litter management	Odour emissions	
						(ou/m³)	(on/s)
NA	NSW	24-44	natural	10.6	Single use	297 (72-997)	6071
NB	NSW	24-44	natural	10.3	Single use	409 (187-732)	7730
VB	Vic	41	cross flow	21.4	Single use	491	13027
VC	Vic	44-46	natural	21.4	Single use	418	12287
VD	Vic	42	tunnel	21.4	Single use	324	20781

Ammonia emissions from farms

High ammonia concentrations inside sheds are a health concern to birds and to farm workers. Numerous studies have reviewed or measured ammonia concentrations inside meat chicken houses with natural or tunnel ventilated systems (Jiang and Sands 2000, Redwine *et al.* 2002, Simons 2010, Walkden-Brown 2010). Walkden-Brown (2010) showed that ammonia concentrations inside meat chicken sheds were well below thresholds at which bird health is compromised. Based on this research, ammonia levels were not deemed a concern within the meat chicken sheds. However, few studies have measured ammonia emissions from meat chicken sheds. In terms of designing vegetative buffers for meat chicken farms, ammonia emissions could have a negative effect on the plant growth of certain tree species (Fangmeier *et al.* 1994). Ammonia emissions from meat chicken sheds reported by international studies range from 59 to 700 g/1,000 birds (Hayes *et al.* 2006, Robertson *et al.* 2002) but these systems were naturally ventilated via roof air vents and side vents.

Disease transfer between meat chicken farms

Diseases of most concern

Avian influenza

Avian influenza (AI) is a highly contagious viral infection in avian species, which is currently not in commercial flocks in Australia, although there have been some sporadic incursions which have been quickly eradicated. Clinical signs range from unapparent in infected waterfowl to a rapidly fatal condition characterised by gastrointestinal, respiratory and / or nervous signs in chickens and turkeys (Animal Health Australia 2011a). All AI viruses are members of the Orthomyxoviridae family and categorised into types A, B or C, of which only type A has been isolated in avian species. AI type A are further subdivided into subtypes determined by heamagglutinin (H) and neuraminidase (N) antigens. To date, 16 H subtypes and 9 N subtypes have been identified. Each virus has one subtype in any combination. Waterfowl are regarded as important reservoir hosts and disseminators of a variety of subtypes of AI viruses but rarely display clinical signs of infection. AI viruses can be found in ducks and geese but only a few virulent viruses produce clinical disease. Chickens, turkeys, guinea fowl, quails, pheasant and partridge are susceptible to infection and clinical disease (Animal Health Australia 2011a). In meat chickens, high pathogenicity AI (HPAI) due to H5 and H7 subtypes can cause clinical disease and subtypes of low pathogenicity (LPAI), including H5 and H7, are associated with severe clinical diseases in the presence of other infectious agents or if not controlled have changed into HPAI (Animal Health Australia 2011a).

Newcastle disease virus (ND)

Newcastle disease (ND) is a highly contagious, generalised viral disease of domestic meat chickens, cage and aviary birds, and wild birds. Clinical signs of ND virus infection vary and are classified according to four syndromes:

- velogenic
  - viscerotropic velogenic — high mortality; haemorrhagic enteritis is the predominant lesion.
  - neurotropic velogenic — high mortality; respiratory and nervous signs predominate;
- mesogenic - low mortality; respiratory signs usually predominate;
- lentogenic - mild, predominantly respiratory disease or subclinical infection; and
- avirulent - no noticeable clinical signs of infection.

Natural infection has also been reported in humans and rodents. ND infection in humans may cause headache and flu-like symptoms, which are usually mild and persist for one to two days. ND infection

in humans can also cause conjunctivitis, which can occasionally become severe. The incubation period is six to seven days. Most infections have occurred among laboratory workers who handle the virus or from workers in close contact with meat chickens (Animal Health Australia 2010).

After the eradication of outbreaks in 1930 and 1932 in Victoria, virulent ND was absent in Australia until the 1998 outbreak of Australian-origin ND in New South Wales. Avirulent strains are endemic in Australia and, since 1966, a variety of avirulent and lentogenic strains have emerged. A mutation of one of these led to the emergence of the virulent ND viruses in 1998 to 2002 in New South Wales and Victoria. Since then, it is important to classify new outbreaks as *Australian-origin* ND and *exotic* ND (Animal Health Australia 2010). "The expected high rates of morbidity and mortality and distinctive clinical signs usually seen with exotic ND outbreaks were often not seen in the Australian-origin outbreaks from 1998 to 2002. The most frequently seen clinical signs, singly or in combination, were depression, nervous signs such as ataxia, paralysis, abnormal posture (opisthotonus) and head nodding, increased mortality and changes to egg shell colour" (Animal Health Australia 2010).

Methods of disease transfer

Avian influenza

Contact with infected faeces or respiratory secretions is an important method of disease transfer, while airborne spread is not significant. AI virus can survive in faeces for at least 35 days at 4°C and survival in dust in meat chicken houses has been reported two weeks after depopulation. AI virus can survive within the meat chicken house environment for up to five weeks (Webster *et al.* 1978, cited in Animal Health Australia 2011a). Aerosols may have caused some secondary spread of AI in Australia during the New South Wales outbreak in 1997, but aerosols and windborne contamination have not been regarded as important in the spread of infection (Swayne & Suarez 2000 cited in Animal Health Australia 2011a). However, work in the USA has detected the virus in air samples, up to 45 m down-wind of infected flocks (Animal Health Australia 2011a).

Direct or indirect contact with waterfowl is the most likely source of infection in meat chicken flocks in Australia. Wild birds, especially waterfowl, are a potential pool of AI viruses, which replicate in the intestine, providing the opportunity for new combinations of H and N subtype viruses. Waterfowl and many other species of wild birds are innately resistant to disease from AI viruses but not from infection. Some exceptions to this was H5N1 subtype virus becoming pathogenic for waterbirds and domestic ducks in China (Sturm-Ramirez, cited in Animal Health Australia 2011a) and for crows in Japan (ProMED 2004a cited in Animal Health Australia 2011a). There is also evidence that bridge bird species who associate with infected waterfowl and meat chickens could also transfer AI to meat chickens (Chiu 2010).

All Australian outbreaks have been associated with obvious or circumstantial evidence of contact with waterfowl (Animal Health Australia 2011a). The transfer of AI from wild birds to meat chickens could occur from close contact with waterfowl (faeces or respiratory secretions) or from the use of untreated water infected with waterfowl faeces (Animal Health Australia 2011a). While movement of infected birds and transmission by personnel and fomites are regarded internationally as important mechanisms of transfer of HPAI between meat chicken flocks, limited movement of live commercial meat chickens outside of outbreak sitruations and controls on movement during outbreaks coupled with improved biosecurity measures have meant that infection of and spread between meat chicken flocks by these means is less important in Australia

In conclusion, AI can be transferred:

- by personnel and fomites contaminated with infected faeces or respiratory secretions
- between infected meat chickens by infected faeces or respiratory secretions, from infected waterfowl by either direct or indirect contact (untreated water contaminated with waterfowl faeces)

- potentially, from dust containing aerosols of AI (unlikely unless meat chicken farms are very close together).

In modern tunnel ventilated sheds, the risk of exposure to wild birds is unlikely and water sources in most Australian meat chicken farms are treated. In free-range production systems, the risk of exposure to wild birds is likely to be higher.

Newcastle disease

The transfer of virulent ND virus between flocks has been attributed to the following (in descending importance):

- movement of infected birds
- movement of feedstuffs, persomel and equipment into and out of premises
- movement of infected meat chicken products and by-products
- faecal virus contamination of clothing/footwear, equipment, litter, manure and feed (Utterbuck 1972, and Alexander 1988, 1997, 2000 cited in Animal Health Australia 2010).

Within a flock, the main methods of transmission are by the inhalation of virus-laden air, by ingestion of water or via feed contaminated with nasal secretions of faeces containing virus.

High levels of ND virus have been detected inside meat chicken sheds and 64 m away at night from infected flocks during an outbreak but not at 165 m. During the day, the survival of the virus was optimal at 70-80% humidity. Vaccination markedly reduced the excretion of the virulent virus (Hugh-Jones *et al.* 1973, cited in Animal Health Australia 2010).

In Australia, the windborne spread of ND by contaminated feathers, dander and other debris in litter is considered by Animal Health Australia to be a serious source of the virus (Animal Health Australia 2010). However, this risk should be reduced by the implementation of an ongoing vaccination program for ND throughout most sectors of the meat chicken industry in Australia, which aims to suppress precursor viruses of ND.

4. How VEBs Work

As stated previously, vegetative environmental buffers (VEBs) are a dense vegetative filter created by planting multiple-rows of suitable grasses shrubs and trees immediately down-wind of livestock buildings to promote the interception of particulates and odours from the fan exhaust plume (Parker *et al.* 2011). The term 'vegetative environmental buffers' was coined to distinguish standard shelterbelts /windbreaks from applications of vegetation specifically designed with an emphasis on air quality improvements (Malone 2004). VEBs are designed to foster good relations with neighbours, maximise environmental stewardship, support farm biosecurity and enhance the aesthetic value of properties. A buffer consisting of multiple rows of different species of trees and/or shrubs, that is properly installed and maintained, is able to achieve all of the objectives listed above and minimise the impact of any tree losses (Scott 2007). VEBs installed down-wind of exhaust fans usually consist of an inner row that is a waxy-leaf shrub or deciduous tree, designed to capture most of the dust emissions, plus row/s of deciduous trees for ammonia absorption and rows of evergreen trees that provide the height for a windbreak (Scott 2007).

VEBs can be designed to perform various functions including:

- filtering and dispersing meat chicken shed emissions over a larger area;
- improving visual amenity and public perceptions;
- intercepting nutrients leaching from the site;
- trapping ammonia and carbon dioxide emissions;
- possibly providing a biofilter for air-borne pathogens;
- providing shade and protection for buildings and free-range areas; and
- providing a windbreak to reduce backpressure on ventilation exhaust fans.

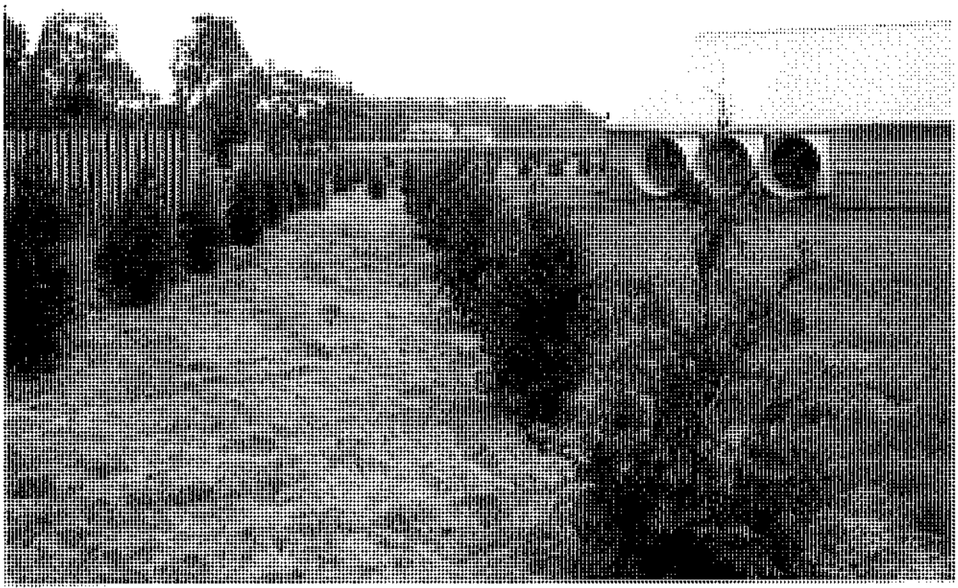
Depending on the purpose for planting the screen, the design and placement of the screen will vary. VEBs can be planted in different formations including:

- around the perimeter of the entire meat chicken farm to screen the facility from public view;
- strategically planted to provide a windbreak and shade; and
- in front of the exhaust fans of meat chicken sheds to trap particulates and reduce emissions down-wind of the fans by dispersing emissions over a larger area.

Photograph 3 shows an example VEB designed for a tunnel ventilated meat chicken farm in the USA.

The location, layout and configuration of a VEB is determined by two main design objectives. They are to:

1. disperse odours and other emissions; and
2. trap dust.



Photograph 3. VEB designed for tunnel ventilated meat-chicken shed in the USA (DPI 2011)

Using VEBs to disperse odours and other emissions

A VEB can work in a similar way to a windbreak or shelterbelt in its ability to disperse odours and other emissions. A windbreak is a barrier on the land surface that obstructs wind flow and alters flow patterns both up-wind of the barriers (windward) and down-wind of the barrier (leeward). As wind approaches a windbreak, some of the air passes through the barrier. The remaining air either flows around the ends of the barrier or is forced up and over the barrier and the streamlines of air are compressed. The upward alteration of wind flow begins some distance windward of the barrier and creates a region of reduced wind speed on the windward side of 2xH to 5xH, where H is the height of the barrier (Brandle *et al.* 2004). On the leeward side of a shelterbelt, there is a somewhat triangular 'quiet' zone (zone of low wind speed, providing maximum wind protection) that extends from the top of the shelter belt down to a distance of about 8xH. Above the quiet zone, the longitudinal turbulent fluctuations are more energetic and larger in scale (mixing zone). In terms of VEBs dispersing odours and other emissions, most of the dilution of the plume occurs in this zone. The dilution effect is caused by the mixing of the odour plume with 'higher-off-the-ground' layers of air but also from the slower release of odorous particulates and gases into airstreams that continue down-wind. Figure 3 shows a schematic representation of the process. Computer simulations have also suggested that this process results in the plume becoming more uniform and constant in concentration. Humans respond better to constant odours rather than fluctuating odours (Tyndall and Colletti 2007).

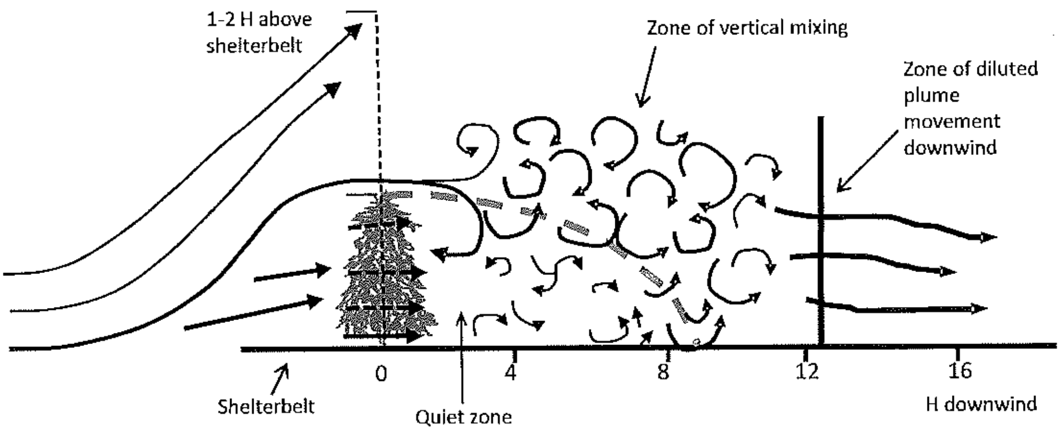


Figure 3. Schematic representation of turbulence and zone of potential odour dilution (adapted from Tyndall and Colletti 2007)

Using VEBs to trap dust

Tyndall and Colletti (2007) have summarised the literature regarding the ability of trees to filter particulates. Their conclusions were:

- There is a high correlation between leaf surface area and the quantity of dust that can be accumulated.
- Efficiency for capturing particles < PM_5 increases with leaf surface roughness. Leaf surface roughness increases with the presence of leaf hairs and pronounced veination.
- Smaller leaves are generally more efficient than larger leaves.
- Leaves with complex shapes and large circumference-to-area ratios (i.e. conifers) appear to be most effective.
- Conifers are generally more efficient in capturing particulates than broadleaf species.
- Non-laminar surfaces (petioles, stems, bark) also accumulate significant amounts of particulates in the PM_{10} range.
- The more irregular in shape the dust particles are, the greater the capture and retention on tree surfaces.

Plants also have the ability to absorb chemicals and pollutants. Aerosol chemicals can enter the plant via three pathways (Leuty 2001):

- gaseous diffusion through open stomata;
- if chemicals are soluble, they can enter the stomata in a dissolved form; or
- adsorbed onto and absorbed into plant tissues.

The rate of pollutant absorption is limited by stomatal resistance and the diffusability and solubility of the pollutants. Wet conditions increase the solubility of pollutants, increasing plant removal rates. Moisture stress and limitations on solar radiation act to limit stomatal openings and can significantly hinder uptake of pollutants. Bacteria, fungi and yeasts that reside on plants may also be able to break

down chemical pollutants. However, their effectiveness in degrading odorous VOCs is not known (Tyndall and Colletti 2007).

To date, most of the research has concentrated on VEBs absorbing ammonia emissions from meat chicken farms. High levels of ammonia can have a negative effect on plant health and some plants are more efficient at absorbing ammonia emissions (refer to Section 0).

5. Benefits of Using VEBs

Planting VEBs around meat chicken farms has many potential advantages including:

- improved relations with neighbours by providing an attractive visual screen;
- reducing amenity impacts by filtering dust, feathers, odour and noise from the meat chicken sheds;
- reducing backpressure on exhaust fans from high winds;
- capturing ammonia emissions;
- buffer for preventing surface and groundwater nutrients from leaving the proximity of the farm complex;
- promoting carbon sequestration;
- strategically planted to provide shade and a windbreaks for buildings and free-range areas; and
- potentially increasing farm biosecurity by filtering air-borne pathogens.

The majority of research attempting to quantify and promote the benefits of VEBs, shelterbelts and windbreaks on intensive livestock farms has been conducted in the USA. Although there are some differences between shed ventilation systems and climate conditions compared to Australia, most of the same design principles are still relevant.

Improving visual amenity and public perceptions

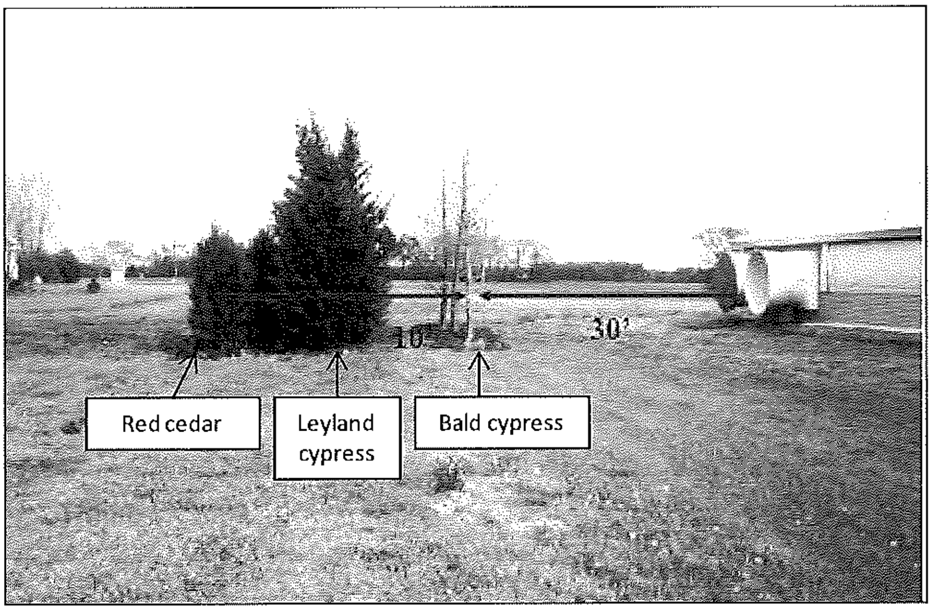
Planting trees around meat chicken farms may foster improved neighbour relations by filtering dust, odour and noise from sheds, providing a visual screen around the sheds and screening routine farm activities. It also promotes a good public image by being proactive in the management of meat chicken shed emissions via a 'green' initiative. The negative image of meat chicken farms by neighbours and the public is blocked by this visual screen and the 'out-of-sight-out-of-mind' concept may be a major benefit of a vegetative screen (Malone 2004). This is especially true for odour, as socio-psychological factors play a role in the perception of odour from livestock facilities as a nuisance (Tyndall and Colletti 2007).

Reduce dust and odour emissions

VEBs planted around intensive livestock facilities in the USA have been shown to incrementally mitigate odours, particulates and ammonia emissions. A decade of research into VEBs has refined their design and efficiency (Parker *et al.* 2011).

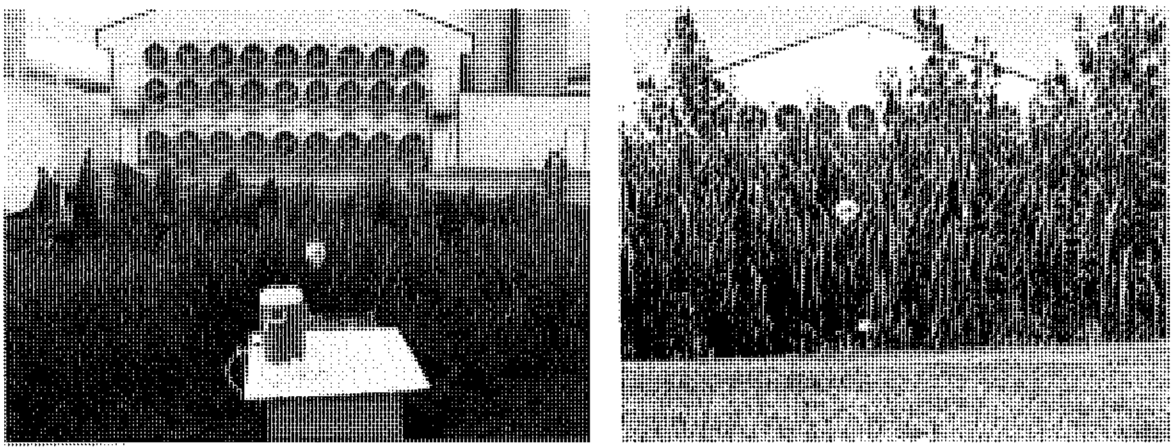
Studies conducted by the University of Delaware (Malone *et al.* 2008, Malone *et al.* 2006) have attempted to better define and assess VEBs planted around meat chicken farms. In 2002, this group planted a trial VEB featuring a triple row planting of 4.88 m tall bald cypress, 4.27 m tall Leyland cypress and 2.44 m tall eastern red cedar 9.15 m in front of two 48" tunnel cone fans (Photograph 4). Spacing was allowed for tree branches to touch. The inclusion of the bald cypress in the inner row was to act as a pre-filter to capture large particles and feathers and to slow airflow as the leaves drop in winter (when fans are less likely to be operating). The efficiency of the buffer was monitored for six years after establishment. After four years growth, dust and feather accumulation was greatest on the lower canopy of the Leyland cypress, which may affect tree health. Suggestions to overcome the problem included substituting the inner row with a deciduous tree with a denser lower canopy and planting the VEB a greater distance away from fans. Over the six years, the VEB reduced total dust,

ammonia and odour emissions by 56%, 54% and 26% respectively. The authors concluded that a properly designed VEB does disperse, capture, assimilate and/or dilute ammonia, dust and odour from fans but is most effective for dust and ammonia abatement rather than odour.

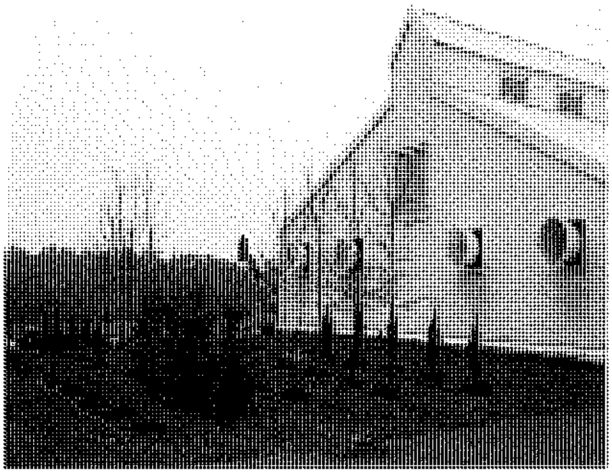


Photograph 4. Trial VEB for meat chicken farm (adapted from Malone *et al.* 2006)

Patterson *et al.* (2009) measured the efficiency of VEBs on odour emissions from a four-row VEB at a 250,000 hen layer house (Photograph 5) and a five-row in-pot VEB at a layer research facility (Photograph 6). A 34% reduction in odour emissions was reported for the four-row VEB and a 46% reduction for the five-row VEB.



Photograph 5. Four-row VEB for 250,000 hen commercial layer house (source: Patterson 2009)



Photograph 6. Five-row in-pot VEB for layer research facility (source: Patterson 2009)

The University of Missouri Centre for Agroforestry hashas trialled the effect of a three-row VEB, at a piggery, on odour emissions (Lin *et al.* 2009). The VEB consisted of a conifer on the inside row closest to the farrowing house (pitch-loblolly pine -*Pinus rigida*×*P. Taeda*); a middle row of alternating deciduous hardwood species red maple (*Acer rubrum*) and pin oak (*Quercus palustris*); and an outside row of a semi-evergreen shrub that quickly reaches heights of 10 to 15 feet (Viburnum 'Allegheny' - *Viburnum rhytidophyllum* X V. lantana).

Parker *et al.* (2011) measured the effect of a five-row VEB for reducing down-wind odour and volatile organic compounds (VOCs) on a commercial tunnel ventilated pig grow-out unit in Missouri. Figure 4 shows the cross section of the VEB. The VEB consisted of 2 m tall hybrid willows closest to the exhaust fans, followed by two rows of 2.4–3.6 m tall eastern red cedars, one row of shrubs (viburnum) and an outer row of 2.4–3.6 m tall eastern red cedars. Pampas grass was planted opposite the fans and native grass was allowed to grow between the fans and the VEB. A deflector above the exhaust fan was used to deflect the exhaust plume into the maximum amount of vegetative density at the base of the VEB (Photograph 7 and Photograph 8). The VEB reduced odour concentrations (as measured as Dilutions-to-Threshold, D/T) by 49% in the VEB and by 66% 15 m down-wind from the VEB. There was also a larger percentage of non-detect odour concentrations (D/T<2) at 15 m down-wind for the VEB site (58%) compared to the control site (16%). Mean odour concentrations 300 m down-wind of the VEB were 2.3 D/T for the control and 2.5 D/T for the VEB site. Wind tunnel fluxes from the VEB vegetation samples after rinsing were 78 to 98% lower, showing that particulate matter captured on vegetation reduces odour emissions. The authors concluded that VEBs reduce down-wind odour by increasing odour dilution and capturing odorous particulate matter in the vegetation.

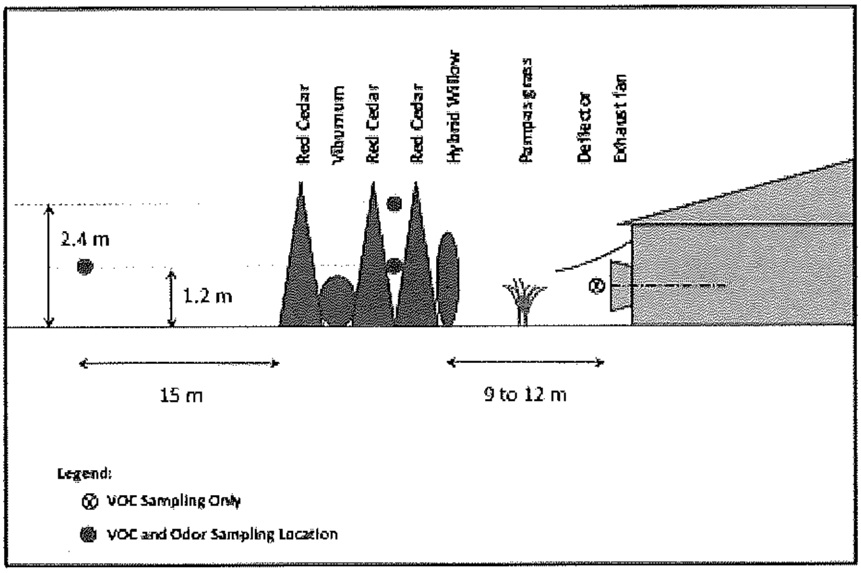
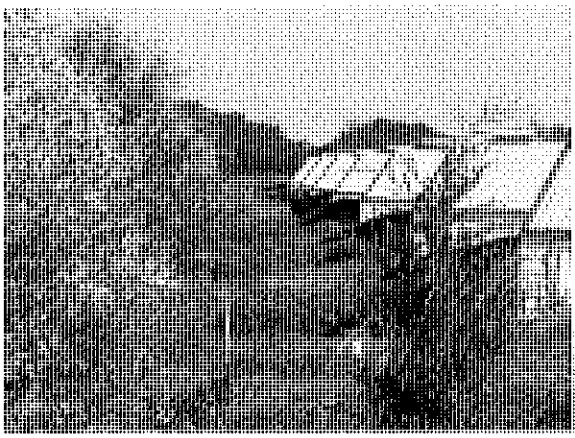


Figure 4. Cross-section schematic of 5-row VEB for a swine grow-out unit (Parker *et al.* 2011)

Photograph 7. VEB for tunnel ventilated swine finisher barns in Missouri during its first year of growth (Parker *et al.* 2011)



Photograph 8. VEB for tunnel ventilated swine finisher barns in Missouri during its second year of growth (Parker *et al.* 2011)

Xing (2006) conducted experiments to measure the effectiveness of windbreaks on odour dispersion. Odour was generated from pig manure and the windbreaks tested consisted of single row planting of either established deciduous trees or conifers. The coniferous windbreak was more effective than the deciduous trees as the conifer windbreak was denser (lower optical porosity). Odour dispersion improved when the odour source was located 15 m upwind from windbreak, rather than 60 m. Odours were dispersed over a shorter distance when temperatures were above 15°C, which was attributed to added convective effects. Wind speed had a limited effect on the size and hedonic tone of the odour plume. Wind direction perpendicular to the windbreak reduced the size of the odour plume but not the trapping of odours on the leeward side of the windbreak.

The most important dynamics identified by the Tyndall (2008) review of literature for VEBs in reducing odour emissions are:

- Enhancement of vertical atmospheric mixing through forced mechanical turbulence, leading to enhanced dilution/dispersion of odour.
- Odour filtration through particulate interception and retention – odour largely travels by the way of particulates so capturing particulates also captures odours.
- Particulate/odour fallout due to gravitational forces enhanced by reduced wind speed.
- Adsorption and absorption of ammonia onto and into the plant due the chemical affinity ammonia has to the waxy coating on leaves.
- Softening socio-psychological responses to odour emission due to improved site aesthetics and creating "out of sight, out of mind" dynamics.
- Improved producer/community relations by instigating a highly visible odour management technology.

Figure 5, adapted from Tyndall (2008), visualises these dynamic processes.

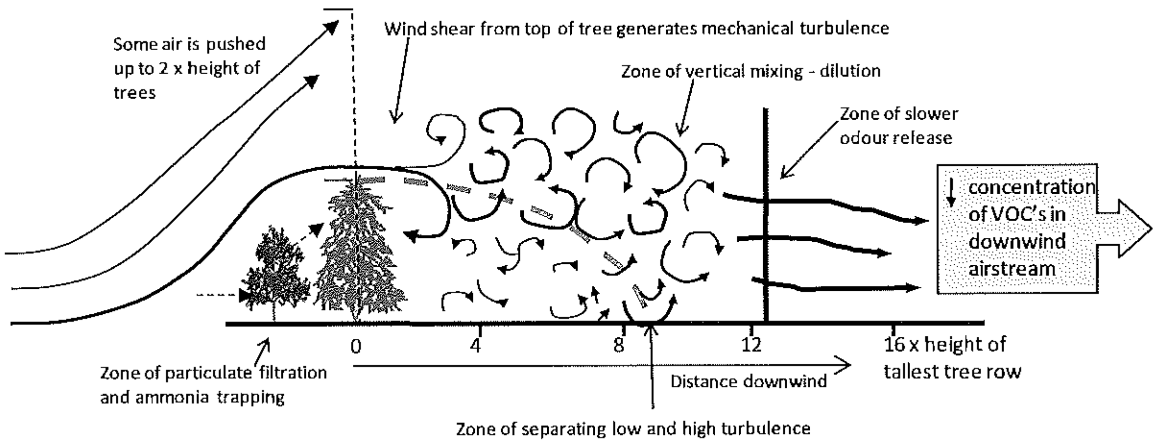


Figure 5. Important dynamics for VEBs in reducing odour emissions (adapted from Tyndall 2008)

Additional benefits

Reduction in pathogen/disease transfer

There is little literature available on the effectiveness of vegetative buffers in reducing the risk of pathogen and disease transfer between meat chicken farms and the environment. The available literature on pathogen emissions from meat chicken farms in Australia suggests that there is a correlation between the levels of some pathogens in the litter, the concentration in aerosols inside the shed and aerosols in the external environment. This suggests that some indicator pathogens (i.e. *E. coli*, *Salmonella* and *Staphylococcus spp*) can survive in the air (as dust) and be transported over a short distance (Blackall *et al.* 2010). Hence, it is a reasonable assumption that vegetative filters may be able to reduce pathogen loads in the air, as they are effective in capturing dust particulates. However, levels recorded in the external environment are low and do not appear to be of great concern for human or animal health (Blackall *et al.* 2010).

Although both avian influenza and Newcastle Disease (ND) are currently not an issue in Australia, the windborne spread of ND by contaminated feathers, dander and other debris in litter is considered by Animal Health Australia as a serious source of the virus (Animal Health Australia 2010). As VEBs are designed to capture dust emissions, and pathogens can be transferred by dust particles (refer to Section 0), theoretically VEBs may reduce the spread of pathogens and disease off-site. Research would be needed to verify this speculation.

A recent USA study (Burley *et al.* 2011)attempted to measure the potential of vegetative buffers to reduce the transfer of Newcastle disease virus (La Sota strain) and infectious bronchitis virus (Mass-Conn strains). This was done by placing seven-week old pathogen-free chickens in coops down-wind of meat chicken sheds with vegetation buffers planted between 50% meat chicken sheds and coops (VEB). There was no significant difference in dust accumulation between coops with VEB and control coops and neither virus was detected from the dust collection filters placed in the vegetation buffers. No differences in virus spread was detected between birds in coops under VEB and Control treatments, but levels of infectious virus-positive serum were significantly greater in birds from Control treatments than VEB.

Nutrient filter

As modern conventional sheds are sealed buildings with concrete or compacted earthen floors and concrete walls, there is a low risk of nutrients from manure accumulating in the soil around the sheds. Spent litter is generally not stockpiled on-farm but is loaded straight into trucks from the shed during end of batch cleanout. The main possible leakage of nutrients from the sheds to the environment is nitrogen contained in the dust, which includes dead skin cells and feathers, which are high in protein and ammonia emissions. No literature is currently available on the concentration of nutrients contained in dust from meat chicken sheds, but it is unlikely to be a substantial source. VEBs are effective at removing soil nutrients (Malone and Abbott-Donnelly 2001) and VEBs on meat chicken farms have a role to play in preventing dust-borne and ammonia nutrients from moving off-site. This is especially true for free-range farms, as some manure is deposited in the range area and nutrients may accumulate in the soil. This has been shown to be the case for free-range egg farms in south east Queensland (Wiedemann and Zadow 2010a, Wiedemann and Zadow 2010b), where high concentrations of nutrients could be found in those areas of the free-range area where the birds frequented most (close to the sheds and under shade trees).

It is expected that in some situations, appropriately selected VEBs could absorb some of the nutrients from manure deposited on the range and lost from the range by leaching and run-off

Greenhouse gas capture

Plants have the ability to assimilate carbon dioxide and ammonia. Therefore, VEBs have the potential to capture these emissions and potentially reduce emissions or sequester carbon. Vegetative buffers

have been shown to be successful in capturing and reducing ammonia emissions from layer houses (Adrizal *et al.* 2008, Patterson *et al.* 2008a, Patterson *et al.* 2006b, Patterson *et al.* 2008b). Some tree species including Spike hybrid poplar (*Populus deltoids* x *Populus nigra*), hybrid willow (*Salix matsudana* x *Salix alba*) and Streamco purpleosier willow (*Salix purpurea*), have been found to be better at absorbing ammonia from meat chicken sheds than others, , whereas Norway spruce (*Picea abies*) and hybrid willow (*Salix matsudana* x *Salix alba*) were determined to be ideal species for trapping dust (Adrizal *et al.* 2008). In a earlier study (Patterson *et al.* 2006a), the tolerance of plant species (cedar, locust, poplar, grass, spruce, arborvitae and willow) to continuous absorb anhydrous ammonia emissions at 4-8 ppm was measured in a controlled chamber to replicate exposure of plants to emissions from meat chicken farms. They found that all plant species exposed to ammonia had greater leaf dry matter and assimilated nitrogen in the plant's foliage. However, all plant species, with the exception of honey locust, had negative effects on foliar condition from exposure to ammonia.

Noise reduction

Research literature and guidelines from the USA on VEBs have quoted that trees can absorb and diffuse noises resulting in sound levels one-half the original volume (Belt *et al.* 2007, Malone and Abbott-Donnelly 2004). To date, most of the research on the effectiveness of VEBs has focused on dust, odour and ammonia emissions rather than noise so there is no measured data on the reduction of noise due to VEBs. Work is needed in this area, as noise is an issue in planning applications for new meat chicken farms.

6. Potential Negative Impacts of VEBs

No literature is available on the potential negative impacts of VEBs. However, a few potential issues can be gleaned from the reviewed literature.

Increased incidence of wild birds

Trees can attract wild birds, which may increase the risk of disease transfer to meat chickens. The diseases of most concern are Newcastle disease (ND) and avian influenza (AI), both of which are currently not an issue in Australia. The transfer of AI from wild birds to meat chickens could occur from close contact with waterfowl (faeces or respiratory secretions) or from the use of untreated water infected with waterfowl faeces (Animal Health Australia 2011a). The transfer of ND is most likely from the movement of infected birds or objects, rather than from wild birds (refer to Section 0). In conventional production systems, the risk of disease transfer from wild birds is low, assuming that water sources are treated, wild birds have no access to the birds inside the sheds, and strict staff biosecurity measures should be in place. The risk of direct or indirect contact with wild birds is higher in free-range systems as the birds have the opportunity to associate with wild birds and their faeces in the range area. The selection of plant species in a VEB that are less likely to attract wild birds (e.g. no fruit, seedpods, open perching branches), and the careful siting of VEBs near free-range areas should reduce the risk of contact with wild birds (refer to Section 0).

Cost of establishment and maintenance

Several studies in the USA have attempted to cost the establishment of VEBs (Scott 2007, Tyndall 2008). There are currently no figures available for the cost of establishing VEBs on Australian meat chicken farms. The cost of establishing a VEB will be site dependent on many factors including:

- design of the VEB required (i.e. length of VEB and number of rows);
- species selected and the type of stock selected (i.e. seedling, potted plant, bare root stock, balled-and-burlapped stock); and
- site preparation required including weed kill, irrigation system, earthworks and cultivation, mulching/weed mat.

There will also be ongoing costs to maintain the VEB to ensure it remains effective. This could include:

- on-going irrigation costs during the establishment period and possibly for the lifetime of the VEB. VEBs planted near exhaust fans may need continual irrigation as they will constantly receive wind form the exhaust fans and will dry out;
- replacing plants that die and replacing fast growing plants at the end of their lifetime;
- weed management between rows or around the VEB; and
- pest and disease management.

Restriction of access to infrastructure

If VEBs are not designed properly, they could impede access to the sheds for machinery and maintenance. The planning process also needs to consider access roads, power lines and potential new developments (refer to Section **Error! Reference source not found.**).

Increased fire risk

Another consideration in Australia's hot and dry environment is the potential risk of fire from planting trees close to buildings. Some species of plants are highly flammable and others are fire retardant. Fire retardant trees actually slow down the spread of fire and protect buildings when planted as a buffer by acting as a heat shield, deflecting fire winds, denying the extra oxygen that can supercharge a fire and trapping the burning embers causing them to die harmlessly (Small Tree Farm 2010). Some general attributes of plants that make them flammable or fire retardant are listed below and a general guide to species that are fire retardant and highly flammable is provide in Figure 6 (Small Tree Farm 2010):

Flammable

- high volatile oil content
- drought stressed
- dead wood or twiggy material
- heavy litter fall
- open-work canopies of hanging foliage which encourages updraughts during fire
- fine leaves which ignite easily and burn fast and intensely.

Fire Retardant

- foliage has a high salt and moisture content.
- soft leaves
- low volatile oil content
- smooth and non-peeling bark
- high leaf density creating a cool humid zone

Some species of plants that fall into the worst (accelerant) category are plant species that have been demonstrated to be effective at capturing particulates in VEBs, namely conifers (see Section 0). It may not be possible to avoid using these species in a VEB but it is maybe worth considering that all other species in the VEB are fire retardant to decrease the risk.

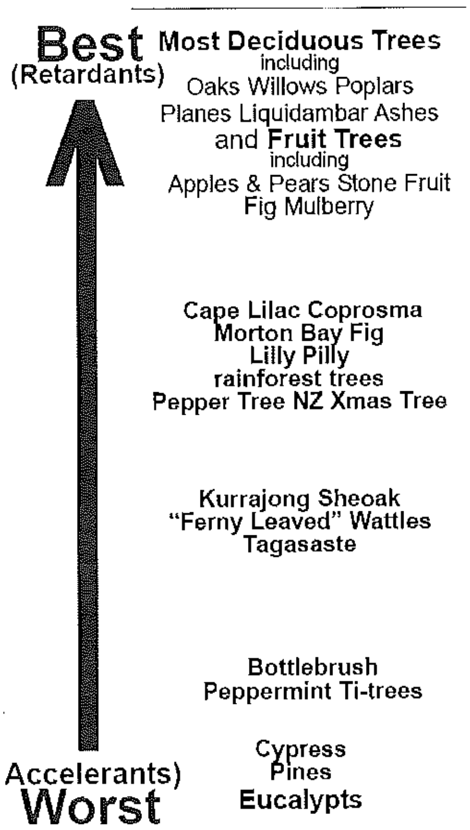


Figure 6. Scale of fire risk for Australian trees (Small Tree Farm 2010)

7. Designing 'Fit for Purpose' VEBs

Each meat chicken farm will have different reasons for planting VEBs. Some farms may need more visual screening from nearby receptors or public roads to promote good public relations if the surrounding topography or existing vegetation is not adequate. On other farms, dust, odour or noise emissions may be of more concern. A full assessment of the farm is essential when planning a vegetative screen. Scott (2007) provides the following check list of questions:

- What specific purposes must the vegetative screen satisfy?
- How are the sheds oriented on the property? Consider location of exhaust fans, distance to property boundaries, feed silos, fuel tanks.
- Where are the prevailing winds? Prevailing winds affect the transmission of emissions and are seasonal in nature.
- Are there any boundary concerns, company restrictions or utility issues that might impact or limit screen planting?
- What are the soil conditions in the planting area?
- Are there any drainage issue or areas that tend to flood in the proposed planting area?
- Are there plans for expanding the meat chicken farm?
- Are there existing trees or other features that can be incorporated into the plan?
- How will the vegetative screen impact on access to the meat chicken farm and to all buildings, equipment etc.

The ideal time to plan and install VEBs is before the construction of meat chicken sheds. This allows the arrangement of screen plantings for maximum benefit, making it an integral part of the operation rather than an afterthought (Scott 2007). Some sites require considerable cut and fill to create a level building pad. In these cases, there may be earth batters (cut or fill) where the VEB is planned. A suitable flat area for the VEB needs to be provided. Furthermore, extensive earthworks may expose sub-soil unsuitable for planting VEB species. Selective stripping and replacement of topsoil may be part of the VEB design.

For tunnel ventilated sheds in the USA, Malone and Abbott-Donnelly (2004) recommend planting VEBs around the perimeter of the meat chicken farm and additional screens at i) exhaust end of the sheds for improved emission scrubbing, and ii) air inlet end of the sheds to provide a cooling effect of the air and soil in summer.

For naturally ventilated sheds, Malone and Abbott-Donnelly (2004) recommend planting vegetative buffers that intercept prevailing winds and provide shed roof shade.

Screen height, width and permeability

As the function of VEBs is to filter and disperse shed emissions over a larger area, rather than act as a windbreak for prevailing winds, some of the design features applicable for windbreaks do not apply. However, most of the theory behind designing windbreaks is still applicable to VEBs. The effectiveness of a windbreak is determined by its external structure (height, length, orientation, continuity, width and cross-sectional shape) and internal structure (function of amount and distribution

of the solid and open proportions i.e. porosity, the vegetative surface area, and the shape of individual plant elements) (Brandle *et al.* 2004).

Screen length

For windbreaks, the length of the windbreak should be ten times the height to reduce the effect of wind flow around the windbreak (Brandle *et al.* 2004). However, for VEBs, the width needs to be adequate to intercept the exhaust plume i.e. at least as wide as the shed ventilation fans. Odour plumes are initially at least as wide as the source and may expand with distance down-wind from the source depending on weather and landscape conditions (Tyndall and Colletti 2007).

Orientation

Windbreaks are most efficient if perpendicular to problem winds (Brandle *et al.* 2004), or in the case of VEBs for scrubbing exhaust emissions, perpendicular to the fan ends of the meat chicken sheds.

Continuity

A gap or opening in a windbreak concentrates wind flow through the gap and creates a zone leeward of the gap that exceeds open field wind velocities (Brandle *et al.* 2004). Hence, for a VEB to be effective there should be no gaps in any of the rows in the VEB and each row should have species that are the same height. Multiple rows provide back-up if some tress die and provision for regular replanting should be made.

Depth

The depth of the vegetative screen influences its efficiency to trap particulates and to act as a barrier to force wind upward over the screen. Multiple rows of grasses, trees and/or shrubs of different species are recommended to provide the optimum density and porosity to achieve all of the objectives of VEBs (Belt *et al.* 2007, Scott 2007).

Density

Density for individual plant species is defined as the amount of space that is occupied by foliage, twigs, branches, and can be estimated by the amount of light that can be seen through the plant. Low density = 25-35% of space is occupied by plant material, medium density (65-75%), high density 60-80%, very high (+80%). The overall density of a VEB will be determined the species selected, the number of rows and the in-row and inter-row spacings between plants (NRCS 2007).

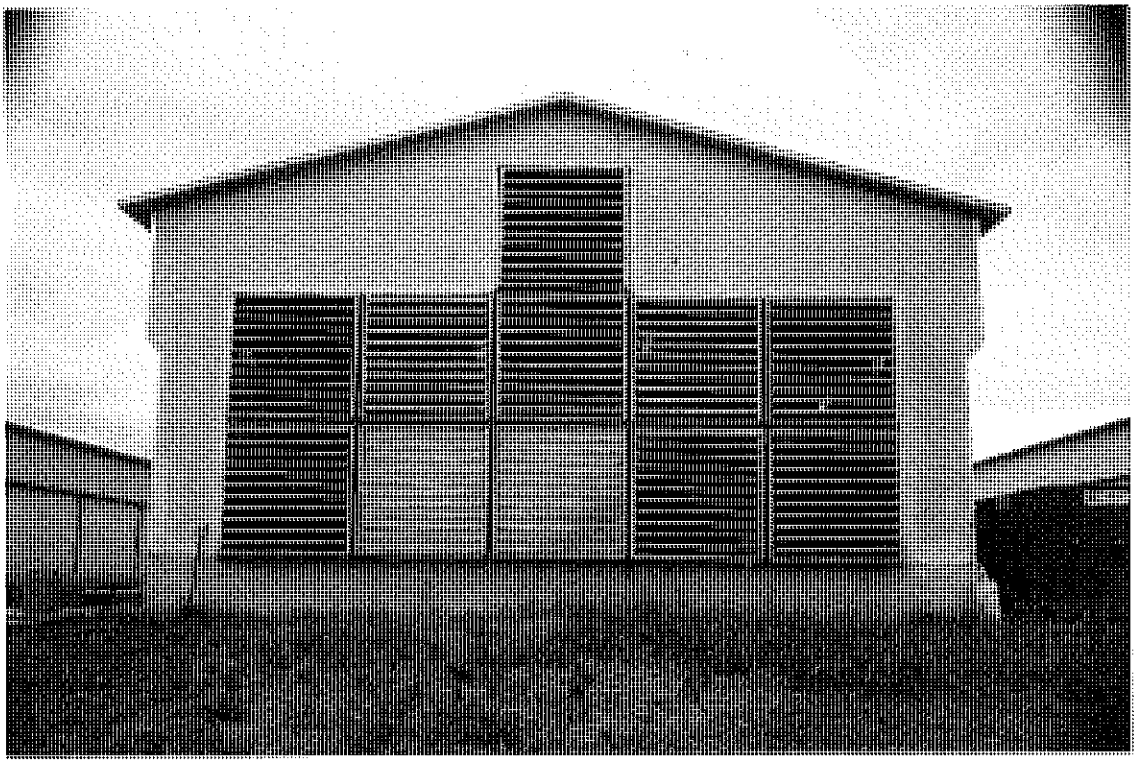
Porosity

To capture particulates, there needs to be adequate airflow through a vegetative screen to provide an opportunity for particulates to make contact with the surface of the trees and create instances of internal turbulence. This needs to be balanced with density of the vegetative screen as sufficient density is required to promote contact with particulates but a screen that is too dense will push most of the air flow over the screen and thus limit the opportunity for capturing particulates (Tyndall and Colletti 2007).

Screen height

The vegetative screen needs to intercept the exhaust plume from the shed if it is to be effective. As odour plumes have the tendency to travel along the ground with limited rising and mixing, even a small screen (5—10 m) may provide adequate plume interception (Tyndall and Colletti 2007). The screen height should be higher than the highest exhaust fan on the meat chicken shed. This is particularly true for sheds with multiple fans that switch on in a sequence aimed at maximising fan

life. Photograph 9 shows a circumstance where there are multiple fans and the VEB would be planted on a downsloping batter. In this case, a high VEB is required to intercept dust from the highest fan.



Photograph 9. Multiple fans with a downsloping batter away from the shed

Shed fan efficiency

Planting VEBs around exhaust fans protects them from prevailing winds, decreasing the backpressure on the fans and increases their efficiency (Malone 2004).

To maximise particulate capture when planting a VEB in front of the exhaust fans of tunnel ventilated sheds, the tree lines should be as close to the fans as possible (Malone and Abbott-Donnelly 2004). However, vegetative buffers must not be too close or they may impede ventilation intakes or restrict access for maintenance (Tyndall and Colletti 2007). The recommended minimum distance from the fans to the VEB to not impede ventilation rates is about ten times the fan diameter (Malone *et al.* 2008, Malone *et al.* 2006). This distance has been revised up from earlier recommendations of five times the fan diameter (Malone and Abbott-Donnelly 2004). In situations where multiple fans are used in one location, this planting distance formula will need to be modified to increase the distance from the nearest row of the VEB to the shed (Belt *et al.* 2007). The definition of 'multiple' fans and the required modification of the planting distance formula is not detailed in the literature. All meat chicken sheds have 'multiple' fans so it is not certain as to whether the author is referring to multiple rows of fans, or multiple fans in a row.

The distance required to prevent fan backpressure is not the only consideration when determining the required distance from the fans to the first row of the VEB. Belt *et al.* (2007) recommends that VEBs should be placed a minimum of about 25 m from the fans to prevent plants being desiccated at high wind speeds.

Example screen designs from the USA

VEBs for exhaust fan scrubbing (tunnel ventilated sheds)

Figure 7 shows the typical design features of a VEB in the USA. The design is broken into two zones. The first zone (Zone 1) is the area that receives the direct impact from the exhaust fans. Odour, ammonia, dust and feather loads predominate in this zone. The combination of harsh growing conditions caused by these issues and the drying effect of forced air makes appropriate plant selection very important. The second zone (Zone 2) is the area in the vegetative screen planting not associated with the fans. There are fewer environmental or plant viability concerns in this zone so essentially plants are selected to create a simple windbreak or visual screen (Scott 2007).

Several key design features of effective VEBs for exhaust fan scrubbing can be drawn from the literature from work done in the USA (Belt *et al.* 2007, Malone 2004, Malone and Van Wicklen 2001, Malone *et al.* 2008, Malone *et al.* 2006, Scott 2007):

- To prevent the vegetative screen affecting shed ventilation, buffers should not be planted any closer than about ten times the fan diameter from the exhaust fan end of the shed. This usually corresponds to approximately 15 m. This distance may need to be increased if multiple fans are used. Further research is needed to accurately determine this setback distance.
- The VEB should consist of several rows of different trees, which provide different functions. This also reduces the risk of the entire screen being affected by pests, disease, drought etc.
- Where site conditions allow, VEBs should be planted around the entire perimeter of the emission source. Curved plantings (e.g. Photograph 3), are easier to cultivate and provide a more pleasing appearance than plantings with square corners.
- The number of rows in a VEB will depend on available space and species used. Three or more rows of deciduous and evergreen species are recommended. Additional rows may be required near tunnel ventilation fans as these plants will endure higher levels of stress and plant deaths will be more frequent.
- Selecting the right species for a situation and following up with proper care is more important than the number of rows in a VEB.
- For Zone 1 (fan impact area), a minimum of three rows is recommended, staggered with a preferred arrangement from the nearest to the fans outwards of Row A = waxy-leaf shrub or deciduous tree, Row B = deciduous tree (for ammonia and carbon absorption), Row C = evergreen tree (Figure 7). If space is a limiting factor, a row of deciduous trees closest to the fans and an evergreen tree on the outside is recommended.
- The use of rows of deciduous trees, rather than evergreens, needs careful thought. Deciduous trees are often used in the USA where fans do not operate during winter. On Australian sites where fans operate throughout the year, deciduous trees may not be an option as the effectiveness of the VEB is decreased once they have shed their leaves.
- The inner row (row closest to the exhaust fans) should be either deciduous trees with a dense canopy or evergreens with waxy leaves. This row captures most of the dust emitted from the shed, which over time builds up on the trees foliage affecting their health. These trees tend to withstand high particulate loads best. The deciduous trees drop their leaves in winter whereas the waxy coating on the leaves of evergreens allows the dust to wash off the leaves when it rains.
- Zone 2 (screen areas) recommended planting of two rows, staggered planting of evergreen trees or a combination of windbreak type trees. The density of planting should correspond with prevailing

winds. To intercept winter-dominant prevailing winds, use a tighter tree density and for summer-dominant winds, a looser density or combination planting.

- Belt (2007) recommends that deciduous shrubs are planted in the perimeter rows, followed by deciduous trees towards the middle or along the down-wind side where they will grow more efficiently. As noted previously, this recommendation may not be appropriate for all Australian locations.
- Evergreens provide year-round visual screening and particulate trapping, but can become overloaded with particulates if planted too close to ventilation fans. Thick coatings of particulates on evergreens can result in early mortalities. The exception to this rule is evergreens with a thick waxy coating to allow dust to be washed off the leaves.
- Leaves with a complex shape (e.g. conifers) appear to be the most effective for capturing particulates.
- The windward side should contain evergreen species that maintain lower branches close to the ground or you may need to interplant with evergreen shrubs to compensate for the opening.
- Spacing between tree rows and between adjacent trees in a row will be determined by tree species, objectives of the planting, farm situation and if mowing between rows, the width of mowing equipment.
- In some situations, it may be desirable to make plantings over multiple years, plant trees with different longevities and in some cases thin trees as they mature.
- The Malone research group from Delaware University have moved towards planting grass strips close to the exhaust fans, namely switch grass which grows tall, as they have found the grass to be hardier in tolerating the dust emissions and dry conditions created by the wind from the fans. Photograph 7, Photograph 8 and Photograph 5 provide examples.

The spacing between plants within the same row will depend on the size of the plants. Faster growing plants need a greater space between them than slower growing plants. The spacing should result in promoting quick vertical growth to shade out weed competition and reduce the time it takes for a vegetative screen to become functional. Spacing between rows will depend on available moisture, the species planted and the width of implements used for cultivation or maintenance. If rows are planted too close together, there will be severe competition for moisture and nutrients and faster growing trees will overtop other species. For example, deciduous trees are generally faster growing than evergreen trees. If maintenance machinery cannot gain access between the rows the buffer could fall into disrepair (Belt *et al.* 2007). However, VEBs designed for research by Bud Malone's group at Delaware University have chosen between-row spacings that allow the branches between each row touch. (Belt (2007) recommends a spacing of 5-6 m and larger spacing for drier conditions. The distance between shrubs and tree rows does not have to be as great.

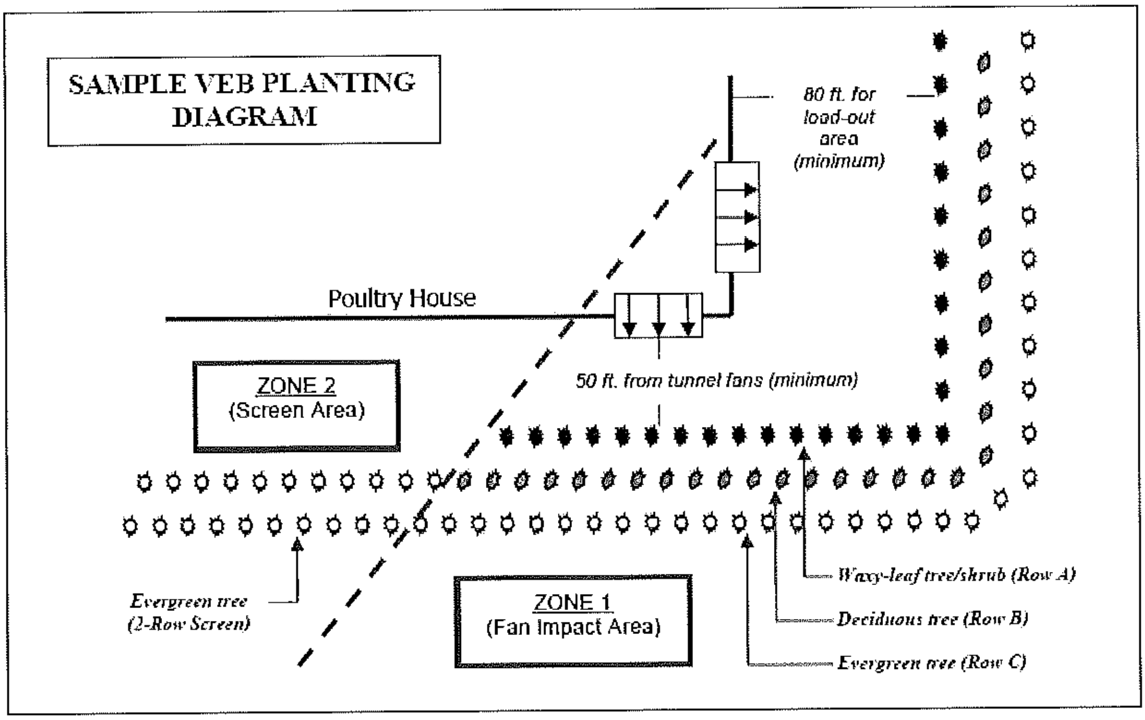


Figure 7. Example VEB planting arrangement for a tunnel ventilated meat chicken shed in the USA (Scott 2007)

Scott (2007) provides a general guide for the spacing of in-row and inter-row trees in a VEB (Table 8). Wider spaces are suggested for double, staggered rows to allow for more surface area to collect and capture particulate matter and narrow plantings for high-density single rows.

Table 8. Suggested in-row and inter-row spacings of trees in a VEB (Scott 2007)

Tree/shrub type	In-row spacing	Inter-row spacing
Evergreens – Pine/Spruce	2.44 – 4.27 m	
Evergreens – all others	1.83 – 3.05 m	
Shrubs - suckering	0.91 – 3.05 m	3.05 – 6.10 m
Shrubs – non-suckering	0.91 – 1.22 m	
Deciduous trees - small	1.52 – 2.44 m	
Deciduous trees - large	2.44 – 4.27 m	

Note: measurements have been converted from feet to metres.

VEBs for naturally ventilated sheds

A different approach needs to taken for designing VEBs for naturally ventilated sheds. Malone and Abbott-Donnelly (2004) recommend planting VEBs that intercept prevailing winds and provide shed roof shade. As the prevailing wind may be from different directions during different seasons (i.e. winter and summer), these VEBs may need to be different in orientation and configuration. For screens intercepting prevailing winds during winter, dense trees are recommended, whereas for summer tall evergreens and/or deciduous trees with no lower limbs are recommended. These promote roof shading while maintaining adequate air flow through the screen for ventilating the sheds (Malone and Abbott-Donnelly 2004).

When planting trees as a windbreak, a progression of smaller shrubs and trees on the outer rows of trees facing the prevailing wind will create a 'ramp' to the taller evergreen trees for the best 'wind-lifting effect' (Malone and Abbott-Donnelly 2004).

Ideal tree characteristics

The ideal characteristics for trees in the vegetative screen will depend on the main purpose of the vegetative screen i.e. whether it is for a visual screen, vegetative filter for emissions, windbreak/shade, or all three. Some generally desirable features for suitable trees are summarised below (Malone and Abbott-Donnelly 2004, Scott 2007):

- ***Maximum vegetative density, especially in the lower canopy.*** The density of the leaf canopy governs the filtering ability of a tree or shrub. This is most critical at lower levels to intercept wind and emission plumes which travel along the ground. Plant species with a loose branched arrangement or have a tendency towards a higher crown may need to be inter-planted with dense evergreen shrubs to compensate these deficiencies.

- ***Ability to retain lower branches.*** Some trees tend to drop their lower branches and, if included in a vegetative screen, will need to be compensated by understorey shrubs to supply the lower vegetation as the trees mature.

- ***Complex leaf shapes and waxy or hairy leaves*** for efficient particulate filtering ability. Complex leaf structures which provide a greater surface area to collect and filter particulates. Waxy leaves reduce the burden of dust building up on the leaves by allowing rain to wash it off.

- ***Wind tolerance.*** The tree species selected need to be able to withstand wind and not be prone to breaking. Other species cannot endure the drying effects of wind or the drying effect of forced air from exhaust fans.

- ***Stable root system.*** Tap roots or deep roots are required to withstand prevailing winds and drought stress. Shallow-rooted trees that have a tendency to fall in high winds should be avoided.

- ***Nutrient tolerance.*** The requirement for nutrient tolerance will depend on where the vegetative screen is planted. Trees planted close to exhaust fans or close to shed sides for naturally ventilated sheds will need to be tolerant of ammonia emissions and nitrogen deposition from the nitrogen contained in dust particles.

- ***Require low care and maintenance***

- ***Fast to medium growth rates.*** The plant species selected need to create an effective buffer in a reasonable period of time. Slower growing plants need to be balanced with faster growing plant to reduce the delaying in establishing a functional screen.

- ***Avoid trees that that fruit or have seeds attractive to wild birds*** to reduce the risk of disease transfer. Some species have non-fruiting varieties or separate male plants which could be used instead.

Establishment and maintenance of VEBs

Site preparation

Good site preparation is recommended, including preparation of the ground, selection of suitable species and early weed control as weeds compete for nutrients and water (Miller 2007). Individual tree shelters may be required for more delicate seedlings until they are established to protect them from the wind (Malone and Abbott-Donnelly 2004).

Ground preparation techniques include ripping, cultivation, weed control and moisture storage. Good weed control is particularly important for establishment success (i.e. first two years). Weed control practices include spraying herbicide between rows of trees, mulching around trees, mowing, cultivation or a combination of these methods (Miller 2007, Scott 2007). Weed mats along the entire row have also been used. This method would significantly reduce weed control measures during establishment of the VEB.

For most regions in Australia, a drip irrigation system would be required to provide sufficient water for establishment and for periods of prolonged drought. VEBs planted to intercept emissions from exhaust fans are also subject to drying winds and irrigation is strongly recommended to improve tree survival rates (Belt *et al.* 2007). Mulching around trees will also assist in reducing water requirements. Depending on the soil type and the tree species being planted, additional fertiliser applications may be required at planting and in subsequent years as most soils in Australia are nutrient poor, most non-native species will require additional fertiliser amendments.

Replacing plants

VEBs are seldom 100% successful in their establishment. The prompt replacement of unthrifty or dead plants is essential for the development of a functional windbreak as the effectiveness of the VEB is reliant on having full rows (Belt *et al.* 2007). Belt *et al.* (2007) recommends that when planting the VEB, extra plants are ordered for replacements for the following establishment years. These spare plants should be 'heeled in', by removing any containers or planting the balled-and-burlapped stock at a very close spacing, and covering the roots with soil and water. Ideally, plants should be 'healed in' where it is cool and shady.

8. Ideal Traits for VEBs in Australia

VEBs for Australian meat chicken farms

As detailed in Section **Error! Reference source not found.**, the majority of meat chicken farms in Australia use tunnel ventilated sheds, although a small proportion of the industry still operates naturally ventilated sheds. In terms of the general design, VEBs are the same for tunnel ventilated sheds and natural ventilated sheds, as for both systems the main purpose of the vegetative filter is to capture and filter emissions and disperse emissions over a larger area to reduce potential impacts. The main point of difference is that VEBs for tunnel ventilated sheds are positioned at the exhaust fan end and VEBs for natural ventilated sheds will be positioned parallel to the open sides of the sheds, but need to be designed so that enough air can penetrate the screens to allow for adequate ventilation. This study predominantly focuses on the design and management of VEBs for tunnel ventilated exhaust sheds as this is the most common production system in Australia. The screen design itself can then be easily adapted to cater for naturally ventilated sheds, screening the facility's boundary or providing shade.

There is a growing proportion of the industry that is operating free range production systems. Free range meat chickens are produced using similar management, housing and feeding practices as conventional meat chickens. The main differences are that free range chickens are allowed access to an outside run for part of each day (at least post the brooding period) and have lower target stocking densities (ACMF 2011b). Free range chicken meat (including organic chicken meat) currently accounts for about 15% of chicken meat produced in Australia. However, this is predicted to grow to become 20-25% of the total market (ACMF 2011a). Free-range systems have some additional management issues in terms of an increased farm biosecurity risk and nutrient management within the range area. As mentioned in Section 0, wild birds have the potential to transfer diseases to domestic meat chickens. The risk of this occurring is higher on free-range farms as birds will have some exposure to wild birds (ACMF 2010) either directly or to their faeces deposited in the range area. To minimise this exposure, it is recommended that measures are taken to minimise the congregation of waterfowl and the impact of wild birds generally including keeping the area around sheds free from debris and regularly mowing grass. Trees and shrubs selected for vegetative buffers and shade trees for range areas need to minimise wild bird attraction (ACMF 2010). Refer to Section 0 for ideal tree characteristics to minimise the attraction of wild birds.

Figure 8 shows the distribution of existing meat chicken farms in Australia. There are 13 main chicken meat production localities. From this information, nine climate zones that best represent the meat chicken industry have been selected to develop producer guidelines for designing, establishing and managing VEBs for Australian meat chicken farms. The producer guidelines characterise suitable arrangements and plant species for VEBs for conventional tunnel ventilated sheds and suitable shade trees for free-range areas for each climate zone. The selection of suitable plant species has been based on the key concepts outlined in this literature review as well as an extensive review of local climate and topographic conditions.

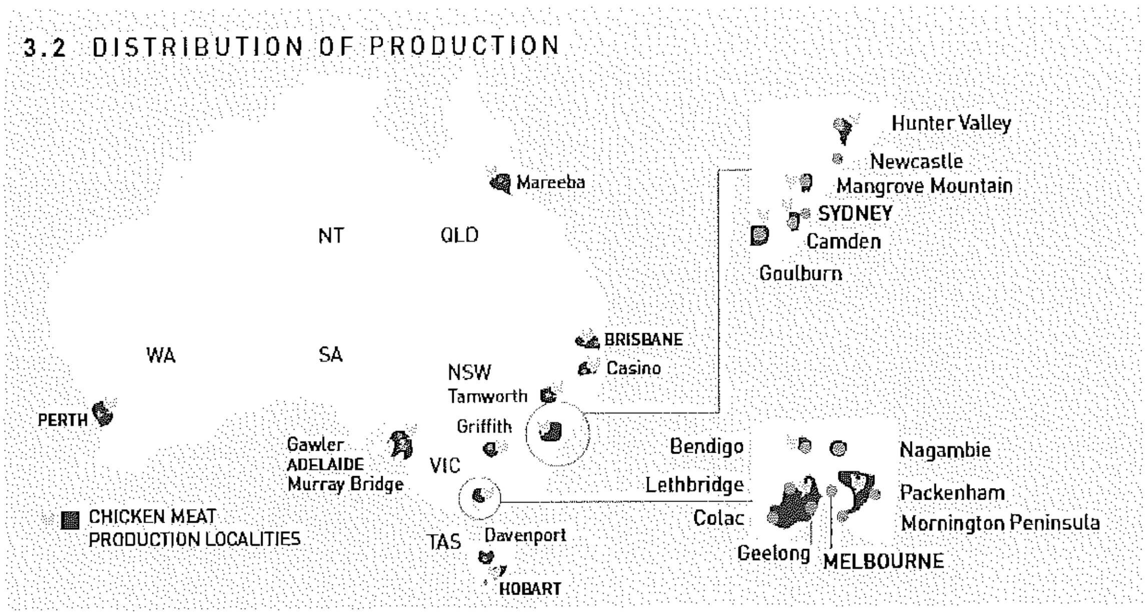


Figure 8. Distribution of meat chicken production in Australia (ACMF 2011a)

Summary of key design principles from reviewed literature

VEBs (or vegetative environmental buffers) consist of several rows of different tree, shrub and/or grass species that have been selected to withstand local conditions and environmental stresses caused by shed exhaust air. They effectively capture particulates, and disperse gaseous emissions over a larger area. VEBs should consist of different grass / trees / shrubs, which provide different functions. The use of multiple plant species also reduces the risk of the entire screen being affected by disease or drought.

There is a gap in knowledge regarding the ideal distance between the shed exhaust fans and the VEB for sheds with multiple fans. Most meat chicken sheds in Australia have multiple fans in a row and multiple rows of fans. This is not always the case in the USA. The general rule developed in the US is that this distance should be about ten times the fan diameter to prevent back-pressure on the fans (Malone *et al.* 2008, Malone *et al.* 2006). However, Belt *et al.* (2007) mentions that where multiple fans are used this formula should be modified (increased), but no details are provided on what constitutes multiple fans and what the modification to this formula should be. The other issue that requires consideration is that the distance between the fans and the VEB needs to be great enough to prevent plants being coated by dust particles or desiccated at high wind speeds (Belt *et al.* 2007). They recommend that VEBs should be planted about 25 m from the fans to prevent plants being desiccated at high wind speeds.

Multiple fans will create plumes of different wind speed and location than a single fan. The method for calculating the distance between the exhaust fans and the VEB for sheds with multiple fans in a row and multiple rows of fans will need to be investigated further when developing the producer guidelines for Australian farms. It may also be possible that there may not be an easy formula for determining the ideal distance as the research may not have been done.

VEBs for tunnel ventilated sheds

For tunnel ventilated sheds, Malone and Abbott-Donnelly (2004) recommend planting VEBs around the perimeter of the meat chicken farm and additional screens at i) exhaust end of the sheds for improved emission scrubbing, and ii) air inlet end of the sheds to provide a cooling effect of the air

and soil in summer. This arrangement is probably suitable for Australian meat chicken farms but will be dependent on the reasons for planting VEB at each farm and the site characteristics (refer to Section **Error! Reference source not found.**). There are however several key differences between the USA and Australia which will need to be addressed when preparing the producer guidelines which are outlined in Section **Error! Reference source not found.**.

From reviewing the literature of research undertaken in the USA it is clear that there are some general key design features of VEBs withthe primary purpose of reducing shed exhaust emissions that are transferable to meat chicken farms in Australia. These are summarised below:

- VEBs should not be planted any closer than ten times the fan diameter from the exhaust fan end of the shed to prevent the buffer impeding fan efficiency. This distance needs to be increased for sheds with multiple fans but the modification of this formula, if there is one, is not clear in the literature.

- VEBs should be planted about 25 m from the fans to prevent plants being desiccated at high wind speeds.

- A minimum of three staggered rows of plants are desirable with the row adjacent to the fans being a waxy-leaved evergreen shrub for Australian conditions versus a deciduous tree/shrub; the inner row/s deciduous trees and the outer rows evergreen trees to provide a windbreak.

- Evergreens with waxy leaves are preferred for the inner row (closest to the exhaust fans) as this row endures most of the dust emissions, which over time build up on the trees vegetation affecting their health. These trees tend to withstand high particulate loads best as the waxy coating on the leaves allows dust to be washed off when it rains.

- Two staggered rows of evergreen trees or a combination of windbreak type trees are recommended for other screen areas e.g. primary purpose of the screen is to provide a windbreak, shade or visual screen. The density of planting should correspond with prevailing seasonal winds from each direction.

- The use of rows of deciduous trees, rather than evergreens, needs careful thought. Deciduous trees are often used in the USA where fans do not operate during winter. In Australian sites where fans operate throughout the year, deciduous trees may not be an option as the effectiveness of the VEB is decreased once they have shed their leaves.

- Leaves with a complex shape (e.g. conifers) appear to be the most effective for capturing particulates.

- The windward side should contain evergreen species that maintain lower branches close to the ground or you may need to interplant with evergreen shrubs to compensate for the opening.

- Spacing between tree rows and between adjacent trees in a row will be determined by tree species, objectives of the planting, farm situation and if mowing between rows, the width of mowing equipment.

- Planting strips of tall-growing grass close the fans, in-between the VEB and the fans may also be beneficial.

- A VEB with a curved design is preferable than one with square corners.

VEBs for naturally ventilated sheds

Essentially, the same design principles apply for VEBs for naturally ventilated sheds as for tunnel ventilated sheds. Shed dust emissions are expected to be lower than for tunnel ventilated sheds.

However, it is likely that the inner row of plants adjacent to the open side walls should be deciduous or have waxy leaves. The most important difference between VEBs for natural ventilated sheds is that they still have to allow sufficient air to flow through the screen to provide adequate ventilation. Malone and Abbott-Donnelly (2004) recommended that VEBs intercepting prevailing winds during winter should be denser whereas for summer tall evergreens and/or deciduous trees with no lower limbs are suitable for promoting roof shading while maintaining adequate air flow through the screen for ventilating the sheds.

VEBs and shade trees suitable for free range farms

Trees are often planted in free range areas to provide shade for the birds. Planting trees adjacent to or within free range areas may create additional issues to be addressed. Wild birds may be attracted to the trees which may increase the risk of disease transfer (refer to section 0). Birds also tend to spend more time in the shade and this will promote an accumulation of nutrients adjacent to the trees. The areas around trees (if accessible by the birds) may become denuded and tree roots exposed.

The reasons for planting VEBs on free range meat chicken farms will generally be the same as for conventional farms, whether they are tunnel or naturally ventilated. However, planting strategically placed VEBs to supply shade instead of individual trees in the range area may be advantageous for several reasons.

- VEBs will still be effective for providing shade if they are fenced off from the range area. This would prevent nutrients accumulating closest to the tree roots and the birds exposing the tree roots, solving two problems faced by individual shade trees. The shade provided would also be over a larger area, promoting more even distribution of nutrients in the range area.

- Wild birds that perch on the vegetative screen plants will deposit their faeces within the containment of the vegetative buffer rather than in the range area if they perched on individual shade trees.

- Vegetative buffers provide additional benefits by acting as a nutrient filter nutrients that may leach from the range area.

Whether planted as individual shade trees or as a vegetative buffer, the trees and shrubs selected will need to have attributes that are less attractive to birds (i.e. limited flowers, fruit and seeds) to reduce the risk of disease transfer. Some species have non-fruiting varieties or separate male plants which could be used instead (Scott 2007).

9. Recommendations for Australian VEB Guidelines

Research conducted in the USA has developed some general design and management guidelines for establishing VEBs on meat chicken farms. Many of these design principles are directly transferrable to designing VEBs for Australian meat chicken farms. There are however several key differences between the USA and Australia which will need to be addressed when preparing producer guidelines.

Shed exhaust fans in the USA are rarely used in winter due to the cold climate. However, in most regions of Australia shed exhaust fans are used all-year-round, due the warmer climate. Therefore planting deciduous tree/shrub in the inner row of the VEB may not be practical in Australia, as the VEB will still have to capture dust emissions during winter. Evergreens with waxy leaves or grasses would provide a better alternative.

As raised in Section 0, establishing trees close to buildings could potentially increase the fire risk of a farm if the species that make up the VEB have features that make them highly flammable (high volatile oil content, create dead wood or twiggy material, heavy litter falls in summer, open-work canopies of hanging foliage and fine leaves). If the VEB consists of species that have features that make them fire-retardant (foliage has high salt and moisture content, soft leaves, low volatile oil content, smooth, non-peeling bark and high leaf density), the VEB could have the opposite effect and act as protect meat chicken farm buildings from an advancing fire. The traits of many native species in Australia fall into the fire accelerant category so most natives may not be suitable to include in VEBs even if they meet the criteria outlined in Section 0 for ideal plants for VEBs. Non-native species that have been identified as being highly successful at capturing particulates in the USA (e.g. conifers) also fall into the 'highly flammable category'. Depending on the fire risk evaluation of an individual farm, it still may be advantageous to plant some of these 'flammable' species if the risk is relatively low and the remainder of the VEB has species that are fire retardant. This issue will have to be further investigated when establishing Australian guidelines.

The ideal distance between shed exhaust fans and VEBs to prevent backpressure on the fans and plant desiccation from high winds still needs to be clarified for sheds with multiple fans in a row and rows of multiple fans. This distance may need to be greater than the ten times the fan diameter, which is the minimum recommended distance to prevent fan back-pressure. To clarify this issue may require discussions with key researchers in the USA who have been designing VEBs as well as researchers in Australia who have a strong background in Australian ventilation systems. There is a possibility that further trials in Australia may need to be conducted before a recommended distance formula can be developed.

This review has identified some key plant characteristics that are required for establishing successful VEBs in the USA as well as some key characteristics that will need to be included for VEBs in Australia (e.g. to reduce fire risk). These criteria were developed into a producer guide (Bielefeld *et al.* 2012) that can be distributed to key players in the landscape/horticultural industry in each region of Australia to work out a list of suitable species for VEBs in each region. The guide can be accessed at https://rirdc.infoservices.com.au/items/14-063.

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