Downwind swine odour monitoring by trained odour assessors - Part I: Downwind odour occurrence as affected by monitoring time and locations.

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1Agricultural and Bioresource Engineering, University of Saskatchewan, 57 Campus Drive, Saskatoon, Saskatchewan S7N 5A9 Canada; and 2Agriculture, Food, and Nutritional Science, University of Alberta, Edmonton, Alberta T6G 2P5, Canada. *Email: guo@engr.usask.ca

Guo, H., Feddes, J., Laguë, C., Dehod, W. and Agnew, J. 2005. Downwind swine odour monitoring by trained odour assessors - Part I: Downwind odour occurrence as affected by monitoring time and locations. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada 47: 6.47 - 6.55. Two trained odour assessors monitored odour occurrences at 105 different locations 0.2 to 6.4 km downwind from three production sites of a 5000-sow farrowing-to-finish operation located in a rural area of the Canadian Prairies during the period of May to October 2003. Swine odours were detected in 16.1% of all measurements, which resulted in a total of 921 odour events. Most measurements (81.7%) occurred in early morning (0600 to 0800h) and late afternoon (1700 to 1900h), during which times the corresponding odour detection frequencies were 13.7 to 20.2%, respectively. The farthest location at which odours were detected was 6.0 km downwind from the swine site. No odours were detected at five locations, including the farthest location (6.4 km). The frequency of odour detection was highest in October and May at 25.7 and 24%, respectively, which might be due to frequent manure land applications. Intensity 1 and 2 odours (very faint and faint) were reported the most (61.4%). Intensity 4 and 5 (strong and very strong odours) were reported the least (19.0%); that occurred most frequently in June and October but least frequently in July and August. A linear relationship reported the least (19.0%); that occurred most frequently in June and October but least frequently in July and August. A linear relationship occurred (r2 = 0.83). Toutes les odeurs d’intensité 1 et 89.7% de odours with intensity 2 were considered not annoying or somewhat annoying by the assessors. This may shed light on setting acceptable odour intensity criterion. Diurnal odour occurrence and odour detection frequency at various distances and directions from the swine sites are discussed. Keywords: swine, odour dispersion, downwind, monitoring, assessor, weather.

Deux évaluateurs d’odeurs entraînés ont évalué des événements odorants à 105 endroits différents de 0,2 à 6,4 km dans la direction des vents dominants en aval de trois sites d’un complexe de production porcine naisseur-finisseur de 5 000 truies situé en milieu rural dans les Prairies Canadiennes durant la période de mai à octobre 2003. Des odeurs porcines ont été détectées dans 16,1% de toutes les mesures effectuées, ce qui a résulté en un total de 921 événements odorants. La plupart des mesures (81,7%) ont été faites tôt le matin (0600 à 0800h) et en fin d’après-midi (1700 à 1900h), et durant ces périodes les fréquences de détection d’odeurs correspondantes étaient de 13,7 à 20,2% respectivement. L’endroit le plus éloigné où des odeurs porcines ont été détectées était situé à 6,0 km sous le vent dominant de la porcherie. Aucune odeur porcine n’a été détectée à trois endroits, incluant l’endroit le plus éloigné (6,4 km). La fréquence de détection d’odeurs était la plus élevée en octobre et en mai avec 25,7 et 24,0 % respectivement, ce qui peut être dû aux fréquents épandages de lisier aux champs. Les intensités d’odeur 1 et 2 (très faible et faible) ont été rapportées le plus (61,4%). Les intensités 4 et 5 (forte et très forte odeurs) ont été observées le moins (19,0%) et ces événements sont survenus le plus souvent en juin et octobre mais le moins souvent en juillet et août. Une relation linéaire a pu être déterminée entre l’intensité et le caractère hédonique déplaisant (r2 = 0,83). Toutes les odeurs d’intensité 1 et 89,7% de des odeurs d’intensité 3 étaient considérées comme n’étant pas déplaisantes ou quelque peu déplaisantes par les évaluateurs. Ceci peut permettre de définir des critères d’acceptabilité pour l’intensité d’odeur. L’occurrence diurne des odeurs et la fréquence de détection à différentes distances et directions par rapport aux porceries sont aussi discutées. Mots clés: porc, dispersion d’odeur, vent dominant, suivi, évaluateur, conditions météorologiques.

INTRODUCTION

Livestock odours from intensive livestock operations (ILOs) have become a public concern due to their impact on the air quality of nearby areas. Because most existing setback distance guidelines are based on experience instead of science, they may not be used to settle related disputes or lawsuits or to site new ILOs (Schauberger and Piringer 1997; Lim et al. 1999; Jacobson et al. 2000; Guo et al. 2004a). With increasing numbers of conflicts in the last few years, determining a science-based setback distance has become an urgent need for the livestock industry and the neighbouring communities. The scientific setback distance should be based on suitable acceptable criteria for community-level exposure to odours, of which little is known. The National Center White Papers of the United States have identified the determination of acceptable odour criteria in terms of frequency, intensity, duration, and offensiveness (FIDO) as an urgent research need (Sweeten et al. 2002). To do so, we first need to understand odour occurrence in the neighbouring area of a livestock operation in order to reveal how the odour occurrence in the area is affected by the size of the operation, weather conditions, and topography. Little is known regarding odour occurrence FIDO at various directions and distances from a livestock operation.

Groups of trained field odour assessors have been used to measure odour intensities downwind of livestock farms within
differences of 0.5 to 1.0 km (Zhu et al. 2000; Zhang et al. 2003). Since setback distances are generally greater than 0.5 or 1.0 km, odour dispersion at greater distances also needs to be measured. Field odour assessor were not suitable for this type of measurement because odours at greater distances are likely intermittent due to changing wind directions, and it is difficult to predict where the odour plumes are in order to locate field assessors. Some researchers have monitored long term odour occurrences in the neighbouring areas of livestock operations using trained local residents because it is a cost-effective method for long term, long distance, downwind odour measurements (Guo et al. 2001, 2003, 2004b; Nimmermark et al. 2003). There are three concerns for using voluntary local residents as odour observers. First, the quality of the data, especially the odour intensity rating, may not be ensured due to the lack of periodic nose calibration using the standard n-butanol intensity scale (Guo et al. 2001, 2003, 2004b; Nimmermark et al. 2003) or the observers’ reluctance to do so (Guo et al. 2004b). Second, some observers might have biased views on ILOs, which may result in biased or inaccurate data. Third, odour monitoring can only be done at the volunteers’ residences, which may not cover all desired locations. High quality and unbiased data can be obtained by selecting unbiased trained odour observers who can travel to designated locations to conduct odour measurements.

The objective of this study was to monitor odours downwind of a 5000-sow farrowing-to-finishing swine operation located in the Canadian Prairies using two trained odour assessors to reveal odour occurrence profiles.

**MATERIALS and METHODS**

**Odour monitoring area and the swine operations**

The selected area was located in a rural area in eastern Saskatchewan (longitude 103.0°, latitude 51.75°). Three different production sites, all part of a 5000 sow farrowing-to-finishing operation, were located in this area. These three sites included the farrowing (5000 sows, 3 barns, one 2-cell earthen manure storage basin (EMS)), nursery (19,200 head, 4 barns, one 2-cell EMS), and finishing (11,550 head, 1 barn, one 2-cell EMS) sites. Table 1 gives the detailed information about these three sites. A total of 147 residences are located within 8 km of these three sites. Figure 1 outlines the study area. The influence of topography on odour dispersion was minimal because of the flatness of the experimental area.

**Odour assessors and odour monitoring method**

Two odour assessors (one male and one female) living outside the study area were selected. To eliminate any possible bias towards intensive swine operations, these assessors were selected from outside of the study area, had a neutral opinion towards intensive swine operations, and had never participated in any protest against or supporting activities for intensive swine operations. They were also selected on their ability to correctly identify each level of the 5-point static reference intensity scale with n-butanol solution in water, which they were trained to use to estimate the intensity of the swine odours they detected (Procedure B, Static-Scale Method, ASTM E544-99, 1999). The n-butanol concentrations-in-water for intensities 1 to 5 were 250, 750, 2250, 6750, and 20,250 ppm, respectively, corresponding to olfactory ratings of very faint, faint, moderate, strong, and very strong odours (Guo et al. 2001). Because the study only intended the observers to measure the field odour intensity rather than the odour detection threshold using an olfactometer in an olfactometry laboratory, they were not tested and trained based on the n-butanol detection threshold. They were also trained to measure the hedonic tone of an odour, i.e., pleasantness or unpleasantness of an odour. In this study, they only dealt with the unpleasantness or offensiveness of swine odours using a word scale, i.e., offensiveness 1 being not annoying, 2 somewhat annoying, 3 annoying, 4 very annoying, and 5 extremely annoying.

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**Table 1. Information about the swine farms.**

<table>
<thead>
<tr>
<th>Site</th>
<th>Facility</th>
<th>Facility capacity</th>
<th>Total area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farrowing</td>
<td>Breeding/gestation barn</td>
<td>5144 sows in 5 rooms</td>
<td>10,246</td>
</tr>
<tr>
<td></td>
<td>Farrowing barn</td>
<td>896 sows (28 rooms, 32 sows per room)</td>
<td>5182</td>
</tr>
<tr>
<td></td>
<td>FR-EMS cell 1</td>
<td>For the whole farrowing site</td>
<td>2916 (54 x 54 m)</td>
</tr>
<tr>
<td></td>
<td>FR-EMS cell 2</td>
<td>For the whole farrowing site</td>
<td>4761 (69 x 69 m)</td>
</tr>
<tr>
<td>Nursery</td>
<td>Nursery barn</td>
<td>22,400 weaner pigs in 32 rooms in 4 barns</td>
<td>7824</td>
</tr>
<tr>
<td></td>
<td>N-EMS cell 1</td>
<td>For the whole nursery site</td>
<td>5625 (75 x 75 m)</td>
</tr>
<tr>
<td></td>
<td>N-EMS cell 2</td>
<td>For the whole nursery site</td>
<td>9801 (99 x 99 m)</td>
</tr>
<tr>
<td>Finishing</td>
<td>Finishing barn</td>
<td>12,500 pigs (10 rooms, 1250 feeder pigs per room)</td>
<td>9550</td>
</tr>
<tr>
<td></td>
<td>FN-EMS cell 1</td>
<td>For the whole finishing site</td>
<td>5625 (75 x 75 m)</td>
</tr>
<tr>
<td></td>
<td>FN-EMS cell 2</td>
<td>For the whole finishing site</td>
<td>9801 (99 x 99 m)</td>
</tr>
</tbody>
</table>

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**Fig. 1. Outline of the odour monitoring area.**
Each assessor was provided with an n-butanol scale set, and they calibrated their noses once a day. They were also provided with a charcoal mask to wear between measurements during the field measurement to prevent nose fatigue. The data recorded included odour intensity and offensiveness; occurrence time, duration, and character; and a general statement about the odour and the observer’s own physical conditions.

They monitored odours around the three swine sites for six months, from May to October 2003, at a total of 105 designated locations. These locations were placed 0.2 to 6.4 km from the closest swine site. Some of these locations were on the grid roads next to the residences so the odour data of the resident observers could be compared with that of the assessors if both recorded odour events at the same time. The documentation of odour occurrences by resident odour observers at their residences was part of another study conducted simultaneously with this study. The other locations were all at or close to the grid roads in order to set up a monitoring grid with a 0.8 km interval around the three swine sites. For each of the 16 wind directions, the assessors were given a specific route to travel in order to cover all downwind locations. For each trip, the odour assessor estimated the wind direction first and then traveled through the area on the particular route corresponding to the wind direction. The assessors also checked wind directions two to three times during a trip to determine the downwind locations. At each location, the assessor got off the vehicle and took measurements for 30 s by sniffing once every 10 s, and recorded the maximum odour intensity and corresponding hedonic tone. The time intervals between measurements at adjacent locations were between 2 to 15 min depending on the distance between the two adjacent locations. Each assessor made one trip a day, five days a week (including some weekends). Each trip took about three hours. Most of the time, they worked separately at different times of the day in the early morning (0530 to 0900h), early evening (1700 to 2000h), and occasionally in the afternoon. They worked together for a total of 12 days between June and September in order to compare their readings.

**Odour emission measurements**

Odour emissions from all types of sources on the three sites were measured monthly from May to October 2003, including two breeding/gestation rooms, two farrowing rooms, four nursery rooms, three finishing rooms, and all six EMS cells.

Exhaust air was collected from the exhaust fans of the rooms in 10-L Tedlar® sampling bags (SKC Inc., Eighty Four, PA) using a custom-built vacuum box, an air pump, and Teflon® FEP tubing (Cole-Parmer Instrument Company, Vernon Hills, IL). A wind tunnel using the design by Schmidt et al. (2002) was used to collect gaseous emissions from the EMS surface with an average surface speed of 0.3 m/s. Air samples were also collected in Tedlar bags at the outlet of the wind tunnel, which covered an area of 0.32 m².

The sample bags were transported to the Olfactometry Laboratory, University of Alberta and analyzed for odour detection threshold, i.e., odour concentration and hedonic tone within 30 hours of collection. Odor detection threshold, in OU/m³, was measured in accordance with ASTM Standard E679-97 (ASTM 1997) using eight trained panelists.

The ventilation rates of the barns were obtained by measuring the speeds of all fans and the vacuum pressure of the rooms and then finding the corresponding airflow rates of the fans from the fan testing reports provided by the fan manufacturer or the fan testing organizations. The odour emission rate from a room was the product of odour concentration and the ventilation rate, and the rate from an EMS cell was the product of odour concentration and the air flow rate of the wind tunnel.

**Other measurements**

A weather station was installed near the swine finishing site. Weather data, including wind speed and direction, temperature, relative humidity, and solar radiation, were collected. The data were monitored once every minute and the average of every 10 minutes was recorded.

Acute odour generation or odour control activities, e.g., EMS emptying, plug pulls, covering the EMS with straw, etc., were documented by the barn managers. Barley straw was applied to the EMS three times on the nursery site in March, June, and again in July, twice on the farrowing site in March and June, and once on the finishing site in June. Manure was injected to the crop land nearby the three sites from May 11 to June 10, 2003, and again from August 7 to October 12, 2003.

**RESULTS and DISCUSSIONS**

**Summary of odour measurement**

During this six-month period, the two assessors worked between 19 to 26 days (average 23.8 days) per month for a total of 143 days. They conducted a total of 5806 measurements, with the most measurements per month occurring in July (26 days; 1139 measurements) and the least occurring in May (19 days) and October (814 measurements).

From the 5806 total measurements, 4795 resulted in no odour detection, 90 in non-swine odour detection (e.g., smoke, chemicals, cattle manure, hay, crop odours), and 921 measurements yielded swine odour. Since it was possible that the smells of other odours might mask swine odour while the other odours were detected, it was possible that swine odours were present at the same time. To analyze swine odour occurrences during the experimental period, the occurrences of other odours were thus eliminated from the analysis. After these measurements were eliminated, the total number of measurements was reduced to 5716: 4795 measurements detected no odour (83.9%) and 921 measurements detected swine odours (16.1%). This result indicated that when a receptor stands downwind in an odour plume, the odours would likely be intermittent and the receptor may not smell the odour all the time. This observation is consistent with general downwind observations using trained odour assessors (Zhang et al. 2005). Zhang et al. (2005) revealed that for distances of 0.1 to 1 km downwind of two swine farms, the farther away from the odour sources the assessor was, the lower the odour detection frequency of the assessor got. The odour detection frequencies 1 km downwind of the two swine farms using 15 trained odour assessors were 11 and 36%, respectively (2005). Frequent wind direction changes, minor or major, might have caused changes in the course the odour travelled.

In terms of geographic distribution of the swine odour measurements, swine odours were never detected in five locations including the farthest location. These locations were 3.3 4.0, 4.2, 5.5, and 6.4 km away from the closest swine sites.
Table 2. Summary of monthly swine odour measurement results.

<table>
<thead>
<tr>
<th>Month 2003</th>
<th>All odours</th>
<th>Intensity 1</th>
<th>Intensity 2</th>
<th>Intensity 3</th>
<th>Intensity 4</th>
<th>Intensity 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Events</td>
<td>%</td>
<td>Events</td>
<td>%</td>
<td>Events</td>
<td>%</td>
</tr>
<tr>
<td>May</td>
<td>201</td>
<td>24.0</td>
<td>98</td>
<td>48.8</td>
<td>51</td>
<td>25.4</td>
</tr>
<tr>
<td>June</td>
<td>206</td>
<td>18.9</td>
<td>72</td>
<td>35.0</td>
<td>39</td>
<td>18.9</td>
</tr>
<tr>
<td>July</td>
<td>122</td>
<td>10.9</td>
<td>38</td>
<td>31.1</td>
<td>40</td>
<td>32.8</td>
</tr>
<tr>
<td>August</td>
<td>108</td>
<td>11.7</td>
<td>44</td>
<td>40.7</td>
<td>37</td>
<td>34.3</td>
</tr>
<tr>
<td>September</td>
<td>80</td>
<td>8.5</td>
<td>22</td>
<td>27.5</td>
<td>29</td>
<td>36.3</td>
</tr>
<tr>
<td>October</td>
<td>204</td>
<td>25.7</td>
<td>45</td>
<td>22.1</td>
<td>51</td>
<td>25.0</td>
</tr>
<tr>
<td>Total</td>
<td>921</td>
<td>16.1</td>
<td>319</td>
<td>34.6</td>
<td>247</td>
<td>26.8</td>
</tr>
</tbody>
</table>

* Detection frequency percentage

The location 3.3 km from the swine site was only measured twice while the other four locations were measured 14 to 47 times. The other locations where swine odours were detected were 0.2 to 6.0 km away from the sources and the number of measurements ranged from 4 to 138. Considering all locations, the overall average number of measurements taken per location was 54.4 ranging from a low of 2 to a high of 138.

There was a total of 12 days from June to September on which the two odour assessors took measurements together in order to compare their odour intensity and offensiveness ratings. A total of 302 measurements were conducted, which resulted in 30 odour events. Both assessors assigned odour intensity 0 and offensiveness 1 to the 272 measurements that resulted in no odours. For the 30 odour events, for each odour intensity level from 1 to 5 measured by Assessor 1, Assessor 2’s rating agreed at 54.5, 100, 87.5, 100, and 100%, respectively, and the overall agreement was 80.0%. Considering all measurements, the overall intensity rating agreement of the two assessors was 98.0%. For the six odour events on which the two assessors’ intensity ratings did not agree, their ratings were one level apart. For the 30 odour events, for each odour offensiveness level from 1 to 5 measured by Assessor 1, Assessor 2’s rating agreed at 77.8, 50.0, 75.0, 0.0, and 100%, respectively, and the overall agreement was 65.5%. Considering all offensiveness measurements, the overall agreement of the two assessors was 96.7%. For the ten odour events on which the two assessors’ offensiveness ratings did not agree, their ratings were one level apart, except for one event for which their ratings were two levels apart. A paired t-test indicated that there was no significant difference in the odour intensity and hedonic tone measurement by the two odour assessors for all odour measurements or all the measured odour events (P>0.05).

Seasonal odour occurrence profile

Table 2 summarizes the average odour detection frequency, total swine odour events, and distribution of various odour intensities during each month. October had the highest odour detection frequency of 25.7% mainly because of frequent manure land applications. Manure application in May might also be the reason why May had the second highest odour detection frequency. September had the lowest detection frequency of 8.5%, while the detection frequencies of July and August were a little higher, although July and August had the most measured days at 26 days. Odours were detected the most in June with a total of 206 odour measurements, followed by October and May with 204 and 201 odour measurements, respectively. September had the least swine odours events at 80. Although October had fewer odour events than June, considering the higher detection frequency in October than in June (25.7 vs 18.9%), odour occurrences in October might be worse than that in June.

Table 3 gives the geometric means of odour concentrations and emission rates from buildings and manure storages measured during the six-month period. Due to the multiple applications of barley straw on the EMS from March to June, sometimes odour emissions could not be measured using the wind tunnel. Manure storage emissions were not measured for October due to the low liquid surface after manure removal. The results indicated that the finishing and nursery barns had much higher odour concentrations than the breeding/gestation barn and farrowing barn. The finishing barn had the highest odour emission rate and total odour emission. Odour emission from the finishing EMS was also the highest of all manure storages. Figure 2 shows the monthly total odour emissions from all barns on the three sites and the emissions from the two EMS cells of the finishing site. The monthly emissions from the manure storages of the other two sites were not complete due to the straw covers as previously mentioned. No certain seasonal patterns of odour emission rates were observed either from the building sources or the outdoor manure storages, although large variations existed for both types of sources as indicated by the magnitude of the standard deviations (Table 3). Figure 2 also gives the monthly odour events. The number of monthly odour events had a weaker logarithmic relationship with total barn odour emissions (r²=0.51). The higher the barn emission was, the higher the number of odour events detected by the odour assessors, except for August. August had high odour emissions from the barns and manure storages, but it had a low number of total odour events and low intensity 4 or 5 odour events (Table 2). As given in Table 2, the high total odour events and high occurrence frequencies of intensity 4 or 5 odours in June and October might be related to high odour emissions from the barns and manure storages and manure land application, although emissions from EMS were not measured in October. Downwind odour occurrences are also determined by other factors such as weather conditions, which will be discussed in Part II of the study.

Distribution of odour intensity and offensiveness levels

As given in Table 2, intensity 1 and 2 odours (very faint and faint odours) were reported the most and made up 34.6% and
### Table 3. Odour concentrations and emissions from barns and manure storages.

<table>
<thead>
<tr>
<th>Odour source</th>
<th>Number of data</th>
<th>Odour concentration (OU/m³)</th>
<th>Odour emission rate (OU m²·s⁻¹)</th>
<th>Total odour emission (OU/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean*</td>
<td>SD†</td>
<td>Mean</td>
</tr>
<tr>
<td>Breeding/gestation barn</td>
<td>12</td>
<td>429</td>
<td>215</td>
<td>10.4</td>
</tr>
<tr>
<td>Farrowing barn</td>
<td>12</td>
<td>832</td>
<td>755</td>
<td>23.4</td>
</tr>
<tr>
<td>Nursery barn</td>
<td>24</td>
<td>1260</td>
<td>778</td>
<td>25.4</td>
</tr>
<tr>
<td>Finishing barn</td>
<td>18</td>
<td>1220</td>
<td>695</td>
<td>49.2</td>
</tr>
<tr>
<td>Farrowing cell 1†</td>
<td>2</td>
<td>390</td>
<td>22</td>
<td>5.5</td>
</tr>
<tr>
<td>Farrowing cell 2</td>
<td>4</td>
<td>1526</td>
<td>1237</td>
<td>34.5</td>
</tr>
<tr>
<td>Nursery cell 1</td>
<td>3</td>
<td>1140</td>
<td>386</td>
<td>24.0</td>
</tr>
<tr>
<td>Nursery cell 2</td>
<td>5</td>
<td>619</td>
<td>1131</td>
<td>25.8</td>
</tr>
<tr>
<td>Finishing cell 1</td>
<td>4</td>
<td>1083</td>
<td>1513</td>
<td>48.1</td>
</tr>
<tr>
<td>Finishing cell 2</td>
<td>5</td>
<td>1680</td>
<td>1876</td>
<td>30.9</td>
</tr>
</tbody>
</table>

* All means are geometric means of the measured values.
† Standard deviation of the measured values
‡ Odour concentrations from EMS cells were from the wind tunnel measurements on the open liquid areas only; odour emission rate and total emissions were calculated by considering the emissions from straw covered area as 20% of that of the open liquid area of the same cell.

26.8% of all odours, respectively. Together they accounted for 61.4% of all swine odour measurements. Intensity 3 odours accounted for 19.5% of all odours. Intensity 4 and 5 odours (strong and very strong odours) were reported the least with 11.7 and 7.3% of all odours, respectively, and together they made up 19.0% of all odours. For individual months, high intensity odours (intensities 4 and 5) were reported the most frequently in October and June and were followed by September with 31.3, 22.9, and 18.8%, respectively. Again, manure application might be the reason for these high intensity odours. August and July had the lowest occurrence frequency for intensity 4 and 5 odours.

A total of 866 reported swine odours were also rated for offensiveness; 29.8% of these odours were reported as ‘not annoying’ (offensiveness 1), 34.5% as ‘somewhat annoying’ (offensiveness 2), 19.1% as ‘annoying’ (offensiveness 3), 10.4% as ‘very annoying’ (offensiveness 5), and 6.2% as ‘extremely annoying’ (offensiveness 5). Therefore, the majority of the odours detected (64.3%) were reported as not annoying or somewhat annoying.

Ratings of odour offensiveness for odours with different intensities are reported in Table 4. A linear correlation exists between intensity and offensiveness (Offensiveness = 0.844 × Intensity + 0.331, r² = 0.83). For all odours with intensity 1, both assessor rated their offensiveness as not annoying (80.2%) or somewhat annoying (19.8%). For odours with intensity 2, 8.7% were considered not annoying and 81.0% somewhat annoying; only 10.4% were considered annoying. The majority

### Table 4. Odour offensiveness rating of odours with different intensities.

<table>
<thead>
<tr>
<th>Offensiveness</th>
<th>Percentage of odour intensity (%)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80.2</td>
<td>8.7</td>
<td>1.7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>19.8</td>
<td>81.0</td>
<td>29.8</td>
<td>1.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>3</td>
<td>0.0</td>
<td>10.4</td>
<td>63.5</td>
<td>27.2</td>
<td>0.0</td>
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</tr>
<tr>
<td>4</td>
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<td>0.0</td>
<td>5.1</td>
<td>65.0</td>
<td>23.0</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>6.8</td>
<td>77.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Fig. 2. Monthly odour events and odour emissions from all building sources and manure storages of finishing site.
of odours with intensity 3 or above were rated as offensiveness level 3 or above. This result may provide information for setting odour annoyance intensity criterion for local communities near swine operations. The Minnesota OFFSET Model (Jacobson et al. 2000) set the acceptable odour intensity level as intensity 2 (faint odour) based on the perception of the researchers. The main reasons were a) certain levels of livestock odours, for example faint odours occurring at a certain frequency, should be expected and acceptable by rural residents, and b) setting a lower intensity as the acceptable level would result in long setback distances and be too stringent for livestock operations. If we consider offensiveness 2 odours as acceptable for a certain occurrence frequency, this study indicated that 89.7% of the intensity 2 odours were rated as ‘not annoying’ or ‘somewhat annoying’ (offensiveness 1 and 2), which means the two odour assessors would agree with the limit set by OFFSET. If the acceptable odour intensity were set at intensity 3, then the assessors would not agree with it because they considered 68.6% of the intensity 3 odours as annoying or more offensive.

Diurnal odour occurrence profile

Figure 3 summarizes average odour occurrences at different time periods in a day during May to October. Measurements were taken more frequently during the early morning and evening because most stable weather conditions occurred at these times, which favoured odour travel. Most measurements (81.7%) were taken during the hours of 0600 to 0800h and 1700 to 1900h with a total of 1073 to 1251 measurements each hour. No measurement was taken from 1000 to 1100h or from 2100 to 0500h. Some odour measurements were conducted during the afternoons to observe odour travel during unstable or neutral weather conditions. Swine odours were also detected the most during the hours of 0600 to 0800h and 1700 to 1900h with a detection frequency from 13.7 to 20.2%. However, the highest percentage of odour detection was 30.8% between 0900 and 1000h with only a total of 13 measurements. The second highest percentage of odour detection was 21.8% during the hour of 0800 to 0900h. During the evening from 1800 to 2100h, odours were detected 16.7 to 17.1% of the time. Daytime odour occurrence was expected to be low because unstable atmospheric conditions occurred during the daytime, which promoted odour dispersion vertically, so traveling distance for odours was relatively short. However, the afternoon odour occurrences were not consistent during different time periods. Some were very low as expected, such as 7.9% between 1200 and 1300h, while some were as high as 16.7% (between 1300 and 1400h). In the early morning between 0500 and 0600h, odour was only detected for 7.9%. The low odour occurrence in the early morning and high occurrence in some periods of daytime were unexpected. One reason might be that this area is rather windy, so some early mornings were windy or overcast instead of having stable atmospheric conditions. Another reason might be that the odour emission in the early morning might be lower than that during the daytime. More analysis of the impact of weather conditions on odour occurrences will be presented in Part II of this study.

Figure 4 shows the percentages of different odour intensities measured during different times of the day. Intensity 1 and 2 odours made up the majority of the odours at all times of the day except between 0800 and 0900h. Strong and very strong odours (intensities 4 and 5) were observed during different times.
in the day. The highest percentages were observed during the
daytime from 1300 to 1700h and from 0800 to 1000h with 25.0
to 33.3% of odours rated with intensities 4 or 5; it was also as
high as 28.6% in the late evening from 2000 to 2100h with only
seven swine odours observed.

**Odour occurrence at various distances**

The odour detection frequencies of all locations were plotted
against the distances from the closest sites, as shown in Fig. 5.
Generally speaking, the closer the receptor’s location to the
source, the more frequently odours were detected \( r^2 = 0.40 \).
However, Fig. 5 also indicated that some locations were close
to the odour sources but had low detection frequencies while
some locations were far away from the sources but had high
odour detection frequencies. To find out the possible reasons,
the number of measurements taken at all locations was analyzed
to make sure all locations were adequately visited and the wind
frequencies from different directions in the study area were
examined.

The average number of odour measurements, odours
detected, and detection frequencies per location at various
distance ranges were summarized as shown in Fig. 6. The
locations closer to the sources were generally visited more than
the ones farther away from the sources. The locations in the
distance range of 0 to 2 km were visited more frequently with
an average of 72.9 to 88.1 measurements per location while the
other locations 2 to 6.4 km away from the swine sites were
visited less with an average of 34.1 to 53.5 measurements per
location. Therefore, monitoring locations at various distances
were adequately visited and the odour occurrence frequencies
at various distances were obtained from an average number of
measurements of between 34.1 and 88.1. The average odour
detection number per location was high when the locations were
close to the sources, with the highest measurement at 32 odours
per location within 0.5 km, and it became lower with increased
distances. The lowest odour frequencies of 2.7 per location were
detected in the distance range of 4.0 to 4.5 km. The average
detection frequency followed the same trend with the highest at
40.3% within 0.5 km and the lowest at 6.3% at a distance of 4.5
to 5.0 km. The detection frequencies of locations within 5 to
6 km were higher than that of 4 to 5 km. The reason might be
that there were more locations within 5 and 6 km were leeward
of the prevailing winds than that between 4 and 5 km.

Figure 7 shows the wind frequencies from various directions
during May to October. Winds from W, WNW, NW, and ESE
were the most frequent in this area with frequencies of 9.3, 13.5,
10.1, and 9.5%, respectively. The winds from S, SSW, and NE
were the fewest with frequencies of 2.9% to 3.3%. Figure 8
shows the odour detection frequency contours of the study area
generated from the results of this study. It is obvious that the
odour detection frequencies differed in various
directions. Locations downwind of the prevailing winds (NW to
Fig. 8. Odour detection frequency (%) downwind of the swine sites.

W) generally had higher odour detection frequencies than the locations downwind of the least frequently occurring wind directions (S, SSW, and NE). The highest odour detection frequency of 43.2% with a total of 44 measurements occurred at location 101, which is 1.9 km from the finishing site in the ESE direction, which was downwind from the site with the prevailing wind from WNW. Location 110 was also located ESE of the finishing site but was 5.5 km from the site and the odour detection frequency was 20.7%. Location 68 was 6.4 km SE of the farrowing site, which was downwind of the prevailing NW wind. It was visited 47 times and no swine odour was detected. Generally, the locations with high odour detection frequencies were either very close to the source(s) or downwind from the source(s) during prevailing winds. Location 37 was on the southwest corner of the farrowing site and was only 0.2 km from the odour source. It was visited 74 times with an odour detection frequency of 39.2%; the frequency of the northeast wind was fairly low but winds from the N and E or calm weather might also bring odour to this location.

Theoretically, with a constantly stable odour source and an ideal flat dispersion area, the odour plumes would be the same under the same weather condition for all wind directions; consequently, odour detection frequencies would be similar at the same distance in various directions for downwind odour measurement. However, the above result did not support this assumption; rather, it indicated that the downwind odour detection frequency was affected by frequencies of wind directions in addition to the other actual determining factors such as the non-uniform ground roughness caused by some trees, bushes, or crops present in this area and the non-constant odour emissions from the odour generation sites. There was not a clear reason for this result, but the frequently changing wind direction was assumed to be the main cause. Although the measurements were supposed to be taken downwind of swine sites and the assessors checked wind directions two to three times during a trip, they might still not catch all the changes and adjust the measurement locations accordingly in the three-hour odour measurement trip. The locations downwind of the prevailing winds from the odour source might have a better possibility of being actually downwind when the measurements took place, which resulted in higher detection frequency than other locations.

To observe the distribution of odour intensities at various distances, the average percentage of each intensity level per location at various distance ranges from the sources are plotted against the detection distances, as shown in Fig. 9. Very faint odours with intensity 1 made up less than 24.1% of all swine odours within 1 km and higher odour intensities prevailed. Beyond 1 km, intensity 1 odours had the highest occurrence rates, except for the distance of 3.5 to 4.0 km, in which odours with intensities 1 and 2 had similar occurrence frequencies. For intensity 5 odours, the occurrence rate was gradually reduced with the increasing of distance and was not observed beyond 4.0 km. Odours with intensity 2, 3, or 4 were detected at all distances, but their detection frequencies were in a decreasing manner with intensity 2 higher than intensity 3 and intensity 3 higher than intensity 4.

CONCLUSIONS

Based on the downwind odour measurements conducted by the two trained odour assessors for six months, the following conclusions can be drawn:

1. Swine odours were detected in 16.1% of all downwind measurements on 105 locations.
locations, which resulted in a total of 921 swine odour events. The farthest detected location was 6.0 km from the closest swine site. Five locations were never detected of any odour, including the farthest location (6.4 km) from the swine site.

2. October and May had the highest odour detection frequency of 25.7% and 24%, which might be caused by frequent manure land applications. September had the lowest detection frequency of 8.5%.

3. Intensity 1 and 2 odours (very faint and faint) were reported the most (61.4%). Intensity 4 and 5 odours (strong and very strong) were reported the least (19.0%); that occurred most frequently in June and October but the least in July and August.

4. As for odour offensiveness, 64.3% of all odour events were reported as ‘not annoying’ or ‘somewhat annoying’ (offensiveness 1 or 2) while 16.6% were reported as ‘very annoying’ or ‘extremely annoying’ (offensiveness 4 or 5). A linear relationship existed between intensity and offensiveness ($r^2 = 0.832$). All odours with intensity 1 and 89.7% of odours with intensity 2 were considered not annoying or somewhat annoying by the assessors. This may shed light on setting acceptable odour intensity criterion.

5. Regarding diurnal odour occurrence, most measurements (81.7%) were taken during the hours of 0600 to 0800 h and 1700 to 1900 h and the odour detection frequencies were 13.7 to 20.2%, respectively. Odour detection frequency was the highest between 0800 and 1000 h (21.8 to 30.8%). Intensity 4 and 5 odours occurred during most of the measured time periods.

6. The odour detection frequency at a receptor’s location had a weak linear relationship with the distance from the odour source ($r^2=0.40$). The average detection frequency per location was the highest (40.3%) within 0.5 km and the lowest (6.3%) at a distance of 4.5 to 5.0 km. Beyond 1 km, the higher the odour intensity, the lower its detection frequency. Odours with all intensities were observed within 6 km except no intensity 5 odour was observed beyond 4.0 km from the source.

The effect of wind speed and atmospheric stability class on odour dispersion will be reported in Part II of this study.

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