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COMMUNITY ODOUR MONITORING USING LOCAL RESIDENT-OBSERVERS

Final Report Submitted to

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by

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EXECUTIVE SUMMARY

This is the final report of the project entitled *Community Odour Monitoring Using Local Resident Observers*. The objectives of this project were a) to monitor the odour exposure levels of residents living in the vicinity of swine production operations regarding odour frequency, intensity, duration, and offensiveness (FIDO) using trained resident odour-observers and hired odour assessors, b) to monitor seasonal and diurnal odour emission profiles of swine operations in Saskatchewan, and c) to provide data for validating odour dispersion models and establish science-based setback distances for swine operations. This report presents the results associated with objectives a) and b) above. The results obtained by this project will be provided to Alberta Odour Control Initiatives where the objective c) will be pursued.

This project had two stages. Stage I took place between December 2001 and February 2003 and was considered to be a preliminary survey that involved odour monitoring by local residents. Stage II was conducted from May 2003 to April 2004. Considerable changes were made to the research work of this stage compared to the research plan projected in the original proposal. In March 2003, realizing the need to encourage the residents to participate in the project and the need for credible odour monitoring data, additional funding was applied for and was approved by Saskatchewan ADF in April 2003 to compensate the residents and for the hiring of two odour assessors (nasal rangers) to measure the odour occurrences in the warm season (May to October). Hence, the work of Stage II included a) odour occurrence monitoring by trained residents using the modified method, b) odour occurrence monitoring using two hired odour assessors, and c) seasonal and diurnal odour emission measurement from the three swine sites. A rural area in eastern Saskatchewan was selected. This area featured a three-site 5,000 sow farrowing-to-finishing swine operation with a flat topography and a total of 147 residences within 8 km radius of the three sites.

Summary of Stage I: Odour Occurrence Monitoring by Trained Resident Observers

Trained resident odour observers living in the neighbourhood of the three swine production sites completed an odour monitoring study to determine their odour exposure levels. Fifty residents from 39 families volunteered to be trained as odour observers and monitored swine odours around their residences for one year (December 2001 to November 2002). They were trained to use a 5-point n-butanol intensity reference scale to rate intensities of swine odours detected around their residences. Twenty-three families located 1.6 to 6.0 km away from the closest swine sites detected a total of 317 swine odour events during that period of time. The following conclusions were drawn:

a) Swine odours were detected by observers from 23 families living 1.6 km to 6.0 km from the swine farms. Eleven families located 2.3 to 6.0 km and five families 6.0 to 8.6 km away from the swine farms did not detect swine odours.
b) Most swine odours (70.3%) were detected during the warm season from May to October. Manure land application contributed to high odour occurrences in May, June, and October. Most of the odours (54.6%) were detected between 1700 and 0900h, from the late afternoon, throughout the night and until the early morning. During the warm season, there were two

peak hours for odour detection: 0600 to 0700h and 1600 to 1700h. However, during the cold season, odours were detected most frequently between 1100 and 1200h.

c) Annual odour detection frequencies for twenty families ranged from 0.01% to 0.80%. Three families had higher odour occurrence frequencies of 1.19% (5.9 km), 1.51% (5.4 km), and 3.32% (2.8 km, near two other livestock farms).

d) Odours with intensity 3 or above were reported the most (82.2%) while very few low intensity odour events were reported. Odours with intensity 5 were reported throughout the year regardless of the season. Odour intensity might have been overestimated by some observers. Similarly, odours with offensiveness 3 or above made up 77.0% of all odours.

e) No correlation was found between the detection distance and number of odour events. In addition to weather conditions and topography, the following factors may affect odour detection frequency and intensity: 1) the distance and direction of the residence from the odour source, 2) the frequency and duration of the periods during which the observer stayed outside, which depended on the habits or lifestyle of the residents, and 3) the olfactory sensitivity of the observers to swine odours, which may vary greatly.

f) Using resident odour observers for long term and long distance odour dispersion measurement has proven to be practical and effective. However, this method needs to be improved in order to increase the quality of the data. Possible options include implementing periodic nose calibration, screening the observers for bias for or against the intensive livestock operations, and taking measurements at designated times.

g) The number of odour events had an inverse linear relationship with the wind speed; the lower the wind speed, the more odour events were reported. Odours with high intensities were detected at various wind speeds up to 9.4 m/s and at a distance of up to 5.8 km from the swine farms.

h) Swine odours were detected under all atmospheric stability classes (SC) except SC A within a radius of 1.6 to 6.0 km from the production sites. Most odour events (61.7%) were detected under atmospheric stability class D, while only 15% of odour events were detected under stable atmospheric conditions, and 23.2% were detected under unstable atmospheric stability classes B or C. These results indicate that atmospheric stability was not the determining factor for odour dispersion. Other factors, such as additional odour emissions from the outside manure storages during the warm season and the availability of observers outside of residences to detect odours (e.g., observers spent more time outside during the warm season and were unavailable during the night when stable atmospheric conditions most frequently occurred), seemed to be more important in determining the odour detection frequencies.

i) The results of this study suggest that odour occurrences, as experienced by the resident odour observers, varied with season, time of a day, location (including distance and direction from the swine farms), weather conditions (wind speed and direction), and presence of the observers outside of their residences (including seasonal and diurnal lifestyles and routines). All these factors need to be considered when setting odour criteria for communities in areas located near intensive swine operations.

Summary of Stage II: Odour Occurrence Monitoring by Trained Resident Observers

Thirty-two resident-odour observers from 28 families (four families had two observers in one family) participated in Stage II of the study during the period between May 2003 and April 2004. Odour observers were trained to use a 5-point n-butanol intensity reference scale to rate intensities of swine odours detected around their residences. They were provided with a set of the intensity reference scale n-butanol solutions and asked to calibrate their nose at least once a week. They were also asked to measure odours at least twice a day, once in the morning and once in the evening, and to record any swine odour they detected during their daily activities. In total, 953 odour events were reported. It was determined that the three swine production sites and manure applications were the probable sources for 638 of all the odour events. Based on the odour monitoring results, the following conclusions were drawn:

(a) The highest odour season was from May to October during May 2003 to April 2004.
(b) 52.1% of annual odours and 57.0% of May-to-October odours were detected during the early morning, evening, and night.
(c) Swine odour was detected up to 6 km downwind. Swine odours were also reported up to 7.6 km from the swine sites, although this rarely happened (in one year, 21 odours were reported by 4 families living 6.0 to 7.6 km away from swine sites), but whether these odours were swine odours and whether they originated from other sources needs to be further validated.
(d) Sixteen families recorded detailed durations of the odour events while the information from the other families was insufficient to calculate the annual odour detection frequency. Annual odour detection frequencies for 15 families ranged from 0.01% to 1.60%. One family had the highest odour detection frequencies of 3.00% (2.7 km from the finishing site).
(e) Of all swine odours, 44.3% were intensity 1 or 2 odours while 28.1% were intensity 3 odours, the other 27.5% were intensity 4 or 5 odours. This was very different compared with the Stage I results, where 3.3% and 13.3% of all odours reported were intensity 1 and 2 odours, but intensity 4 and 5 odours made up more than 50% of all odours. This result indicates that periodical nose calibration was indeed needed to ensure the quality of intensity rating.
(f) Of all swine odours, 43.8% were assigned offensiveness 1 (not annoying) or 2 (somewhat annoying) and 27.5% were assigned offensiveness 4 (very annoying) or 5 (extremely annoying).
(g) As rated by the observers, 77.2% of intensity 2 odours were considered not annoying or somewhat annoying regarding offensiveness. This finding may help in selecting acceptable odour intensity criterion for local communities.
(h) Some odour observers may have overestimated the odour intensity of some odours due to their perception and sensitivity to swine odour characteristics.
(i) The following factors may have affected the odour detection frequencies of the observers: distance from the swine site, direction from the swine site, living style/habit of the residents, and olfactory sensitivity of the residents.
(j) Odour occurrence was inversely related to the wind speed. Under certain weather conditions, odour may travel a long distance and remain high in intensity even when wind speeds were high.
(k) Most odour events were detected under SC D (62.9%) and no odour was detected under SC A. Stable weather SC E to G occurred mostly at night when observers were likely not

outside to conduct measurement. Odours with varies intensities were observed under various stability classes except SC A, suggesting that stability class may have a limited effect on odour dispersion within the measurement distance (<8 km), which may be different than long distance air contaminant transportation.

Summary of Stage II: Downwind Odour Occurrence Monitoring by Trained Odour Assessors (Nasal Rangers)

Two trained odour assessors monitored odour occurrences at 105 different locations 0.2 to 6.4 km downwind from the three production sites during the period from May to October 2003. Most measurements (81.7%) were taken in the early morning (0600 to 0800h), evening (1700 to 1900h), and some afternoons. Based on the downwind odour measurements conducted by the two trained odour assessors over the six months of warm season, the following conclusions were drawn:

(a) Swine odours were detected in 16.1% of all downwind measurements on 105 locations, which resulted in a total of 921 swine odour events. The farthest detected location was 6.0 km from the closest swine site. At five of the locations, no odour was ever detected, including the farthest location (6.4 km) from the swine site.
(b) October and May had the highest odour detection frequencies of 25.7% and 24.0%, respectively, which might be caused by frequent manure land applications. September had the lowest detection frequency of 8.5%.
(c) 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%); they occurred most frequently in June and October but least frequently in July and August.
(d) 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 ($r^2 = 0.83$**). All intensity 1 odours and 89.7% of intensity 2 odours were considered not annoying or somewhat annoying by the assessors. This may help set acceptable odour intensity criterion. Considering both the odour measurement by the resident observers and the hired odour assessors, odour intensity 2 may serve as odour annoyance free level in rural area around livestock operations.
(e) Regarding diurnal odour occurrence, most measurements (81.7%) were taken during the hours of 0600 to 0800h and 1700 to 1900h and the odour detection frequencies were 13.7% to 20.2%, respectively. Odour detection frequency was the highest between 0800 and 1000h (21.8% to 30.8%). Intensity 4 and 5 odours were detected during each of the time periods during which measurements were taken.
(f) The odour detection frequency at a receptor's location had a weak linear relationship with the distance from the odour source. The average detection frequency per location was the highest within 0.5 km (40.3%) and the lowest at a distance of 4.5 to 5.0 km (6.3%). Beyond 1 km, the higher the odour intensity, the lower its detection frequency was. Odours with all intensities were observed within 6 km except no intensity 5 odour was observed beyond 4.0 km from the source.
(g) The number of odour events has an inverse linear relationship with the wind speed; the lower the wind speed, the more odours were reported except when the wind speed was less than 1

m/s. Most odour events (81.7%) were detected when the wind speed was equal to or less than 5 m/s.

(h) The majority of odour events (61.0%) were detected under SC D. A total of 22.3% of odour events were detected under unstable atmospheric conditions (SC A to C), which was the same as the occurrence frequency of SC A to C during the measurement periods. Only 16.7% of all odour events were detected under stable atmospheric conditions (SC E to G), which was lower than the occurrence frequency of SC E to G during the measurement periods (17.2%). Wind direction and wind speed are determining factors for odour dispersion whereas the effect of atmospheric stability on odour dispersion is very limited. The result of this study indicated that the air dispersion models may not be applicable for odour dispersion within short distance.

Summary of Stage II: Seasonal odour emission measurement from the swine barns

The objective of the second stage was to obtain seasonal odour emission profiles from different swine production buildings. Odour emissions from different types of barns on the three sites were measured including 2 breeding/gestation rooms, 2 farrowing rooms, 4 nursery rooms, and 3 finishing rooms. The emissions from the building sources were measured once a month from March to November 2003 and again in January and March 2004. Instantaneous (or snapshot) measurements were conducted during the daytime between 0900 and 1600h. The followings conclusions can be drawn from these observations:

(a) Odour concentrations from all types of swine barns varied seasonally ($P<0.05$); these concentrations were high in winter and low in summer. Odour emission rates also varied throughout the year but did not show a specific seasonal pattern ($P<0.05$). This might explain why swine odours were detected throughout the year including during the winter when the manure storage basins were frozen. The geometric mean of odour emission rates measured in different seasons may be used to represent the typical odour emission condition of an odour source for setback determination or odour dispersion modeling, but the maximum odour emission rate measured would represent the worst case scenario.

(b) Odour concentration was the highest in the nursery rooms, followed by the finishing, farrowing, and gestation rooms. The odour emission rate from the finishing rooms was the highest, followed by the nursery, farrowing, and gestation rooms. Comparing total odour emission rates from the barns on the three sites, the finishing site had the highest odour emission rate followed by the nursery site which had slightly higher emission rate than the farrowing site.

(c) During the warm season of May to October, the finishing barn had the highest odour emission rate, followed by the nursery, farrowing, and gestation barns. Comparing the barns and EMSs, the odour emissions from the farrowing EMS were lower than those from the farrowing barns (which included the farrowing and gestation barns) by 21%; however, the odour emissions from the nursery and finishing barns were lower than those from the nursery and finishing EMSs by 95% and 22%, respectively. This indicated that a) during the warm season, barns and the EMSs were all major odour sources, b) straw covers on the EMSs were effective for reducing odour emissions. Without straw covers, the EMSs would be much greater odour sources than the barns. Comparing the three sites, the finishing site had the highest odour emission rate; the emission rates of the nursery and farrowing sites were 56.2% and 39.2% of the finishing site emission rate, respectively.

(d) Odour concentration in all types of barns was affected mainly by ambient temperature ($P<0.01$). Indoor temperature and number of animal units might have affected odour concentrations and emissions to a lesser extent. Odour concentrations could be predicted by regression equations using indoor and ambient temperatures and animal unit ($r^2 = 0.58$ to 0.67 for all rooms except nursery). The odour emission rate could not be predicted by using the indoor and ambient temperature and animal unit.
(e) Odour concentration could also be predicted by ambient temperature using a second-order polynomial relationship generated by this study ($r^2 = 0.63$ to 0.76 for all rooms except nursery).
(f) Animal density in the nursery and finishing rooms had no significant effect on odour concentrations and emission rates ($P>0.05$).
(g) Odour concentration might have a second order polynomial relationship with CO_2 concentration ($r^2= 0.51$ to 0.75 for all rooms except nursery).
(h) The ventilation rate estimation based on the CO_2 mass balance method was much lower than the actual values. Swine CO_2 production rates used in ASAE Standards may be lower than the actual value and need to be updated.

Summary of Stage II: Diurnal odour emission measurement from the swine barns

The objective of this part of the study was to obtain diurnal odour emission profiles from different swine production buildings. The measured sources for diurnal odour emissions were one breeding/gestation room, one farrowing room, one nursery room, and one finishing room. The measurements were taken between July and September 2003. Each room was measured for two consecutive days. Each day, measurement was taken once every two hours during the period between 0600h and 2000h to cover the main period of odour detection monitored by the resident observers. The following conclusions were drawn from these results:

(a) Large diurnal variations of odour concentrations and emissions were observed in each of the four types of rooms. Therefore, it is unlikely that representative odour concentration and emission rate (e.g. daily mean) can be obtained from instantaneous measurements. Odour and gas concentrations are likely to be high in the early morning and late afternoon but the odour emission rate did not show any diurnal pattern. Odour and NH_3 concentration and emissions were affected by animal activities whereas CO_2 concentration was not. Statistical analysis indicated that there were no significant differences among the seven measurement periods ($P>0.05$) for all rooms.
(b) Measured in July, nursery room N29 had the highest geometric mean of odour concentration and emission rate, followed by finishing room FN1, while breeding/gestation room BG1 had the lowest value. Farrowing room F25 was measured in September. Its odour concentration was lower than N29 but higher than FN1 and BG1, and its emission rate was lower than room N29 and FN1 but higher than BG1.
(c) No correlation was found between odour or gas concentration or emissions and room and the ambient temperature and ventilation rate except the odour emission rate of the farrowing room was significantly affected by the ventilation rate ($P<0.05$) and the NH_3 emission rate from the gestation room was also significantly affected by ventilation rate ($P<0.05$).

Summary of Stage II: Odour Emission Measurement From The Earthen Manure Storage Basins

For seasonal odour emission measurement, odour emissions from all six manure storage basins on the three sites were measured once a month from May to October 2003. For diurnal odour emission measurement, odour emissions from the two EMS cells on the finishing site were measured. Cell 1 was measured once for two consecutive days while Cell 2 was measured twice for two consecutive days. The measurement period started at 0600h and ended at 2100h and air samples were taken once every 3 hours using a wind tunnel.

The following conclusions were drawn from the measurements of the odour emissions from earthen manure storage facilities during the warm season from May to October:

(a) No clear seasonal patterns were found regarding odour concentration or emission rate. Due to the large seasonal variations, geometric means of odour concentration and emission rates are recommended for estimating odour emissions from similar manure storage facilities. Relying on one or two measurements may either underestimate or overestimate odour emission values.
(b) Using the wind tunnel method to measure the odour emission rate for individual cells, finishing cell 2 had the highest odour concentration and emission rates, followed by farrowing cell 2, nursery cells 1 and 2, and finishing cell 1, while farrowing cell 1 had the lowest values. The geometric mean of odour concentration was higher for cell-2s than cell-1s (1111 vs. 878 OU) as was the odour emission rate (geometric mean of 79 OU m^{-2} s^{-1} for cell-2s and 67 OU m^{-2} s^{-1} for cell-1s).
(c) Ambient and manure temperature had little effect on the odour concentration and emissions from manure storage facilities ($P>0.05$).
(d) The finishing EMS had the highest odour emissions, followed by the nursery EMS, while the farrowing EMS had the lowest emissions.
(e) The method of surface sampling needs to be standardized and the odour emission rate calculated by this method needs to be further investigated.

The following conclusions were drawn from the diurnal emissions from the earthen manure storage facilities:

(f) No consistent diurnal patterns were observed regarding odour concentration or emission rate.
(g) The diurnal variations of odour concentration and emission were relatively small for finishing cell 2 as the result of two 2-day measurements (the geometric mean of odour emission rate was 35.9 (S.D. 6.8) OU m^{-2} s^{-1} for August 13th and 14th and 44.4 (S.D. 14.2) OU m^{-2} s^{-1} for September 7th and 8th). However, finishing cell 1 showed higher diurnal variations with a geometric mean odour emission rate of 55.6 (SD 50.5) OU m^{-2} s^{-1}. The results from cell 2 indicate that a snap-shot measurement would likely give a representative odour emission data; however, the result from cell 1 implies that multiple measurements are needed to get the representative odour emission data. Hence, multiple measurements at different times of a day are recommended and the geometric means should be used as odour emissions from similar manure storage facilities.

(h) Correlation analysis indicated that air and manure temperature did not have a significant effect on the odour concentration and emission rates of the two cells ($P>0.05$). However, the odour emission rate was found to have a linear relationship with ambient air temperature for cell 1($r^2 = 0.58$ and 0.64 for days 1 and 2, respectively); however, this relationship was not found for cell 2. Because the data set sizes were very small, more work is needed to verify this result.

Keywords: Odour, Odour dispersion, Swine, Barn, Manure storage, Emission, Resident, Observer, Assessors, Downwind, Monitoring, Weather

Part 1. Introduction

The nuisance and health concerns caused by odours from livestock facilities are among the key issues that affect neighbouring communities and the growth of the livestock industry in Saskatchewan and other Canadian Prairie provinces. Among the various odour control methods, keeping livestock operations an appropriate distance away from established residences may be the most effective, economical, and practical way to ensure acceptable air quality for the neighbouring residents. Most current setback guidelines are experience- and/or survey-based; the credibility of these guidelines is unconvincing from the point of view of both the neighbouring residents and the livestock producers (Guo et al. 2004). Hence, science-based setback distances need to be established.

There are many factors that affect odour dispersion to the neighbouring areas and the resultant impact on the neighbouring residents, including the odour emission rate from the source, the receptor's distance and direction from the source, weather conditions, topography, and the odour sensitivity and tolerance of the neighbours. To generate science-based setback distances, two problems need to be solved first, i.e., a) acceptable odour exposure levels for the surrounding neighbours in terms of frequency, intensity, duration, and offensiveness (FIDO) must be determined and b) odour occurrence level (FIDO) in the neighbouring area must be predicted, which can only be done by odour dispersion models that are validated by field odour dispersion measurement data. The National Center White Papers of the United States (Sweeten et al. 2002) have identified the determination of acceptable odour criteria in terms of FIDO as an urgent research need. To solve any of these problems, field data on odour occurrence as affected by odour sources, weather conditions, and topography is needed.

Compared to extensive odour emission measurements from livestock operations, very limited research work has been done on odour dispersion or plume measurement in areas near livestock operations. There are two methods of measuring odour dispersion. The first method is to measure the odour plume using a panel of trained odour observers. The second method is to monitor odour occurrence at neighbouring residences using trained resident odour observers. For the first method, groups ranging from 5 to 15 trained odour observers are brought leeward of an odour source and the odour intensity of the odour plumes are measured. Several studies have used this method to measure odour plumes (Li et al. 1994; Hartung and Jungbluth 1997; Kaye and Jiang 1999; Zhu et al. 2000; Jacobson et al. 2000; Zhang et al. 2003). Usually, one measurement only takes 10 min and the downwind distance from the odour source is less than 1 km and most often less than 0.5 km. Beyond this distance, little odour could be detected. There are two reasons for the observers' inability to detect odour at a greater distance: a) due to the changing wind direction, it is difficult to position the odour observers in the right place on time at such a long distance to catch the odour plume, and b) the measurement takes place mostly during the daytime when unstable or neutral atmospheric stability may not allow odours to travel for a longer distance. Hence, although rather costly, this method is only practical for short distance measurement and the results are obtained under specific weather conditions and topography, which may not be replicated under other conditions. This method is used because the quality of the data is relatively easy to control when compared with the other method using

resident observers. However, the setback distances in most setback guidelines are greater than 0.5 km, and livestock odours have been detected up to 6 km away from the odour source, so this method will not be helpful for odour dispersion model validation for long distances. Besides, most industrial air dispersion models are intended for long distance predictions up to 100 km rather than 1 km or less (EPA US 2004). Ideally, an alternative way for using trained assessors to monitor odours in a certain area over a long period of time would be to arrange odour observers, who would live at the monitoring locations and work full time as assessors, on a grid area (VDI 1993). The high cost would make it impractical.

The second method, i.e., using trained voluntary resident odour observers to monitor odour, has it merits and demerits. It is very useful for long term odour monitoring at the resident's location considering that the resident is at home for a relatively long period of time. Residents are normally at home and available to observe odours during the stable atmospheric weather conditions from the late afternoon, throughout the night, and to the early morning, and some rural residents may be available to monitor odours at home all the time. Therefore, odour occurrence can be observed under various weather conditions and seasonal and diurnal odour occurrence profiles can be obtained. The cost is relatively low because the assessors are voluntary. There has been very limited research done with this method. Jacobson et al. (2001) monitored odour in a 4.8 x 4.8 km grid of farmland in Minnesota, U.S.A. Nineteen trained resident odour observers monitored odour at their residences from late June to mid-November for five months during their normal daily activities. A total of 264 livestock odour events were documented. This research had some limitations for use in setback distance determination purposes. First, because there were 20 livestock operations within or adjacent to this area, observers perceived odours at the same time from multiple sources including dairy, poultry, and swine operations. Second, the odour monitoring period only took place during the warm season and spring and winter odours were not monitored. Third, it used a 3-point n-butanol referencing intensity scale, which might be too coarse for the purpose of odour intensity criteria determination. Fourth, because the main objective of that study was to validate an odour dispersion model, odour occurrence profiles at each observer's location, odour occurrence as affected by the distance from the odour source(s), the odour emission rates of the source(s), and the frequency of various wind directions, etc. were not analyzed. Finally, it is not likely that adequate odour exposure criteria (FIDO) could be determined based only on one experiment. Nimmermark et al. (2003) also used a similar method and measured odours in five areas of Minnesota. Odour emission rates and odour dispersion are affected by the differences in livestock facilities and management practices, varying climatic conditions, and topography in different areas. Neighbouring residents in different areas may experience different odour exposure levels even if the scales of the livestock operations are similar. Further research work is needed to obtain odour occurrence profiles in the neighbouring area of livestock operations.

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; Nimmermark et al. 2003) or the observers' reluctance perform the calibration. Second, some observers might have biased views of the livestock industry, 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.

Weather conditions are the most important factors that affect odour dispersion. The major weather conditions include atmospheric stability, wind speed, wind direction, temperature, relative humidity, solar radiation, and mixing height, etc. Wind direction and speed and atmospheric stability are the dominant factors for air dispersion. The atmospheric stability classes denote atmospheric conditions that represent the amount of vertical mixing in the atmosphere. It is estimated using the Pasquill atmospheric stability classes, as defined by Pasquill (1961), i.e., atmospheric stability classes A (strongly unstable), B (moderately unstable), C (slightly unstable, D (neutral), E (slightly stable), F (moderately stable), and G (strongly stable) (Table 1-1). Stable atmospheric conditions usually occur at night. Strongly stable atmospheric conditions (stability class G) occur during calm, clear nights when vertical mixing is nearly non-existent. Thus, stable atmospheric conditions favour odour and gas travel horizontally so odour and gas may be detected at a great distance from the emission source. Unstable atmospheric conditions occur during daytime. Strongly unstable weather, i.e., atmospheric stability class A, occurs during hot, sunny days when rapid vertical mixing occurs, thus, odour and gas would be dispersed rapidly and may not be able to travel great distances. Neutral atmospheric conditions (stability class D) may occur day or night with high wind speed and/or overcast sky.

Table 1-1. Pasquill stability classes (Pasquill 1961)

Wind speed (m/s)	Daytime solar radiation			Night	
	Strong	Moderate	Slight	Thin overcast or ≥ 0.5 cloudiness	<0.5 cloudiness
<2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

Source odour emission rates are the basic data needed for odour dispersion modeling and they change constantly as a result of changing animal condition and climate. None of the existing setback models or odour dispersion models considered the diurnal and seasonal variations of the odour emission rates. Odour emission rates have been measured randomly during specific time periods (Heber et al. 1998; Lim et al. 2001; Jacobson et al., 2000, Zhu et al. 2000b; Wood et al. 2001, Zhou and Zhang 2003, Zhang et al. 2005). Great variations have been found for odour concentrations and emission rates measured by each study and among different studies (Wood et al. 2001). The mean or geometric mean of the odour emission rates were used for odour dispersion prediction or setback modeling (Zhu et al. 2000a; Jacobson et al. 2000; Lim et al. 1999). Little research has been done to address this problem.

Hartung et al. (1998) reported some observations on diurnal odour emissions from two hog barns and one dairy house. The two hog barns were mechanically ventilated and the dairy barn was naturally ventilated. They found that the odour emissions from livestock housings had a pronounced diurnal pattern and could vary during the daytime due to animal and worker

activities inside the buildings. Zhu et al. (2000b) observed seven different animal facilities for daily variations in odour emissions. Measurements were taken every two hours over a 12-hour period during the day. The differences between the diurnal high and low odour emission were up to five times. However, there was only one 12-hour measurement for each barn, which could not provide statistically sound results. It is reasonable to assume that the seasonal variations would be greater. Schauberger et al. (1999) developed a theoretic model to calculate the diurnal and annual variation of odour emission. The annual variation of the odour concentration of the exhaust air calculated for a hog finishing building was between 687 and 3226 OU while the difference between the daily high and low odour concentrations was found to be 4.6 times. However, Schauberger *et al.* (1999) suggested that long-term measurement of the odour emissions from livestock buildings is necessary to validate the model. Aarnink *et al.* (1995) studied the ammonia emission of swine buildings with partially slatted floors. Ammonia emission was higher during the day than during the night and peak emission occurred in the morning for nursery pigs and in the afternoon for finishing pigs. Ammonia emission changed significantly during the day and during the growing period and varied between seasons (Aarnink et al. 1995). Hence, it is necessary to reveal whether odour emissions may follow similar seasonal and diurnal patterns.

In summary, the odour concentrations and emission rates of an odour source may not be accurately represented by random measurement(s). To use desired odour emission rates for odour dispersion modeling and setback determination, the diurnal and seasonal odour emission profiles need to be identified.

Unlike the progress made in quantifying odour emissions from building sources, little odour emission data was available for manure storages. The major problem is the lack of a standardized method for measuring the odour emission of manure storages. However, until the odour emission data from manure storages has been quantified, little progress can be made in determining the impact of these emissions on the surrounding areas.

One widely used method of measuring emissions from area sources is to place portable wind tunnels, which are open bottomed enclosures, over the emitting surface. Ambient air is filtered and drawn through the tunnel. The air mixes with the emissions from the covered liquid surface and exits from the outlet. Air samples are taken from the outlet. The odour emission rate will be estimated as the product of odour concentration and the air flow rate. Wind tunnels have been used by many researchers to measure gas or odour emissions from cropland, pastures, feedlots, and manure storages (Pain 1988; Watts 1994, Smith 1993).

Unfortunately, little effort has been made to standardize either wind tunnel design or the measurement protocol. Basic mass transfer principles from surfaces suggest emissions are dependent on surface velocity. Other factors such as tunnel geometry and the materials used to construct the tunnel are also expected to influence the results (Smith 1994a). Smith (1994b) compared odour emissions rates from a feedlot using a small (1 m long by 0.25 m wide and 0.2 m high) and large (2 m long by 0.5 m wide and 0.45 m high) wind tunnels. The emission rates using the same bulk wind speeds were shown to be strongly correlated. Emission rates from the larger wind tunnel were consistently lower than those in the smaller tunnel by a factor of 0.8. It was suggested that this difference was largely due to the difference in velocity profiles of the tunnels, e.g., there was a steeper velocity profile gradient in the smaller tunnel resulting in a

higher wind speed near the surface; this study also showed increased odour emissions as bulk tunnel wind speed increased from 0.2 to 2.0 m/s.

Jiang et al. (1995) attempted to design a wind tunnel that provided stable horizontal and vertical flow velocities throughout the tunnel. The resulting design was a tunnel with a 0.8 m length, a 0.4 m width and a 0.25 m height. A perforated baffle and wind vanes were installed in the inlet expansion chamber to create uniform flow in the tunnel. Results from initial studies showed horizontal and vertical profiles fluctuated more as the bulk velocity increased. Bliss et al. (1995) studied the effect of bulk wind speed on ammonia emissions and found that odour emission rate was a function of air velocity to the power of 0.5. Only 11 measurements were taken at bulk wind speeds of 0.33, 0.43, 0.54 and 0.78 m/s.

Loubet (1999) evaluated the impact of wind speed technique and gas sampling method in the exhaust duct of the tunnel. In their study, the recovery rate for tracer gas (carbon dioxide) varied between 70 and 87%. The primary cause of error was discovered to be the non-uniformity of the concentration profile in the measurement section of the tunnel (11%) while the second greatest cause of error was the non-uniformity of the wind speed profile (3%).

Schmidt et al. (2002) used a wind tunnel similar to what used by Bliss et al. (1995). The wind speed on the liquid manure surface was in the range of 0.19 to 1.14 m/s. The odour emission rate had power function relationship with wind speed. It was based on a total of 9 measurements.

Heber et al. (2002) used a buoyant convective flux chamber to measure the odour flux of a stratified lagoon using a simulated wind speed of 1.1 m/s and obtained an average of 1.72 OU per second per square meter of lagoon surface area. Odour flux has an exponential relationship with wind speed. However, it was based on only 5 data points.

In summary, there was insufficient information on estimating the actual odour emission rate by measuring the odour emission rate of the manure storage surface using the wind tunnel method. Therefore, the basic odour emission rate obtained by the wind tunnel method is still reported as odour emission instead of adjusting it according to the actual surface wind speed.

OBJECTIVES OF THIS PROJECT

A rural area with a 5000 sow swine operation on three separate sites in eastern Saskatchewan was selected in order to monitor swine odours using residents living in the vicinity of three swine production sites. The University of Saskatchewan odour research group, the Spirit Creek Watershed Monitoring Committee, and the Alberta Odour Control Team collaborated on this odour monitoring project. Saskatchewan Agriculture, Food and Rural Revitalization and Big Sky Farms Inc. provided strong support to the field work of this project. This project was conjunctly funded by the Saskatchewan Agriculture Development Fund (ADF), Sask Pork, and the Alberta Livestock Development Fund.

The objectives of this project are a) to monitor the odour exposure levels in the vicinity of swine production operations while measuring odour frequency, intensity, duration and offensiveness (FIDO) using trained resident odour-observers, b) to monitor seasonal and diurnal odour

emission profiles of swine operations in Saskatchewan, and c) to provide data to validate odour dispersion models and set science-based setback distances for swine operations. This report presents the results regarding objectives a) and b). The results obtained by this project will be provided to Alberta Odour Control Initiatives where objective c) will be pursued. Hopefully, the results will help to set acceptable levels of odour for the neighbouring community and set appropriate science-based setback distances from swine production sites.

This project had two stages. Stage I took place from December 2001 to February 2003 and was considered to be a preliminary study. Stage II was conducted from May 2003 to April 2004. Considerable changes were made to the research work of this stage compared to the research plan laid out in the original proposal. In March 2003, realizing the needs to encourage the residents to participate in the project and in order to obtain credible odour monitoring data, additional funding was applied for and was approved by Saskatchewan ADF in April 2003 to provide funding to compensate the residents and hire two odour assessors (nasal rangers) to measure the odour occurrences during the warm season (May to October).

To obtain more data on seasonal odour emissions, the research team also decided to increase the frequency of odour emission measurements from once every two months to once a month (except during December and February), which doubled the cost of odour measurement. To look for differences in diurnal odour emission, we also decided to collect diurnal odour emission measurements from 6 types of swine production facilities (4 different types of swine rooms and 2 stages of manure storage cells), and each facility was measured for two days. The additional funding was provided by the Alberta Livestock Development Fund to cover the lab cost of the odour measurements.

Hence, the research work at Stage II included residents' odour monitoring, odour assessors (nasal ranger) odour monitoring, and odour emission measurements including seasonal and diurnal measurements.

Part 2. Stage I: Preliminary Study Of Odour Occurrence Monitoring By Trained Resident-Observers In The Area Neighbouring Swine Farms

OBJECTIVE

This part reports the results from the Stage I of the project. The objective was for trained resident odour observers to monitor the odour exposure levels of the residents living in the vicinity of swine production operations.

MATERIALS AND METHODS

ODOUR MONITORING AREA AND THE SWINE OPERATIONS

The study area was located in eastern Saskatchewan, Canada (longitude 103.0^{o} and latitude 51.8^{o}). Three separate sites of a 5,000 sow farrowing-to-finishing operation were located in this area. The three sites are the farrowing (5,000 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. The gestation barn on the farrowing site had five rooms of different sizes. The farrowing barn had 28 identical rooms with 32 crates per room. The nursery site had 32 identical rooms while the finishing barn had 10 identical rooms. Table 2-1 gives the information on the facilities on each site. The nursery site was 3.0 km west of the farrowing site, and the finishing site was 11.5 km northeast of the farrowing and nursery sites. A total of 147 residences were located within 8.0 km of the three sites, including a small town. Figure 2-1 outlines this area. The influence of topography on odour dispersion was considered minimal due to the flatness of the experimental area and the sporadic presence of bushes.

There were other small livestock farms in this area. Thirty-four families had cow-calf farms ranging from 4 to 250 cows, of which five large farms had 100 to 150 cows and the largest farm was a 250 head cow-calf operation. There was a 100-milking-cow dairy operation and a small swine farm with up to 100 pigs located south of the town. The other three swine finishing sites were 16 km north of the town.

RESIDENT ODOUR OBSERVERS AND DATA COLLECTION

Fifty resident volunteers were trained as odour observers. They were trained to use a 5-point static referencing intensity scale with n-butanol solution in-water to rate 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 are 250, 750, 2250, 6750, and 20250 ppm, respectively, corresponding to oral ratings of very faint, faint, moderate, strong, and very strong odours (Table 1-1; Guo et al. 2001). They were also trained to use a 5-point oral scale for hedonic tone, i.e., offensiveness, offensiveness 1 being not annoying, 2 somewhat annoying, 3 annoying, 4 very annoying, and 5 extremely annoying.

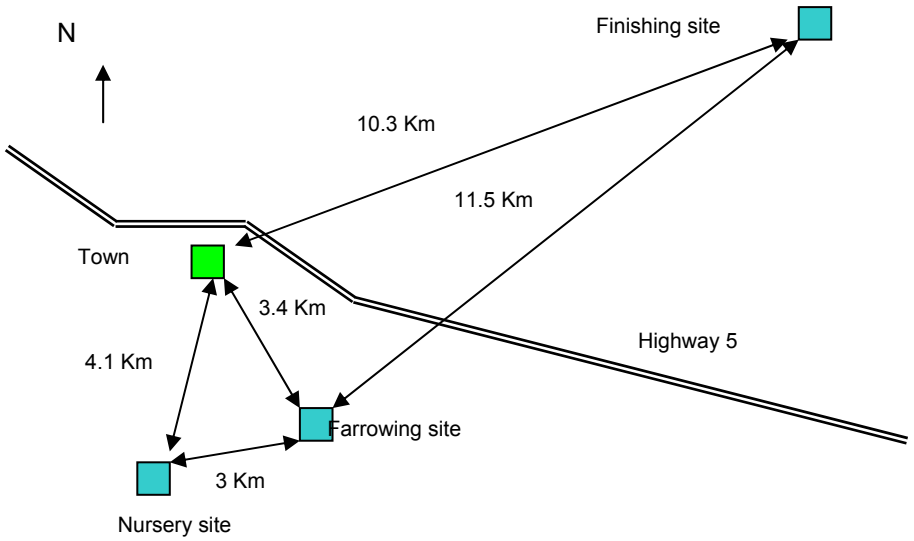


Figure 2-1. Outline of the odour monitoring area

Table 2-1. Information on the swine farms.

Site	Facility	Capacity	Total area (m2)
Farrowing	Breeding/gestation barn	5144 sows in five rooms	10,246 m^2
	Farrowing barn	896 sows (28 rooms, 32 sows per room)	5182 m^2
	FR-EMS cell 1	For the whole farrowing site	2,916 m^2 (54 m x 54 m)
	FR-EMS cell 2	For the whole farrowing site	4,761 m^2 (69 m x 69 m)
Nursery	Nursery barns	22,400 weaner pigs in a total of 32 rooms in 4 barns (736 pigs per room)	7824 m^2
	N-EMS cell 1	For the whole nursery site	5,625 m^2 (75 m x 75 m)
	N-EMS cell 2	For the whole nursery site	9,801 m^2 (99 m x 99 m)
Finishing	Finishing barn	12,500 pigs (10 rooms, 1250 feeder pigs per room)	9550 m^2
	FN-EMS cell 1	For the whole finishing site	5,625 m^2 (75 m x 75 m)
	FN-EMS cell 2	For the whole finishing site	9,801 m^2 (99 m x 99 m)

Table 2-2. 5-point odour intensity referencing scale.

Odour Intensity	Odour Strength	n-Butanol in Water (ppm)
0	No odour	0
1	Very faint	250
2	Faint	750
3	Moderate	2250
4	Strong	6750
5	Very strong	20250

The odour observers were asked to record odours they detected at or around their residences during their daily activities. The data recorded included odour intensity, offensiveness, occurrence time, duration, character, a general statement about the odour, and their own physical conditions. The study started in December 2001 and was completed in November 2002.

METEOROLOGICAL DATA MEASUREMENT

A weather station was installed near the finishing site. Weather data, including wind speed and direction, temperature, relative humidity, and solar radiation, were monitored once every minute and 10-minute averages were recorded. However, it was not set up until April 2002. Therefore, in order to generate annual wind rosette and atmospheric stability distributions, the weather data of Yorkton, a city 68 km southeast of the study area, was used. The Yorkton and Rama area is fairly flat and the difference in weather was considered negligible. Wind speeds were obtained from the local weather station while hourly atmospheric stability class data were obtained from the Yorkton weather station.

As discussed previously, although many weather parameters may have an impact on air dispersion, wind speed and direction and atmospheric stability class are the most important factors; therefore, their impact on odour occurrences will be analyzed. Temperature impact on odour occurrences will be reflected by seasonal odour occurrence.

DOCUMENTING ODOUR GENERATION AND CONTROL ACTIVITIES

Acute odour generation or odour control activities, e.g., emptying the EMS, draining manure pits, or covering the EMS with straw, etc., were documented by the barn managers. Chopped barley straw was blown over the surface of the manure storage cells three times on the Nursery site in March, June, and July, twice on the farrowing site in March and June, and once on the finishing site in June. Manure was applied to the nearby crop land of the three sites twice during the study period: between May 28 and June 8, 2002, and again between October 4 to 12, 2002.

RESULTS AND DISCUSSION

Between December 2001 and November 2002, fifty individuals from 39 families participated in the study. Twenty-three families detected swine odour while the rest did not detect any swine odours. Sixteen families did not detect any swine odours, 11 of them located 2.3 and 6.0 km from the nearest swine sites and five of them were beyond 6.0 km from the nearest swine sites. The distances between the 23 residences where odours were detected and the nearest swine site were between 1.6 and 6.0 km. Of the 23 families, seven owned cow-calf operations and one owned a dairy operation. All the families owned grain farms except one swine barn worker's family and two families who were retired from farming. A total of 322 odour events were reported. By checking the wind direction recorded by the weather station and the manure application record, five odours were assumed not to be from the three swine production sites or manure application fields because the detected locations were either not leeward of the swine sites, out of the area (greater than 18 km away), the locations were uncertain, or the odour characters were unknown. For example, one odour event was reported as an unknown odour at 6.5 km away from the closest swine site in December and was considered invalid. These five odour events were excluded from the study. Therefore, the three swine sites and nearby manure application fields might be the probable sources of a total of 317 odour events. However, some other odours from other livestock operations including the observer's or the neighbour's cow-calf operations, the dairy operation, or the small family swine farm could have been mistakenly

considered as swine odours, especially during the manure removal periods when there were a high number of odour emissions.

Because eight observers' families also owned beef or dairy cattle farms, a concern was raised as to whether exposure to one livestock odour such as cattle odour would reduce the observer's olfactory sensitivity to different odours such as swine odour. In a five-month period of odour monitoring by resident observers, no swine farmers reported swine odours and no cattle or dairy farmers reported cattle or dairy odours, although their residences were just next to or very close to their own livestock operations. However, they could all detect odours from other livestock operations with different animal species which were 0.5 to 4.8 km from their residences (Guo et al. 2001). According to VDI 3940 (1993) and CEN (1997), smokers are allowed as odour panellists because no statistically significant differences in odour assessment are found between smokers and nonsmokers. Hence, the individuals involved in cattle production were assumed to be unaffected in their ability to detect swine odours.

SEASONAL ODOUR OCCURRENCE PROFILE

Table 2-3 presents the number of odour events reported during the study on a monthly basis. Figure 2-2 also shows the seasonal odour occurrence profile and gives the percentages of each month's odour events. Swine odours were observed every month during the entire experimental period. The months with high odour occurrences were May, June, and July; the total number of odour events made up 49.2% of annual events. The least odorous months were March, April, and December; each had only 2.5 to 4.1% of annual odours. During mid-November to late April, the manure storages were frozen, which was probably the main reason for low odour occurrence during this period of time. The warm season from May to October had a total of 223 odour events (70.3%), which was more than twice of that for the cold season from November to April, which had 94 odour events (29.7%).

The manure storages were covered with barley straw in March to keep them frozen longer into the spring and to reduce odour emission after the storages thawed. This might be the reason for the rapid increase in odour events in May instead of in April. A total of 47 odour events were reported during the two manure application periods, 38 and 9 in the May-to-June and October manure application periods, respectively. Spring manure application resulted in more odour events than that of fall. Swine odours were detected more frequently during the manure application period than at other times. For instance, during the June manure application period, an average of three odour events per day was reported, whereas the rest of June had 1.5 odour events per day.

DIURNAL ODOUR OCCURRENCE PROFILE

Figure 2-3 shows the diurnal distribution of odour events annually, during May-to-October, and during November-to-April. As shown in Fig. 2-3 a), most odour events (99.4%) were detected from the early morning (0500h) to the late evening (0000h) when observers were awake. Only two odour events were detected by one odour observer during 0000 to 0500h when the observer went outside to check the cattle. For all odour events that occurred during the year, 54.6% of the odours were detected before 0900h or after 1700h. The remaining 45.4% were detected between 0900h and 1700h. For air dispersion purposes, daytime refers to 1 h after sunrise and 1 h before

sunset. The rest of the time is then referred to as night. Since the daytime length is different for different times of the year, the data were further separated into two periods: the warm season from May to October and the cold season from November to April. From May to October, if we consider daytime from 0900 to 1700h, then the majority (59.6%) of the odour occurred during night (Fig. 2-3 b)). Similarly, from November to April, 63.8% of odours were detected during night-time from 1600 to 1000h (Fig. 3 c)).

Table 2-3. Summary of monthly odour events.

Month-Year	All odour Events	Intensity 1* Events	%**	Intensity 2* Events	%**	Intensity 3* Events	%**	Intensity 4* Events	%**	Intensity 5* Events	%**
12-2001	9	0	0	0	0	7	77.8	1	11.1	1	11.1
01-2002	25	1	4.0	5	20.0	9	36.0	8	32.0	2	8.0
02-2002	17	2	11.8	0	0.0	2	11.8	9	52.9	4	23.5
03-2002	8	0	0.0	1	14.3	5	71.4	1	14.3	0	0.0
04-2002	13	2	15.4	1	7.7	3	23.1	4	30.8	3	23.1
05-2002	42	3	7.1	6	14.3	14	33.3	16	38.1	3	7.1
06-2002	59	1	1.8	6	10.7	10	17.9	27	48.2	12	21.4
07-2002	55	2	3.7	3	5.6	20	37.0	21	38.9	8	14.8
08-2002	19	0	0.0	5	26.3	7	36.8	2	10.5	5	26.3
09-2002	29	0	0.0	4	26.7	3	20.0	6	40.0	2	13.3
10-2002	19	0	0.0	0	0.0	1	5.3	12	63.2	6	31.6
11-2002	22	1	4.5	10	45.5	6	27.3	5	22.7	0	0.0
Total	317	12	4.0	41	13.8	87	29.2	112	37.6	46	15.4

*The numbers reported in these columns include only odour events with reported intensities; the 19 odour events without reported intensities are not included.
**The percentages reported were calculated using all odour events with reported intensities.

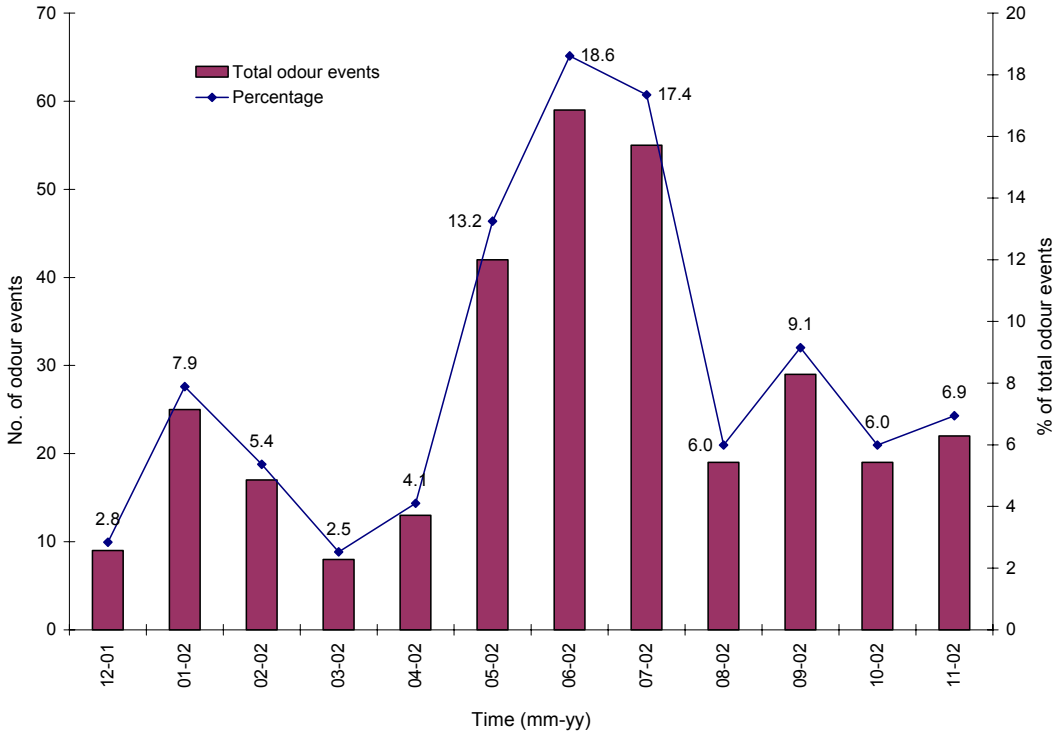


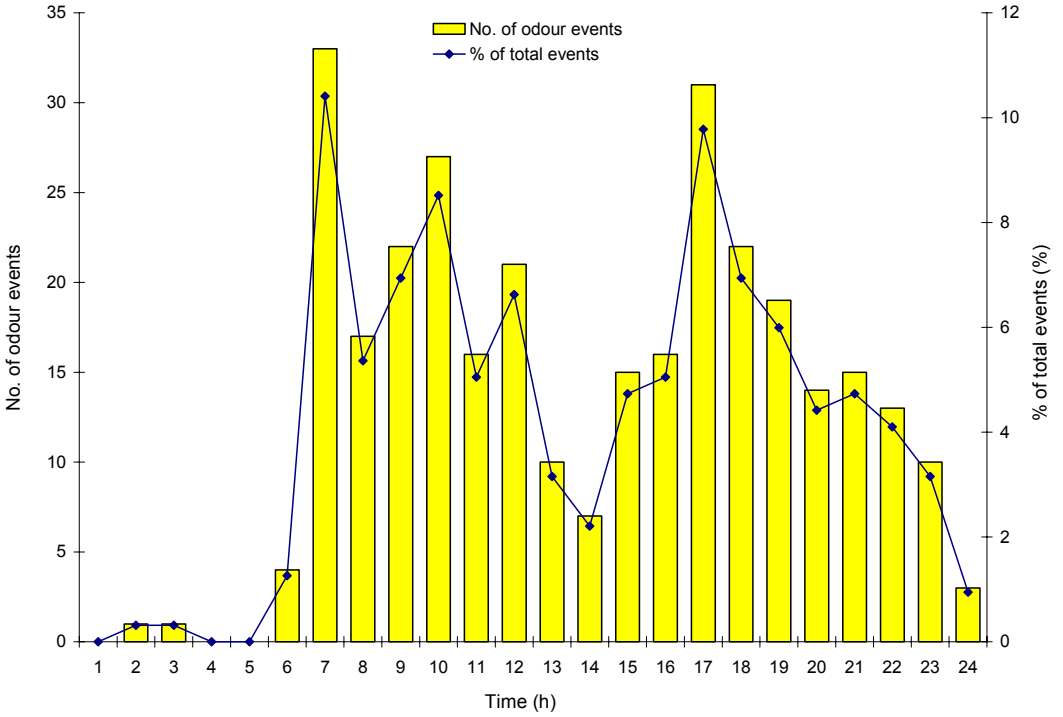
Figure 2-2. Seasonal odour occurrence profile

As shown in Fig. 2-3 a), there were two peak hours for odour detection. One was in the early morning between 0600 and 0700h and another in the late afternoon between 1600 and 1700h which accounted for 10.4% and 9.8% of the annual odour events, respectively. There was a low odour detection period during the daytime between 1200 and 1400h with only 5.4% of odour events detected during this period of time. There were two reasons for the observed odour diurnal occurrence profiles, i.e., the atmospheric stability and the availability of observers who were outside. Atmospheric stability was the main determining factor for odour dispersion. Stable atmospheric stability classes that favour odour travel can only occur during the late afternoon, throughout the night, and until the early morning. Observers were most likely to be outside during the two peak odour detection hours during which stable atmospheric conditions were likely to occur, which resulted in high odour detection. However, observers were not outside to detect odours at night. During the daytime, unstable weather was not in favour of odour travel, which explains the low odour detection between 1200 and 1400h. However, this area was fairly windy, which might result in neutral atmospheric stability class, and therefore, odours were detected through out the daytime. A more detailed analysis on the impact of atmospheric stability on odour dispersion is presented in Part II of the study (Guo et al. 2005).

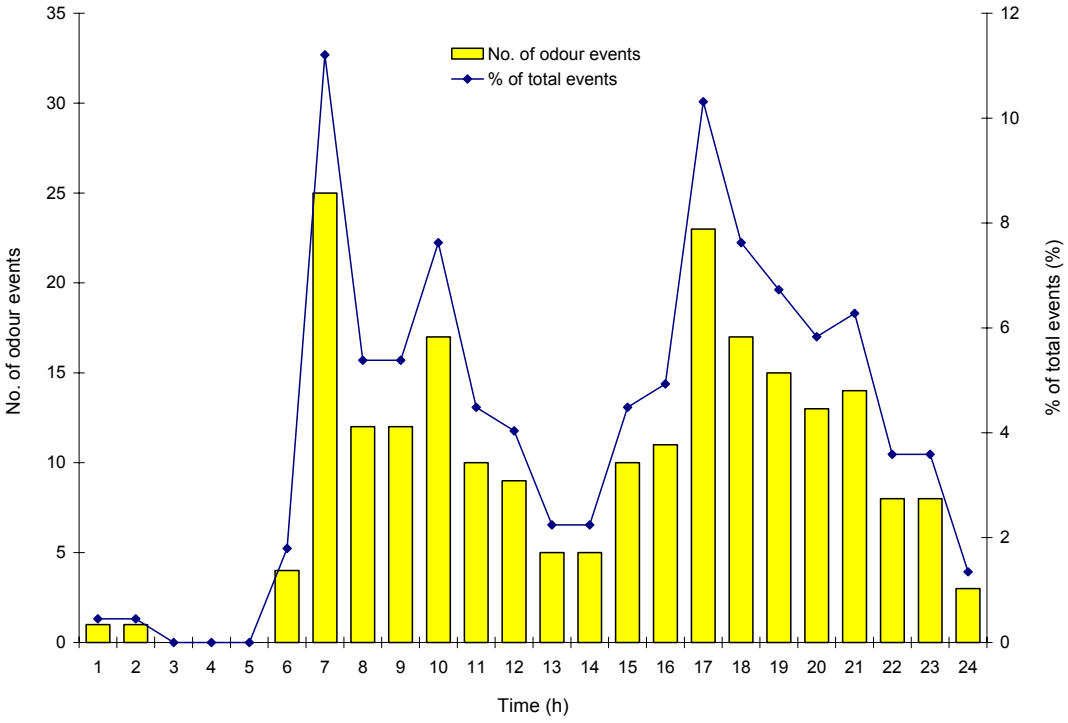
Figure 2-3 b) and c) show the different diurnal odour detection profiles of the warm season and the cold season. With the majority of the odour events detected in the warm season, the diurnal odour detection profile was similar to the annual one. However, during the cold season odour events were detected the most during the hour before noon from 1100 to 1200h followed by 0800 to 1000h, and then 0600 to 0700 and 1600 to 1700h. There are three possible explanations: a) the stable atmospheric conditions were longer in the cold season due to the short day length, b) the observers who did not own livestock might have got up at a later time than they did during the warm season, c) like most people, the observers might have been outside the most in the afternoon between 1600 and 1700h regardless of the season.

ODOUR OCCURRENCE AT VARIOUS DISTANCES AND DIRECTIONS FROM THE ODOUR SOURCE

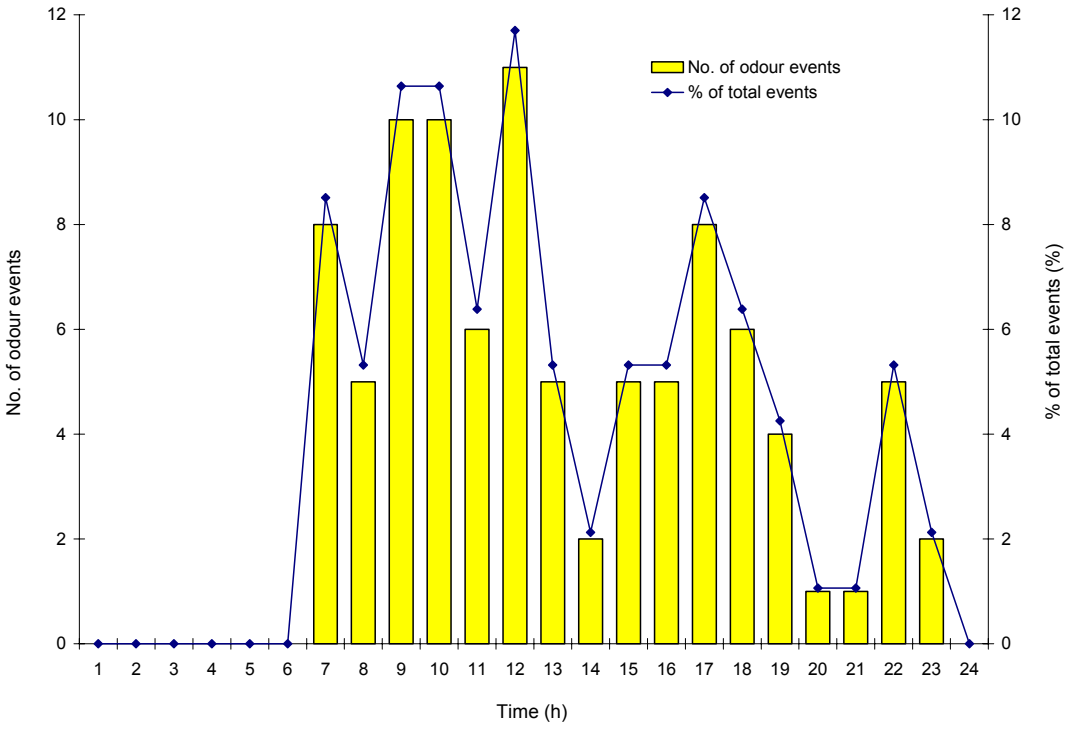
As shown in Fig. 2-4, there was no correlation between the number of odour events and the distances from the observers' residences to the swine production sites ($P>0.01$). It indicated that the distance between the observer and the swine site was not the only determining factor for odour detection frequencies. The direction of the residence from the odour source was another important determining factor. The annual and May-to-October frequencies of winds from various directions are shown in Fig. 2-5. The annual prevailing winds came from four directions: northwest (NW), west (W), west-north-west (WNW), and south (S) with frequencies of 11.1%, 10.1%, 9.5% and 9.9%, respectively. During the warm season, the prevailing winds also came from these directions: W (13.1%), WNW (8.6%), NW (8.7%), and S (10.1%) while in cold season they came from W (9.0%) to NW (13.5%) and also S (9.6%).



a) December 2001 to November 2002



b) May to October, 2002



c) December 2001, January to April, and November 2002

Figure 2-3. Diurnal odour occurrence profile

The locations with high odour events were mostly downwind from these four directions. Observer R1 reported the most odour events and was 2.8 km northeast of the nursery site and 3.8 km northwest of the farrowing site. Winds from S, SSE, and SSW could transport swine odours to this location. Seventy-eight odour events were detected at this location on 62 days during the year. The small family swine farm (about 100 pigs) was located southwest across the intersection from the residence of R1. It is possible that some of the odour events detected were from this farm. The 100-cow dairy operation was also located close to the observer's residence.

The second highest number of odour events were reported by Observer R3 who lived 5.4 km southeast of the finishing site and NW winds could bring odours to this location. No other livestock operations were located in the same direction as the finishing site. A total of 50 odours were detected on 47 days. The residence of Observer R6 was also located 1.6 km southeast of the nursery site and 3.3 km southwest of the farrowing site. Most odours that occurred at this location were brought by the prevailing NW winds. Compared to R3, this observer was much closer to the odour source yet only detected 16 odour events.

Observer R5 reported 17 odour events and lived 5.8 km south-south-east of the finishing site where NNW winds (annual frequency 5.6%) or NW winds might have brought swine odours to the location.

Observer R4 lived 5.7 km east of the farrowing site and downwind of the west winds and reported 26 odour events. Observer R8 was also located 5.9 km east of the farrowing site and detected 13 odours.

Observer R2 lived 3.1 km and 7.0 km WSW of the nursery and farrowing sites, respectively. The frequencies of ENE and E winds were only 1.8% and 2.7% annually, and 2.4% and 3.3% during May-to-October, respectively. This location was in a direction with the fewest winds blowing odours from the swine sites to it. Even so, this observer detected 21 odour events. However, observer R7, who also lived 1.6 km west of the nursery, only reported six odour events.

Some other observers also lived closer to the swine sites but detected fewer odours. Observer R10 lived 2.1 km northeast of the finishing site and reported five odour events. R11 was 2.1 km northwest of the finishing site and reported 13 odour events. The swine worker, R12, lived 1.8 km northeast of the farrowing site and reported two odours with intensity 1 and 2, respectively; however, the olfactory sensitivity of R12 to swine odours might have been affected by working in a swine barn.

The farthest detection location was 6.0 km away from the farrowing site; Observer R9 detected two odour events. This location was also 6.3 km southwest of the finisher site. This observer raised cattle on his farm. It is notable that of the 16 families that did not detect any swine odours, the closest family was located 2.3 km north of the nursery site (downwind of prevailing S winds) and northwest of the farrowing site.

Therefore, besides distance and direction, other factors may have affected the number of odour events reported by individual observers, including the frequency and duration of time spent outside by the observer, which depended on the habits or lifestyle of the residents, and the olfactory sensitivity of the observers to swine odours, which may vary greatly from one observer to another.

Figure 2-6 shows the reported annual odour durations and frequencies of the 23 families. Twenty locations with the distances of 1.6 to 6.0 km had annual odour durations between 1 and 70 h and detection frequencies from 0.01% to 0.80%, which means annual non-odour detection frequencies of 99.20% to 99.99%. Three locations exceeded 1% occurrence frequency, i.e., R1 (2.8 km, 79 odour events, 291 h, 3.32%), R3 (5.4 km, 50 odour events, 132 h, 1.51%), and R8 (5.9 km, 13 odour events, 105 h, 1.19%). It is should be noted that when the recorded durations were not well defined, estimations were made according to the observers' claims of durations such as durations recorded by observer R1 as "the whole morning," "the whole afternoon," "all day," etc. and the wind direction changes during the claimed time period. As previously discussed, odours from other sources such as the dairy farm and the nearby small swine farm could have been included in the total odours detected by observer R1; therefore, the actual odour occurrence frequency of this location as caused by the farrowing and nursery swine farms might be lower.

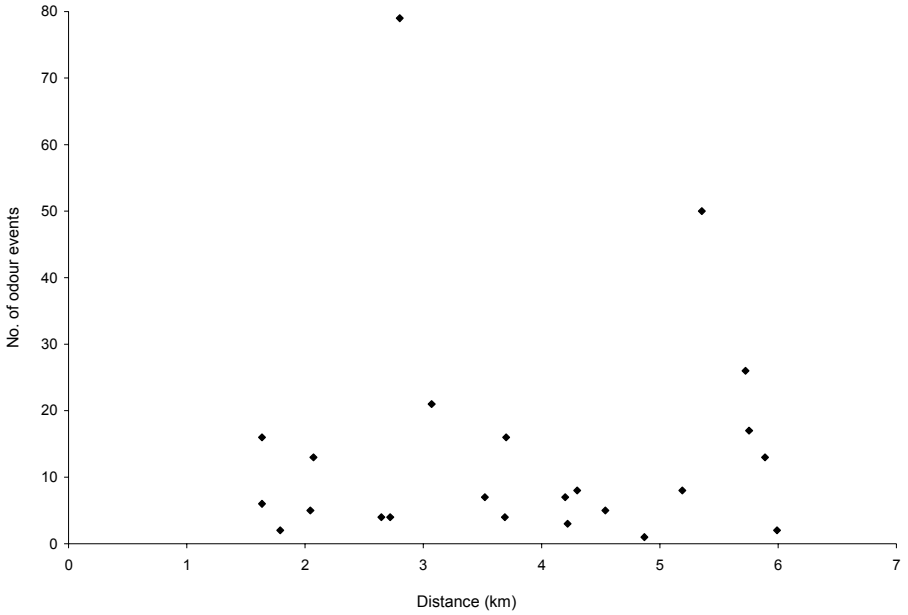
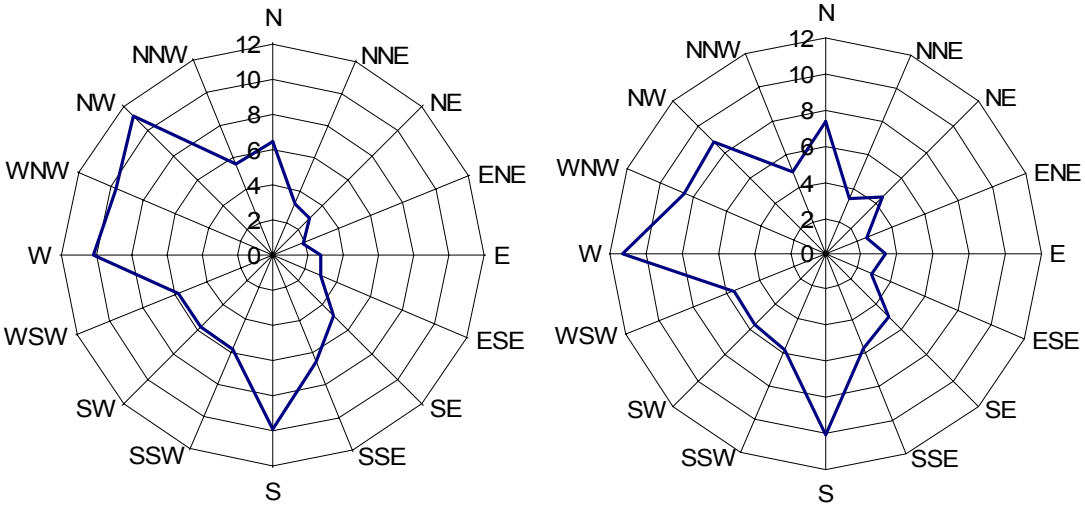


Figure 2-4. Odour occurrence number at various distances



(a) Annual (calm 5.1%) (b) May-to-October (calm 5.3%)

Figure 2-5. Wind rosette of the study area for 2002

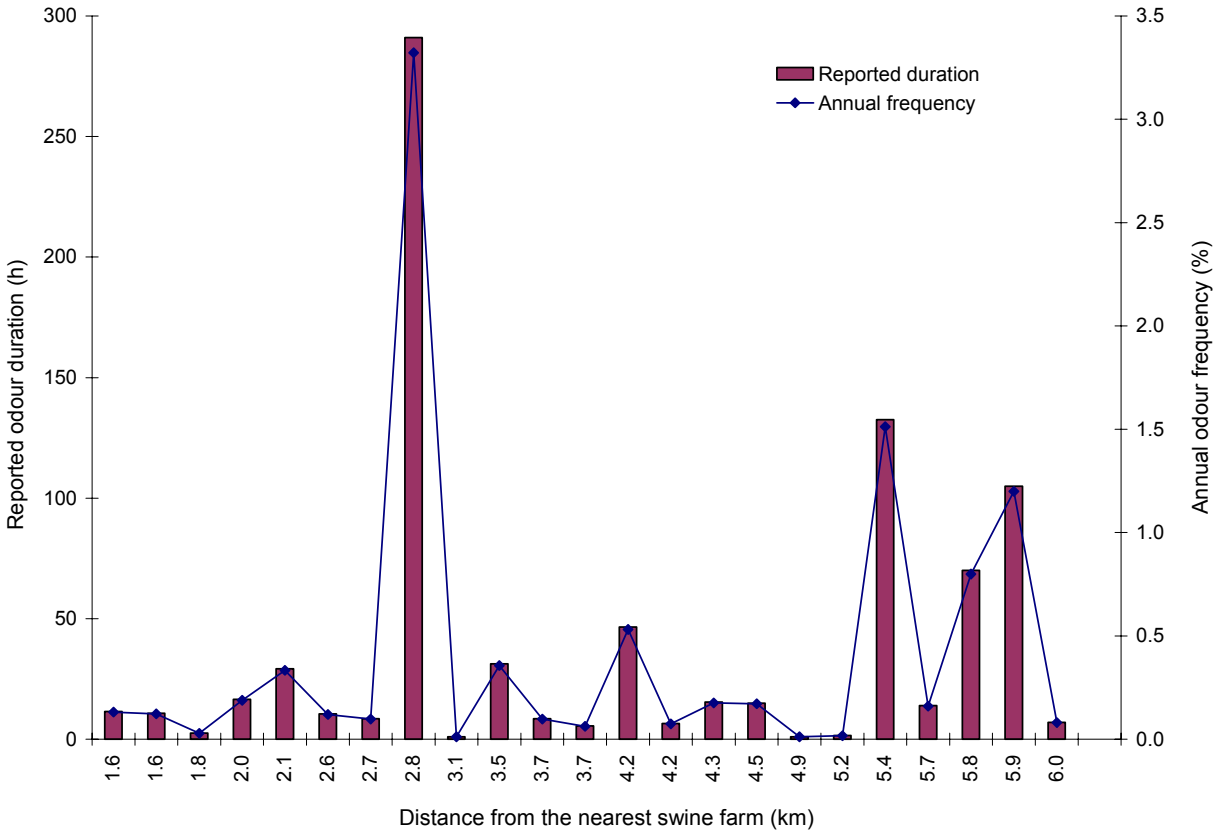


Figure 2-6. Reported annual odour durations and frequencies of each location

DISTRIBUTION OF ODOUR INTENSITY AND OFFENSIVENESS

A total of 298 odour events were reported with odour intensities. As shown in Table 2-3, odours with intensity 4 (strong odour) were reported the most and accounted for 37.6% of all odours. Odours with intensity 3 (moderate odour) were the second highest (29.2%) followed by odours with intensity 5 (very strong odour, 15.4%). Odours with intensity 1 (very faint odour) were reported the least (4.0%) while intensity 2 (faint odour) was reported as 13.8% of all odours. This is quite different from the result reported by Guo et al. (2003), where odours with intensity 1 or 2 made up 66.5% of the total 263 odours reported by local resident odour observers.

The distribution of various odour offensive levels was similar to intensity distributions. Odour events with offensiveness 1 to 5 made up 4.7, 18.2, 30.7, 29.4, and 16.9% of all events, respectively. Odour events with offensiveness 3 or above accounted for 77.0% of all events.

Regarding seasonal intensity distributions, odours with intensity 3 or 4 were detected all year round, as presented in Table 2-3. Odours with intensity 5 were also reported almost every month except March and November. Odours with intensity 1 or 2 were not reported for some months. During the winter time, with the manure storage frozen, total odour emissions from the swine farms were reduced. However, odours with high intensities had been continuously reported. For example, in December 2001, all odours reported were with intensity 3 or above.

To obtain the intensity distribution at various distances from the odour sources, the total number of odour events for various intensities are plotted against the detection distances in Fig. 2-7. Within 2.5 km from the odour sources, odour events with intensities 1 and 2 were reported more than higher intensities while when distance increased, high odour intensities were reported more often.

The above result caused concerns regarding the accuracy of odour intensity ratings by the observers. The percentiles of odour intensities observed by the five odour observers who reported the most odour events are given in Fig. 2-8. It was found that these observers reported most of the odours as intensity 3 or above. Of the 79 odour events that observer R1 reported, 20.3% consisted of intensity 1 or 2 odours, which was the highest among these five observers. Observer R5 living 5.8 km from a swine site reported 17 odour events: 88% were reported as intensity 4 or 5, 12% as intensity 3, and the observer never reported intensity 1 or 2 odour events. The most distant observer R9 reported two odours with intensity 4 and 5, respectively. At such distance from the swine site, very faint or faint odours were most likely to occur. It is obvious that some observers might have over-estimated odour intensities. They were only trained once in using the referencing n-butanol scale and did not calibrate their noses periodically during the experimental period. They might not be able to memorize the strength of the intensities and simply used the oral scale, which mainly depends on one's understanding of odour intensity. Besides, when the odour is offensive, it is sometimes difficult to distinguish intensity from hedonic tone.

The above results caused three concerns for using the voluntary local residents as odour observers. First, the quality of the data, especially the odour intensity rating, might not be ensured due to the lack of periodic nose calibration using a standard n-butanol intensity scale (Guo et al. 2001, 2003, 2004b; Nimmermark et al. 2003) or some observers' reluctance to do so (Guo et al. 2004b). Secondly, some observers might have biased views on intensive swine operations, which may result in biased data. Thirdly, odour monitoring was only done at the volunteers' residence locations, which might not cover all desired locations. Hence, improvement of this method is needed to increase the accuracy and credibility of the data obtained by this method. The possible options include implementing periodic nose calibration, screening the observers for bias for or against the intensive livestock operations, and taking measurements at designated times.

IMPACT OF WIND SPEED ON ODOUR OCCURRENCE

Wind speeds recorded by the local weather station were used. Figure 2-9 shows a total of 179 odour events for which on-site wind speed data were available. The number of odour events has an inverse linear relationship with the wind speed ($r^2 = 0.613$); the lower the wind speed, the more odours were reported.

The total number of odour events with different intensities at various wind speeds is shown in Fig. 2-10. Odour events with high and low odour intensities were reported at almost all ranges of wind speeds. No specific pattern or relationship was found between the total number of odour events with a specific intensity and wind speed except that the number of odour events for all intensities generally decreased with the increasing wind speed. High odour intensities were reported even with high wind speeds. For instance, a total of 11 odour events were reported

when the wind speed was between 8.0 and 9.4 m/s. Of these events, one with intensity 3 was reported 1.6 km away from a swine site. Another one with intensity 4 was reported at a distance of 2.8 km from a swine site. The other nine events were of intensities 4 or 5 and were detected at distances ranging from 4.9 to 5.8 km away from the odour source(s). At such great distances from the swine farms, combined with high wind speeds, the odour would be much diluted and low intensities were generally expected. As discussed in Part I of this study, this again caused concern about the possible over estimation of odour intensity by the odour observers.

IMPACT OF ATMOSPHERIC STABILITY ON ODOUR OCCURRENCE

IMPACT ON SEASONAL ODOUR OCCURRENCE

Atmospheric stability data from the Yorkton weather station was used in this study. Table 2-4 gives annual, warm season (May to October), and cold season (November to April) occurrence frequencies of various stability classes during the experimental year. Figure 2-11 shows the monthly frequencies. This area was windy; stability class D had the highest annual occurrence frequency (55.2%) with monthly variations from 38.2% in July to 62.5% in November. Stability class E occurred 16.8% annually with some seasonal variation (the lowest, 12.2%, in June and highest, 21.7%, in September). Stability class F occurred 7.9% annually with seasonal variation ranging from 4.5% in February to 11.0% in October. Stability class G occurred 3.9% annually with seasonal variation ranging from 1.8% in June to 7.0% in January. For all stable weather conditions (stability classes E to G), the annual frequency ranged from 20.1% in June to 32.9% in January with average of 28.8%, as shown in Fig. 2-11.

Unstable weather conditions mostly occurred during the warmer season from May to October with the highest occurrence frequencies in June and July, as given in Table 2-4 and Fig. 2-11. Stability classes A to C had low annual occurrence frequencies ranging from 0.3% to 11%. For all the unstable weather conditions (stability classes A to C), the annual average frequency was 16.3% with seasonal variations ranging between 6.0% in December and 32.4% in July, as shown in Fig. 2-11.

Table 2-5 gives the number of odour events detected under various atmospheric stability classes. It only includes the 298 odour events with recorded intensities. Of these odours, 61.7% were detected under stability class D. During the daytime under stability class C, 19.8% of odour events were detected, which is higher than the annual occurrence frequency of stability C of 11.1%. Only 3.4% odours were detected under stability class B while no odours were reported under stability class A. Together, 23.2% of odour events were detected under unstable atmospheric conditions (stability classes A to C), which was higher than the total occurrence frequency of stability classes A to C of 16.1% (Table 2-4).

Fewer odour events were detected under stable weather conditions than had been expected. In fact, 10.7% of odours were detected under stability class E, and only 2.3% and 2.0% of odours were detected under stability classes F and G, respectively. Together, only 15% of odour events were detected under stable atmospheric stability classes E to G, which was lower than the total annual occurrence frequency of stability classes E to G of 28.6% (Table 2-4).

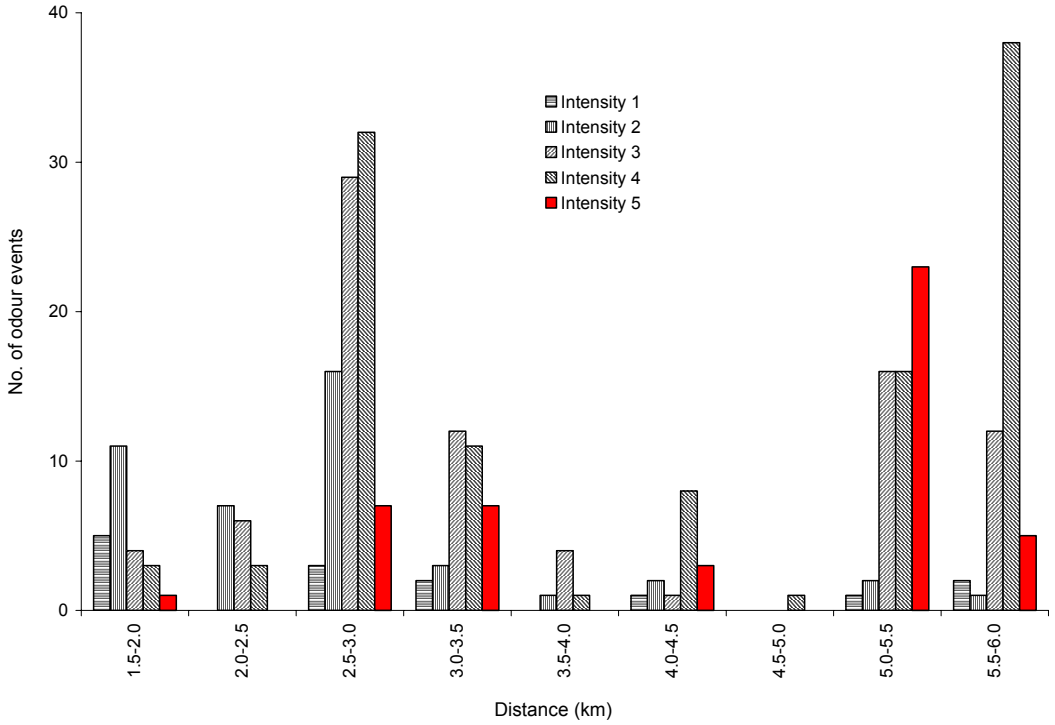


Figure 2-7. Odour events with various intensities at different distances

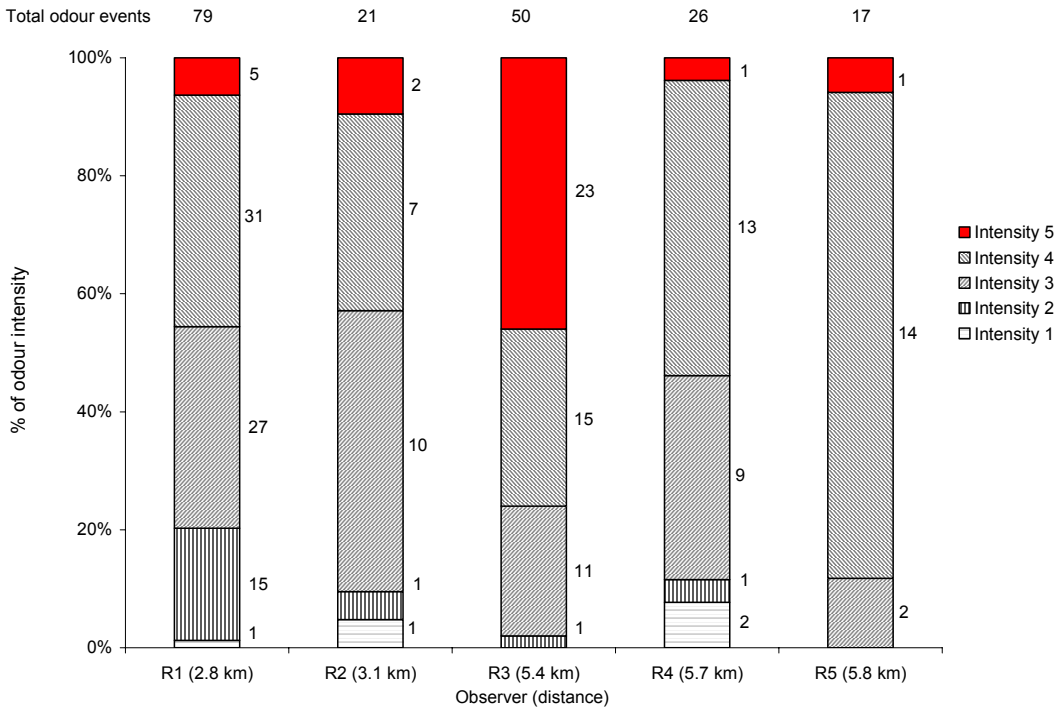


Figure 2-8. Odour intensity distribution of the five observers reporting the most odours.

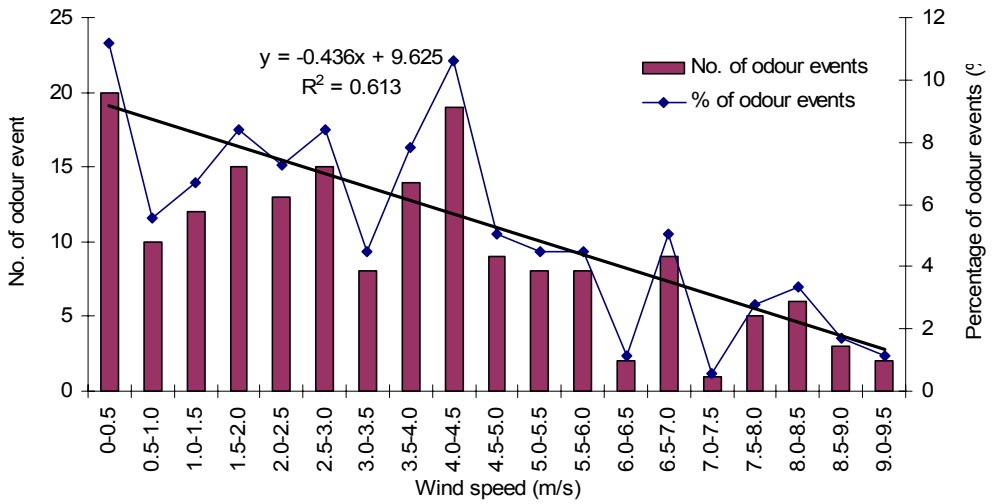


Figure 2-9. Number of odour events at various wind speeds (the regression line corresponds to the number of odour events)

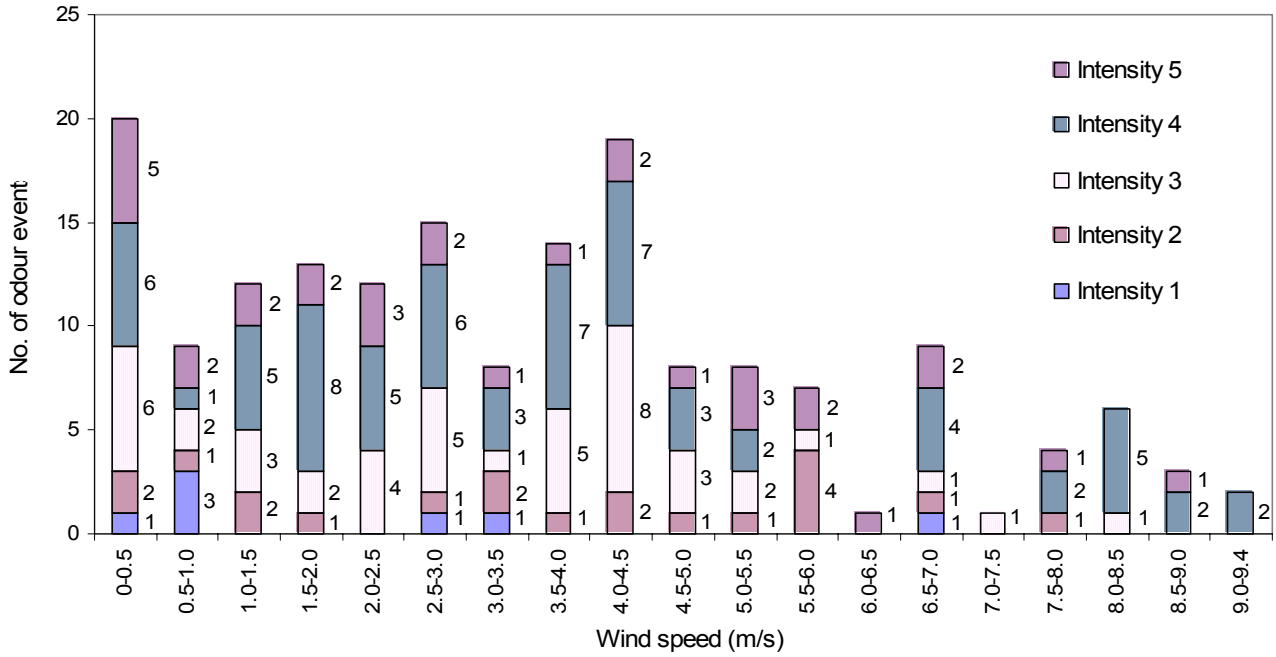


Figure 2-10. Number of odour events with different intensities at various wind speeds

Figure 2-11 also shows the monthly odour events during the year. During May to August, unstable weather was at the highest occurrence frequency while stable and neutral weather conditions were at the lowest occurrence frequencies of the year, which indicated that this period of time was the least favourable for odour travel. However, this period had the highest number of odour events. Comparing Tables 2-4 and 2-5, it would appear that odour occurrence frequencies to some degree reflect the occurrence frequencies of various stability classes. In another word, it seems that the atmospheric stability classes did not have much influence on odour dispersion. This would be contrary to the basic air dispersion principle that stable weather

conditions would allow air to travel for farther distances than unstable weather conditions. There might be two main reasons for the observed results. First, atmospheric stability is not the sole determining factor for odour dispersion. Source odour emission rates increased significantly during the warm season due to a) the increased odour emission from manure storage basins during this season compared to the cold season when the manure storage basins were frozen, and therefore emitted little or no odours, and b) the odour emission rate of swine barns was generally higher in the warm season due to the higher temperature compared to that of the cold season. Increased odour emissions would allow odour travel for longer distances, even under unstable atmospheric conditions. Second, the occurrence frequency detected by odour observers was partly determined by the availability of observers outdoors. Generally people spent more time outdoors during the warm season than during the cold season and are therefore in a better position to detect odours. Furthermore, stable atmospheric conditions occurred mostly during the night when observers were not outside to detect odours. Odour observers were most likely to be available during the daytime to detect odours that traveled to their locations, which explains the higher percentage of odours detected under stability class C. The diurnal odour occurrence will be discussed further in the next section. In summary, the odour occurrence as detected by observers indicated that source odour emissions and availability of observers for odour detection might be the dominant factors for odour detection frequencies. Atmospheric stability had thus less impact on odour detection frequency. The high percentage of odours detected under stability class D indicates that odours could travel long distances when high wind speed or overcast conditions were present.

IMPACT ON DIURNAL ODOUR OCCURRENCE

Figure 2-12 shows the mean cumulative occurrence frequency of each stability class in each hour period during a day in the study period. The data were obtained by cumulating the occurrences of each stability class during each hour period of every day over the year and then calculating the percentage of each stability class during each hour. With an occurrence frequency ranging from 39.9 to 72.0%, stability class D was dominant during the day and night. During the daytime, stability class C had a higher frequency (29.0%) than classes B and A (the maximum being 14.0% and 2.3%, respectively). Unstable weather with stability A to C peaked between 1200h and 1300h with the total frequency of 44.2%. The stable weather conditions with stabilities E, F, and G occurred mostly at night with the maximum frequencies values of 34.3, 17.9, and 11.9%, respectively, which occurred between 2100 to 0400h. The overall frequency of classes E to G had a peak at 0200 to 0300h with a frequency of 60.1%. The occurrence frequency in the early morning or early evening was lower compared to that at night.

Table 2-4. Occurrence frequencies of atmospheric stability classes during the study period

Stability class	Occurrence frequency (%)		
	Nov.-Apr.	May-Oct.	Annual
A	0.1	0.5	0.3
B	2.4	6.9	4.7
C	7.3	14.9	11.1
D	60.7	49.9	55.2
E	16.9	16.8	16.8
F	8.1	7.7	7.9
G	4.5	3.4	3.9

Table 2-5. Odour occurrences under various atmospheric stability classes

Atmospheric stability class	Number of odour events by intensity					Total odour events*	Percent of odour events (by stability class)
	1	2	3	4	5		
A	0	0	0	0	0	0	0.0
B	1	2	1	3	3	10	3.4
C	3	10	20	21	5	59	19.8
D	5	25	51	77	26	184	61.7
E	2	3	9	9	9	32	10.7
F	1	0	4	1	1	7	2.3
G	0	1	2	1	2	6	2.0
Total	12	41	87	112	46	298	100.0
Percent of odour events (by intensity)	4.0	13.8	29.2	37.6	15.4	100.0	

*Only included odour events with recorded intensities.

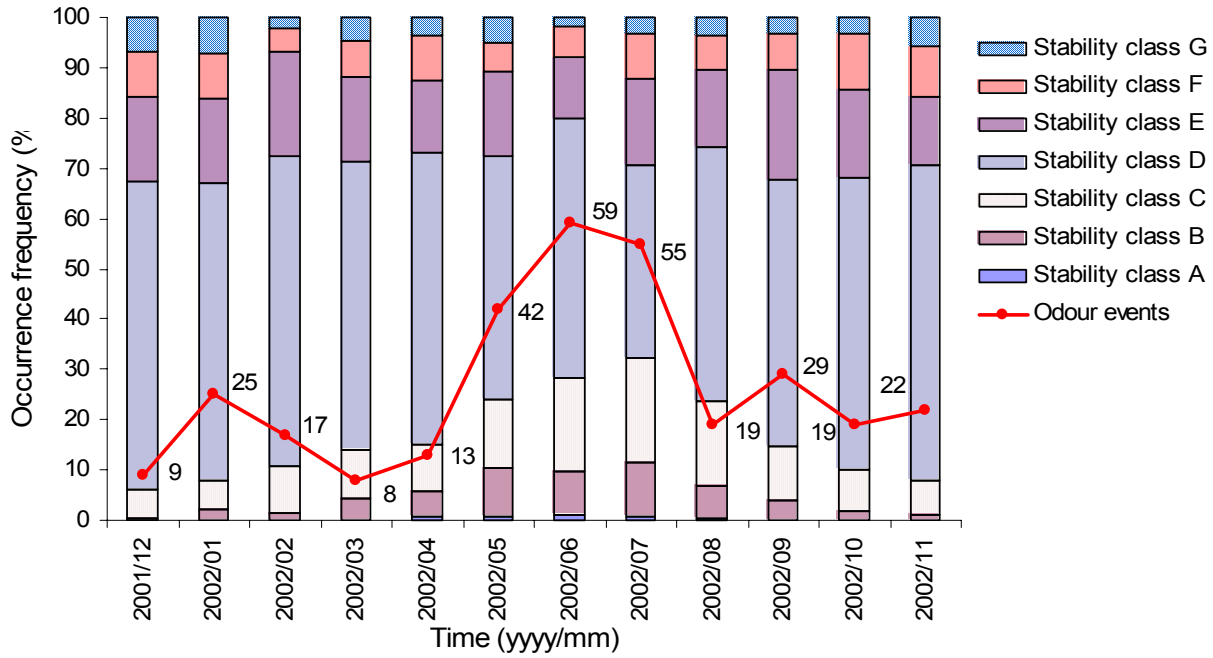


Figure 2-11. Monthly atmospheric stability distributions.

The above results indicated that stable atmospheric conditions that were favourable for odour travel occurred during the night while unstable atmospheric conditions that were unfavourable for odour travel occurred during the daytime, especially during the early afternoon period. However, as shown in Fig. 2-3, only five odour events were reported at night between 2300 and 0500h. The availability of observers appeared to be a more important determinative factor than weather conditions. During the daytime, although odours were not detected under stability class A and were seldom detected under stability class B, 19.8% of odour events were detected under stability class C. Under the dominant stability class D, odours occurred at any period during the daytime. The combined high occurrence of stable weather and the availability of observers

outside made the morning hour from 0600 to 0700h the highest period and the afternoon hour from 1600 to 1700h the second highest period of odour detection during the day. The frequency of unstable weather at noon and during the early afternoon resulted in the lowest odour detection periods during the daytime.

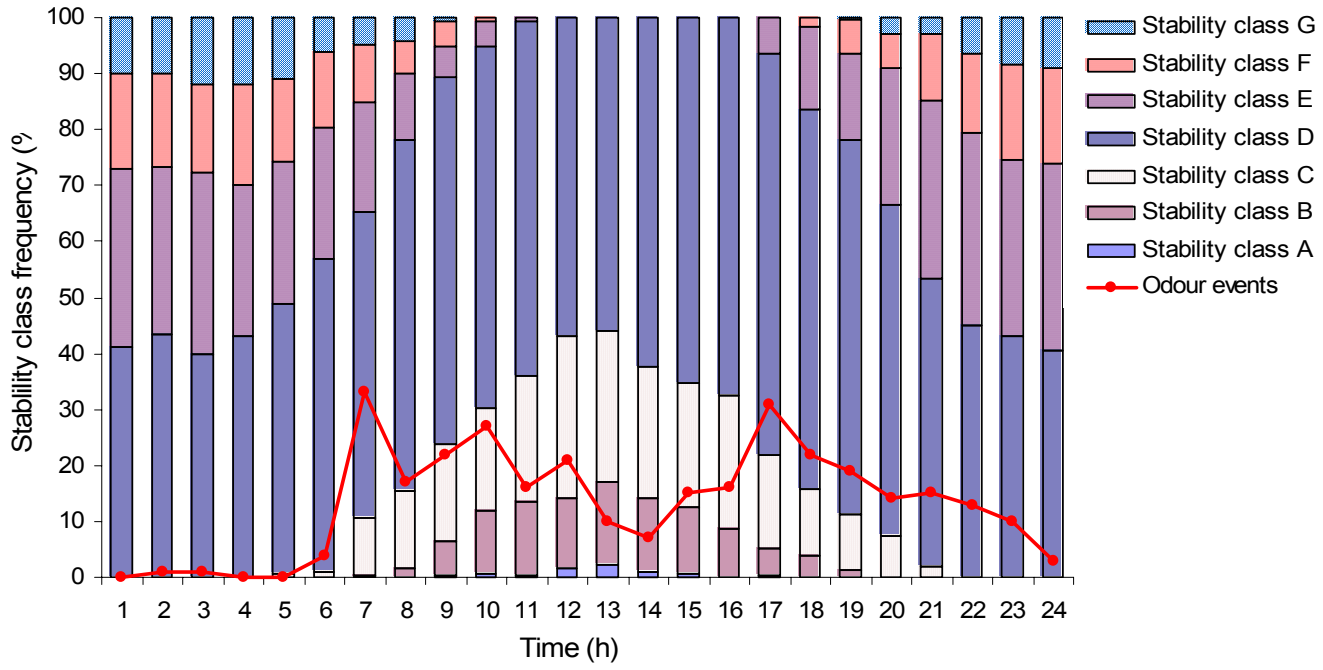


Figure 2-12. Diurnal atmospheric stability distribution and detected odour events

IMPACT ON ODOUR INTENSITY

As indicated in Table 2-5, low or high odour intensities occurred under various atmospheric stability classes ranging from B to G. Odour events with intensity 1 (very faint) and 2 (faint) only constituted 17.8% of all odour events. Odour intensities 4 and 5 constituted 53.0% of all odour events while intensity 3 made up 29.2% of all. As discussed previously, odour intensity might have been over estimated by the observers.

The observed results did not support the hypothesis that stable atmospheric conditions would favour odour travel, i.e., high intensity odours were expected to occur mostly under stable weather conditions rather than under neutral or unstable weather conditions. Odour events with intensity 4 occurred the most under stability class D (68.8%), followed by stability class C (18.8%), while intensity 5 odour events also occurred the most under stability class D (56.5%), followed by stability E (19.6%). Similarly, odour events with intensity 3 occurred the most under stability class D (58.6%), followed by stability class C (23.0%). Intensity 1 or 2 odour events occurred the most under stability classes D and C.

Under each individual stability class, except stability class E, high intensity odour events (intensities 4 and 5) occurred the most, from 44.1% under stability class B to 60% under stability class C. Under stability class E, intensity 3 odour events were detected the most frequently (57.1%) while intensity 4 and 5 odour events accounted for 28.6%. Six of the ten odour events

detected under moderately unstable conditions (class B) were given intensity levels of 4 or 5 while only two of the seven odour events under moderately stable conditions (class F) were reported as intensity 4 or 5. It should be noted that the data sizes were small and the results may change with a larger data set.

IMPACT ON ODOUR DETECTION DISTANCE

Figure 2-13 shows the number of odour events detected at various distances under each atmospheric stability class. Swine odours were detected under almost all atmospheric stability classes within a 1.6 to 6.0 km radius from the production sites. It is notable that under moderately unstable conditions (class B) three odour events were reported by two observers living over 5.5 km east of the farrowing site. One observer located at 5.7 km from the source did not record the duration of the two intensity 4 odour events that he reported in June and July. Weather conditions just before the first odour detection corresponded to atmospheric stability C and then changed to B. Therefore, it may be more appropriate to group this event under stability C instead of B. The atmospheric stability was B before and after the second odour event was detected. Another observer located at 5.9 km from the source reported one odour event with intensity 5 that lasted for 6 hours. Right after the first detection time the atmospheric stability turned to C. There were no other known odour sources west of the observers' locations. As discussed previously, the observers might have over-estimated odour intensity.

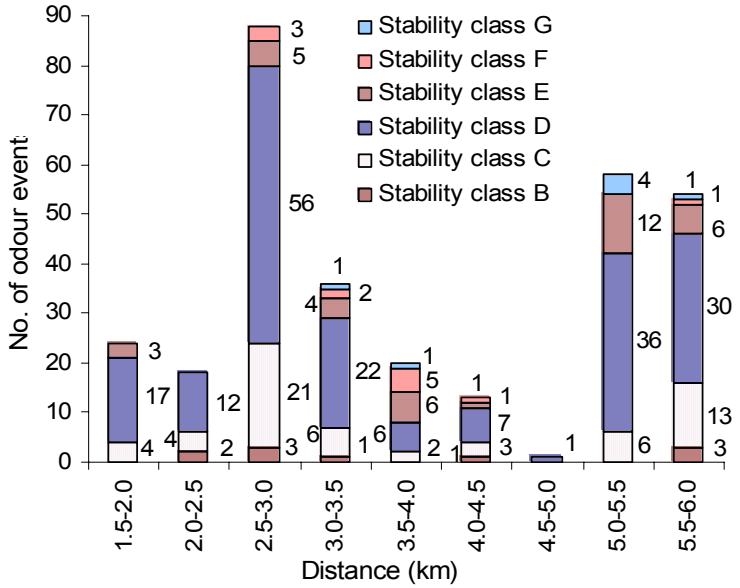


Figure 2-13. Odour events under various atmospheric stability classes at different distances.

IMPACT ON ODOUR OCCURRENCE AT VARIOUS DIRECTIONS

Figure 2-14 shows the frequencies of various stability classes as a function of wind direction. For unstable stability classes A to C, the occurrence frequencies were very low, with the maximum of A at 0.034% and B at 0.55% for winds coming from the N and S, and C at 1.2% from the S. The total occurrence frequencies of the unstable stability classes (A to C) are shown in Fig. 2-14 a). As also shown in Fig. 2-14a, neutral stability class D has the highest occurrence

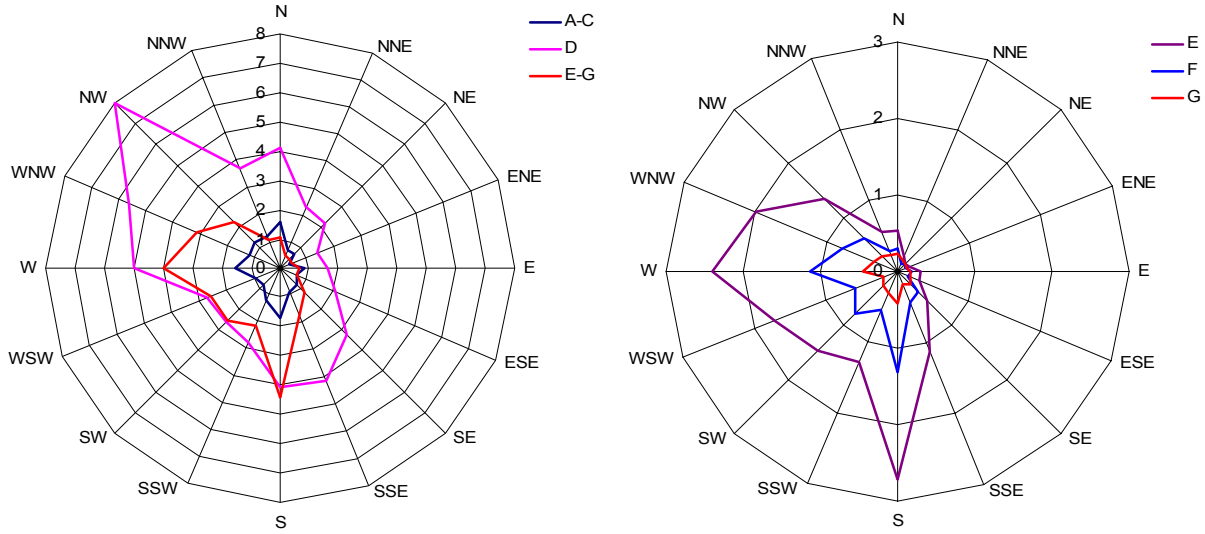
frequencies for all wind directions compared to the other stability classes, with the highest occurrence of 7.95% from the NW, followed by WNW and W. For stable weather, as shown in Fig. 2-14 b), stabilities E and F had the highest frequencies when winds were coming from the S at 2.72% and 1.31% respectively, then followed by W and WNW winds. For stability G, the highest frequency (0.45%) occurred under west winds, followed by winds coming from S. The total occurrence frequencies of all the stable stability classes (E to G) are shown in Fig. 2-14 a). The highest frequency of stability classes E to G was 4.44% under south winds, followed by W and WNW wind directions. Considering both neutral and stable conditions favouring odour travel downwind from the swine sites, winds from the NW, W, WNW, and S under neutral or stable atmospheric stability had the highest occurrence frequencies of 10.2, 8.9, 8.7, and 8.5%, respectively. Therefore, the residences located SE, E, ESE, and N of the swine sites would be most frequently subjected to swine odours. The neutral and stable weather conditions occurred the least in the directions of NNE to ESE ranging from 1.8 (ENE) to 2.8% (NNE). As a result, the residences located downwind of those directions from swine sites (SSW to WNW) should experience low odour occurrences.

The observers who reported the most odour events were typically located downwind of the swine sites, corresponding to winds coming from the NW, WNW, W, and S. Observer R1, who reported the most odours, was located 3.8 km to the north of the nursery site and 3.0 km NNE of the farrowing site. Of the 79 odour events reported, 63.3% were detected between 1600 and 0900h. Most odours were detected under stability class D (62.8%) while 24.4% were detected under stability class C and 3.8% under stability class B. Only 8.9% of odours were detected under stability classes E or F. No odours were detected under stability classes G or A. Observer R3 lived 5.4 km SE of the finishing site and reported 50 odour events. However, observer R6, who was located 1.6 km SE of the nursery site and 3.3 km SW of the farrowing site, only detected 16 odour events. Observer R4 was located 5.7 km E of the farrowing site and detected 26 odour events.

Observer R2, who recorded the fourth highest number of events, reported 21 odour events. This observer was located 3.1 km WSW of the nursery site, which was the direction that had the least number of occurrences of neutral or stable weather from the ENE direction. Observer R7, located 1.6 km W of the nursery site, reported six odour events. This again indicated that the availability of the observers for odour detection outside was very important for determining odour detection frequencies.

The results of this study indicate that odour detection frequency is determined more by seasonal factors, such as air temperature, the condition of outside earthen manure storages (i.e., liquid vs. frozen surface), and residents' lifestyles, which determine the amount of time spent outside and the possibility of open windows in the home, rather than by atmospheric stability alone. The majority of the odour events (61.7%) were detected under stability class D and only 15.0% were detected under stability classes E to G. This result is quite different from the result obtained by Guo et al. (2003) in Minnesota, U.S., in which 71% of odour events were detected under stable weather conditions (classes E or F) and only 16.3% under stability class D. The annual frequency of stability class D was 55.2% in the Yorkton area during the study period, which was slightly lower than the average of 61.7% from 1982 to 1990 in Minneapolis.

The observations made by Guo et al. (2003) found 35% of the strong odours were reported under stability class D. In this study, 65.2% of odour events with high intensity 4 or 5 were observed under stability class D. This proved again that neutral atmospheric conditions with high wind speeds could also result in strong odours. Odours were observed under unstable weather conditions, which suggested that swine odours could also travel distances of more than 5 km under unstable weather conditions.



(a) Stabilities A to C, E to G, and D (b) Stability classes E to G

Figure 2-14. Distribution of stability classes as a function of wind direction

CONCLUSIONS

Based on the results obtained from this study, the following conclusions can be drawn:

a) Swine odours were detected by observers from 23 families living 1.6 km to 6.0 km from the swine farms. Eleven families located 2.3 to 6.0 km and five families 6.0 to 8.6 km away from the swine farms did not detect swine odours.

b) Most swine odours (70.3%) were detected during the warm season from May to October. Manure land application contributed to high odour occurrences in May, June, and October. Most of the odours (54.6%) were detected between 1700 and 0900h, from the late afternoon, throughout the night and until the early morning. During the warm season, there were two peak hours for odour detection: 0600 to 0700h and 1600 to 1700h. However, during the cold season, odours were detected most frequently between 1100 and 1200h.

c) Annual odour detection frequencies for twenty families ranged from 0.01% to 0.80%. Three families had higher odour occurrence frequencies of 1.19% (5.9 km), 1.51% (5.4 km), and 3.32% (2.8 km, near two other livestock farms).

d) Odours with intensity 3 or above were reported the most (82.2%) while very few low intensity odour events were reported. Odours with intensity 5 were reported throughout the year regardless of the season. Odour intensity might have been overestimated by

some observers. Similarly, odours with offensiveness 3 or above made up 77.0% of all odours.

e) No correlation was found between the detection distance and number of odour events. In addition to weather conditions and topography, the following factors may affect odour detection frequency and intensity: 1) the distance and direction of the residence from the odour source, 2) the frequency and duration of the periods during which the observer stayed outside, which depended on the habits or lifestyle of the residents, and 3) the olfactory sensitivity of the observers to swine odours, which may vary greatly.

f) Using resident odour observers for long term and long distance odour dispersion measurement has proven to be practical and effective. However, this method needs to be improved in order to increase the quality of the data. Possible options include implementing periodic nose calibration, screening the observers for bias for or against the intensive livestock operations, and taking measurements at designated times.

g) The number of odour events had an inverse linear relationship with the wind speed; the lower the wind speed, the more odour events were reported. Odours with high intensities were detected at various wind speeds up to 9.4 m/s and at a distance of up to 5.8 km from the swine farms.

h) Swine odours were detected under all atmospheric stability classes (SC) except SC A within a radius of 1.6 to 6.0 km from the production sites. Most odour events (61.7%) were detected under atmospheric stability class D, while only 15% of odour events were detected under stable atmospheric conditions, and 23.2% were detected under unstable atmospheric stability classes B or C. These results indicate that atmospheric stability was not the determining factor for odour dispersion. Other factors, such as additional odour emissions from the outside manure storages during the warm season and the availability of observers outside of residences to detect odours (e.g., observers spent more time outside during the warm season and were unavailable during the night when stable atmospheric conditions most frequently occurred), seemed to be more important in determining the odour detection frequencies.

i) The results of this study suggest that odour occurrences, as experienced by the resident odour observers, varied with season, time of a day, location (including distance and direction from the swine farms), weather conditions (wind speed and direction), and presence of the observers outside of their residences (including seasonal and diurnal lifestyles and routines). All these factors need to be considered when setting odour criteria for communities in areas located near intensive swine operations.

Part 3. Stage II: Odour Monitoring By Trained Resident-Observers In The Area Neighbouring Swine Production Sites

OBJECTIVES

This was the second stage of the project. The objective of this part of the project was to monitor the odour exposure levels of the residents living in the vicinity of swine production operations by using trained resident odour-observers to measure odour frequency, intensity, duration and offensiveness (FIDO).

MATERIALS AND METHODS

ODOUR MONITORING AREA AND THE SWINE OPERATIONS

This is identical to the description presented in Part 2.

RESIDENT ODOUR OBSERVER'S INFORMATION AND DATA COLLECTION

Thirty-two resident-volunteers from 28 families were trained as odour-observers and participated in the study. They were trained using the same method presented in Part 2.

The odour observers were asked to record odours they detected at their residences at least twice a day, once in the morning and once in the evening. They were also asked to record any swine odours they detected during their daily activities. The data recorded included odour intensity, offensiveness, occurrence time, duration, character, etc. and a general statement about the odour, and the residents' own physical conditions. Each family was provided with an n-butanol scale set and the odour observers were required to calibrate their noses at least once a week. The study lasted one year from May 2003 to April 2004.

ODOUR EMISSION MEASUREMENTS

Odour emissions from all types of sources on the three sites were measured monthly from May 2003 to April 2004, including two breeding/gestation rooms, two farrowing rooms, four nursery rooms, three finishing rooms, and all six EMS cells. The detailed information is presented in Parts 5 to 7.

METEOROLOGICAL DATA MEASUREMENT

This is identical to the description presented in Part 2.

RECORDING ODOUR GENERATION OR CONTROL ACTIVITIES

Acute odour generation or odour control activities, e.g., emptying the EMS, plug pulls, and covering the EMS with straw, etc., were documented by the barn managers. Barley straw was applied to the manure storage cells three times on the Nursery site in March, June, and again in July, twice for the farrowing site in March and June, and once for the finishing site in June. Manure was occasionally applied to the nearby crop land in the area of 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 OCCURRENCE

During May 2003 to April 2004, thirty-two resident-odour observers from 28 families (four families had two observers in one family) participated in the study. Nine of the families raised cattle, and 2 observers were full time swine barn workers. The distances between these residences and the closest swine site are between 1.2 and 7.8 km. Twenty-seven families living 1.2 to 7.6 km away from the swine sites reported swine odours during the year while one family living 7.8 km away from the closest swine site did not detect any swine odours. As shown in Fig. 3-1, the number of odour observers varied from 19 to 28 a month and 22 observers participated for more than 10 months.

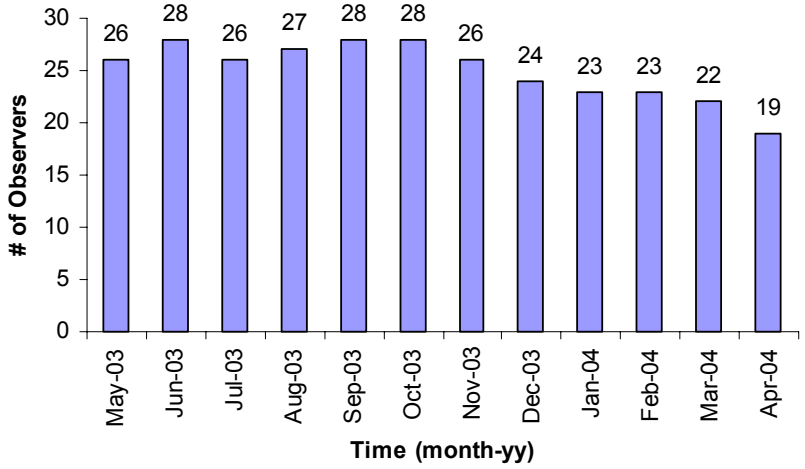


Figure 3-1. Number of odour observers per month

A total of 953 odour events were reported. Over a third of the reported odours, i.e, 315 odours, were confirmed to not originate from the swine production sites because they were detected when the receptors' locations were not downwind of the swine sites according to wind directions recorded by the local weather station. Ten of these odours might have originated from crop lands receiving manure application. Other livestock operations in this area might have been the sources of the other odours. Some odours were recorded as non-swine odours. Therefore, the three swine production sites and manure applications might be the probable sources for a total of 638 odours. The following analysis was based on these 638 odours.

SEASONAL ODOUR OCCURRENCE PROFILE

Table 3-1 gives the odour events reported over the year. Figure 3-2 shows the number of odour events recorded in each month during the year. The high odour occurrence season was from May to October and August had the highest number of detected odours (111 odours). The odours detected during this six-month period made up 71.5% of total recorded annual odours. It may be notable that the period from May to October had the highest number of participants,

which ranged from 26 to 28 (Fig. 3-1). However, although there were 28 participants during June, only 44 odours were reported.

A significantly lower number of odour events was reported from November to February. November had the lowest number of odour events of 13 although 26 observers monitored during that time. More odour events were reported again in March and April. The manure storages were covered with straw in March to keep them frozen longer and to reduce odour emission after they thawed. This may be the reason that the odour events started to increase in May instead of April. Manure was occasionally applied to the nearby crop land in the area of the three sites from May 11 to June 10, 2003, and again from August 7 to October 12, 2003, which contributed to the odour occurrences in this area. It is also notable that although the manure storage cells were frozen from December to April, the odours from the swine barns could still be detected in the neighbouring area. Therefore, the barns, manure storages, and manure application all contributed to the high odour occurrence season from May to October.

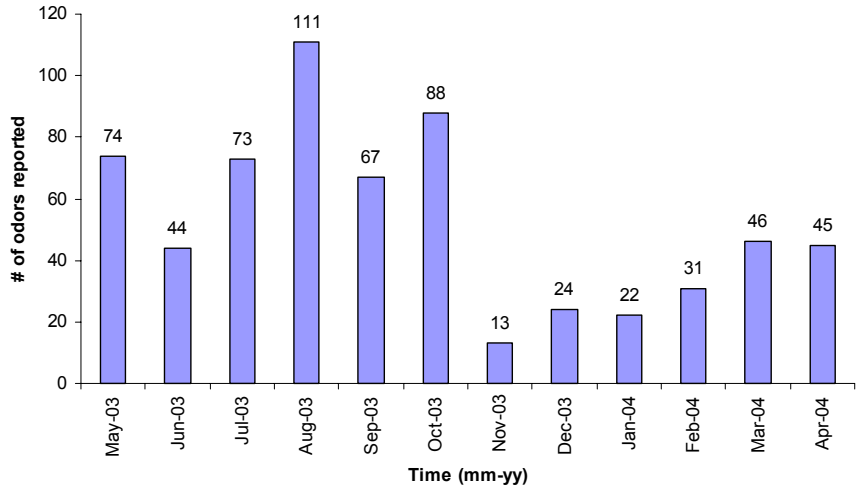


Figure 3-2. Monthly number of odours during the year

DIURNAL ODOUR OCCURRENCE PROFILE

Figure 3-3 summarizes odour occurrences for different times during the day for the year and the high odour occurrence season from May to October. The times presented in the figure were the times at which odours were detected regardless of the duration of odours (note: only odours with an exact starting time were included, odours recorded as morning, afternoon, evening etc. were excluded). Most odours (97.8% annually and 97.5% from May to October) were detected between 0600 to 2200h. There was a peak in the morning from 0600 to 1100h. From 1100 to 1300h fewer odours were detected. Another peak of odour occurrence started at 1300h, lasted for the whole afternoon and evening, and peaked during the hour from 1900 to 2000h. If we consider 900 to 1700h as the daytime, 47.9% of the annual odours were detected during this period of time and 43.0% of the odours detected between May and October. Therefore, more odours were detected during the rest of the day in the early morning, evening, and night when atmospheric conditions favoured odour travel. How often and how long people were outside would affect the number of odours reported by observers. For example, from 2200 to 0500h, the

atmospheric stability class was likely more stable and favoured odour travel more than the early mornings or evenings, but odours were usually not detected because the observers were not outside.

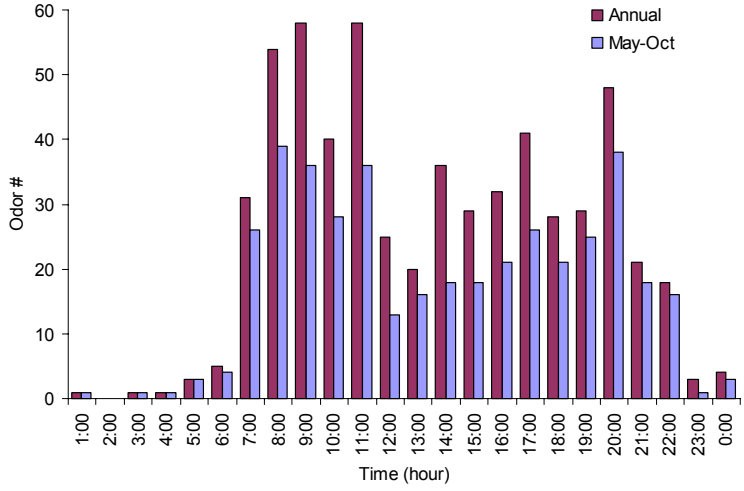


Figure 3-3. Diurnal odour occurrence profiles

DISTRIBUTION OF ODOUR INTENSITY

Table 3-1 gives the number of odours of different intensities that occurred in each month of the year. As shown in Fig. 3-4, intensity 3 odours, i.e., moderate odour, were reported the most (28.1%) while intensity 5 odours were reported the least (6.4%). Very faint and faint odours (intensities 1 and 2) constituted 44.3% of all odours. Strong and very strong odours (intensities 4 and 5) made up 27.5% of all odours; 78.3% of them were reported during May to October and much fewer were reported in the cold season from November to March.

There is a considerable difference when these results are compared with the results obtained from Stage 1 and Stage 2 of this project. In Stage 1, intensity 1 and 2 odours only accounted for 3.3% and 13.3% of all odours while intensity 4 and 5 odours made up over 50% of all odour events. Periodical nose calibration increased the accuracy of intensity rating by the observers in Stage 2.

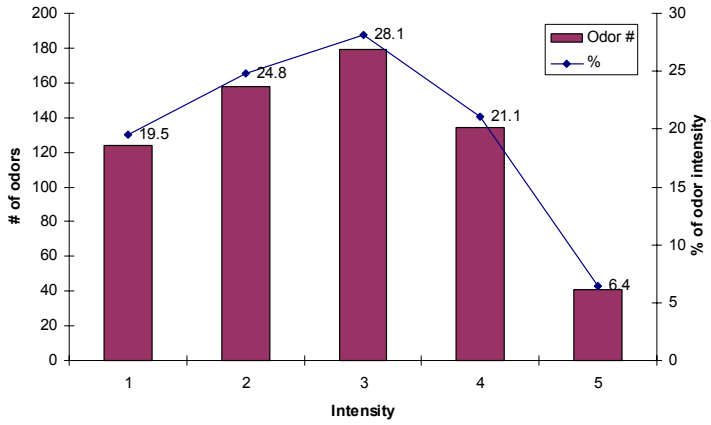


Figure 3-4. Distribution of odour intensity

Table 3-1. Summary of monthly odour events.

Month	All odour	Intensity 1		Intensity 2		Intensity 3		Intensity 4		Intensity 5	
	Events	Events	%	Events	%	Events	%	Events	%	Events	%
May-03	73	19	26.0	9	12.3	19	26.0	15	20.5	11	15.1
Jun-03	46	8	17.4	10	21.7	16	34.8	11	23.9	1	2.2
Jul-03	73	16	21.9	21	28.8	20	27.4	10	13.7	6	8.2
Aug-03	108	14	13.0	28	25.9	30	27.8	27	25.0	9	8.3
Sep-03	66	15	22.7	17	25.8	13	19.7	16	24.2	5	7.6
Oct-03	88	14	15.9	19	21.6	29	33.0	23	26.1	3	3.4
Nov-03	13	3	23.1	5	38.5	4	30.8	1	7.7	0	0.0
Dec-03	24	5	20.8	12	50.0	6	25.0	0	0.0	1	4.2
Jan-04	22	6	27.3	5	22.7	8	36.4	3	13.6	0	0.0
Feb-04	31	13	41.9	4	12.9	7	22.6	5	16.1	2	6.5
Mar-04	47	9	19.1	15	31.9	12	25.5	11	23.4	0	0.0
Apr-04	45	2	4.4	13	28.9	15	33.3	12	26.7	3	6.7
Total	636	124	19.5	158	24.8	179	28.1	134	21.1	41	6.4

Note: The odours in this table only include odour events with recorded intensities.

DISTRIBUTION OF ODOUR OFFENSIVENESS LEVELS

Regarding the offensiveness of the odours, as shown in Fig. 3-5, 15.1% of the 588 odours with reported intensity levels were recorded as 'not annoying' (offensiveness 1), 28.7% as 'somewhat annoying' (offensiveness 2), 28.6% as 'annoying' (offensiveness 3), 19.7% as 'very annoying' (offensiveness 5), and 7.8% as 'extremely annoying' (offensiveness 5).

Ratings of odour offensiveness of different odour intensities are reported in Table 3-2. A linear correlation exists between intensity and offensiveness (offensiveness=0.8685 x intensity + 0.4259, $r^2 = 0.7575$**). For odours with intensity 1 (very faint odour), 100% of observers assessed their offensiveness as not annoying (offensiveness 1) or somewhat annoying (offensiveness 2). For odours with intensity 2 (faint odour), 77.2% of observers thought they were not annoying or somewhat annoying (offensiveness 1 and 2) and 20.9% thought they were annoying (offensiveness 3). For intensity 3 odours, 81.9% assessed them as offensiveness 3 and over (annoying or very annoying). Only 18.1% assessed them as offensiveness 2. This result provided information for setting odour annoyance intensity criterion for local communities near swine operations. The Minnesota OFFSET Model, a setback distance estimation model, set the

acceptable odour intensity level as intensity 2 (faint odour) based on the perception of the researchers. The above result indicated 77.2% of the intensity 2 odours were rated as 'not annoying' or 'somewhat annoying' (offensiveness 1 and 2), which means the majority of observers would agree with the limit set in OFFSET.

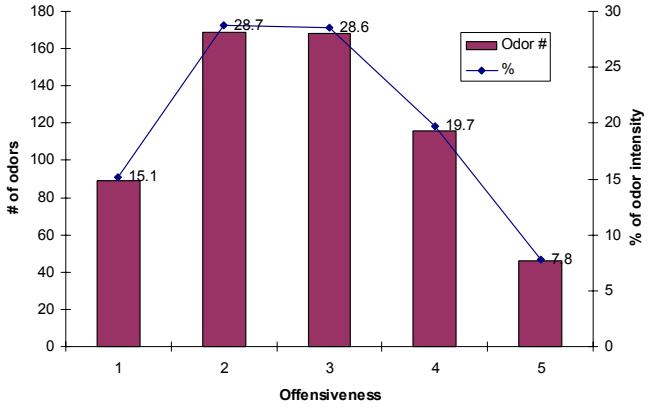


Figure 3-5. Distribution of odour offensiveness

Table 3-2 Odour offensiveness rating of odours with different intensities

Offensiveness	Percent of odour intensity (%)				
	1	2	3	4	5
1	54.6	19.0	0.0	0.0	0.0
2	45.4	58.2	18.1	0.0	0.0
3	0.0	20.9	71.3	11.0	0.0
4	0.0	1.3	9.4	80.5	8.3
5	0.0	0.7	1.2	8.5	91.7

ODOUR OCCURRENCE VS. DISTANCE AND DIRECTION FROM THE SWINE SITES

Figure 3-6 a) gives the total number of odour events reported at various distances from the closest swine sites. The observers living 1.5 to 2.0 km and 5.0 to 5.5 km reported the most odours (124 and 109 odour events, respectively). Odours were detected up to 7.6 km away from the closest swine site, but at 7.6 km only 3 odours (2 intensity-1 odours and 1 intensity-3 odour) were detected during the year. At such a long distance from swine sites, the origin of the odours detected might be one of the three swine sites, but it was possible that other odour sources might be a source that had a smell similar to swine odours, e.g., cattle manure odours. At distances of 5.5 to 6.0 km, 38 odours were reported as swine odours by observers from two families. Although it was possible that some of the odours reported might be other odours rather than swine odours, it was not likely all 38 odours were mistakenly reported as swine odours but in fact were other odours. Therefore, it is quite possible that swine odours could be detected up to 6.0 km downwind of swine sites. It may be necessary to validate whether the other 21 odours detected beyond this distance were generated from the swine farms or not.

Because there were different numbers of families at various distances, Fig. 3-6 b) describes the average number of odours per family reported at various distances. Odours were reported the

most per family at the distances of 2.5 to 3.0 km from the closest swine sites, followed by 1.5 to 2.0 km, 5.0 to 5.5 km, and 4.5 to 5.0 km, etc. The observers living closer to swine sites might not detect as many odours as those living farther. For example, the observers living 2.0 to 2.5 km away detected fewer odours than the observers who lived up to 6.0 km away from a swine site; the observers living 3.5 to 5.0 km detected fewer odours than those living 5.0 to 5.5 km away. There was no correlation between the number of odour occurrences and the distances from the residents to the swine production sites. The number of odour events for 1.0-1.5 km only includes one month of data.

To obtain the intensity distribution at various distances from the odour sources, the total number of odour events for different intensities are plotted against the detection distances in Fig. 3-7. Intensity 1 to 3 odours were reported at all distances. Intensity 4 or 5 odours were also reported at a distance up to 7.5 km.

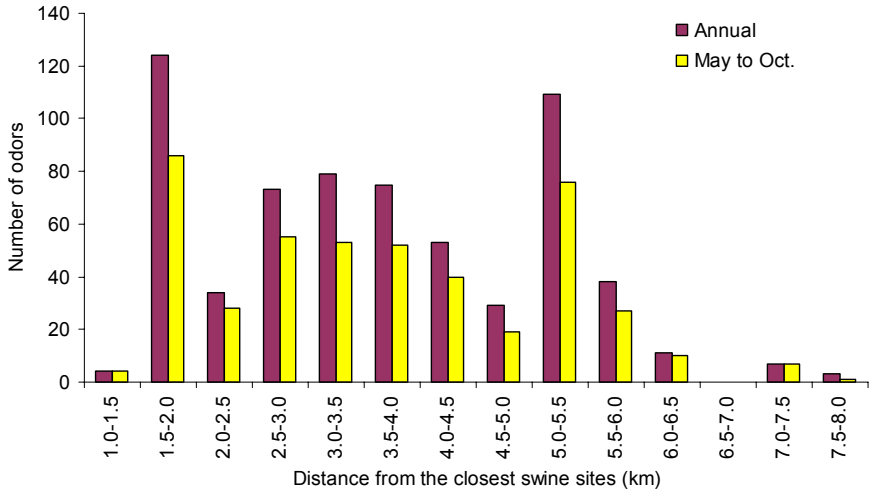
The percentiles of odour intensities of the five odour observers (residences) who reported the most odour events are given in Fig. 3-8. The annual and May-to-October wind frequencies recorded by the local weather station are given in Fig. 3-9. Table 3-3 gives the same information in table format. WNW and ESE winds were the most frequent in this area. These five locations were all located downwind and are NW or SE of one or two swine sites. They detected more odours than other locations closer to the swine sites because winds blowing from the swine site to these locations were much less frequent. For example, 94 odours were reported at location 57, which was the highest number of odour events among all locations, but although locations 34 and 26 were similar distances from the swine sites, only 24 and 6 odours, respectively, were reported at these sites. As shown in Fig. 3-9, it is interesting to see that although observers at location 57 (1.6 km from one swine site and 3.3 km from another swine site) detected 94 odours, only 6 of them were intensity 4 and 1 intensity 5, which together accounted for 7.4% of the 94 odours. Odours with intensities 1 and 2 made up 81.9% of the 94 odours. Odours with intensities 1 to 3 at each of the locations 57 to 121 made up 95.6%, 75.2%, 88.6%, 85.5%, and 42.5% of all odours at each location, respectively. It was notable that location 121 was 5.4 km from a swine site but high intensity odours (intensities 4 or 5) accounted for 57.5% of all the 40 odours reported.

The following factors might have affected the odour detection frequencies:

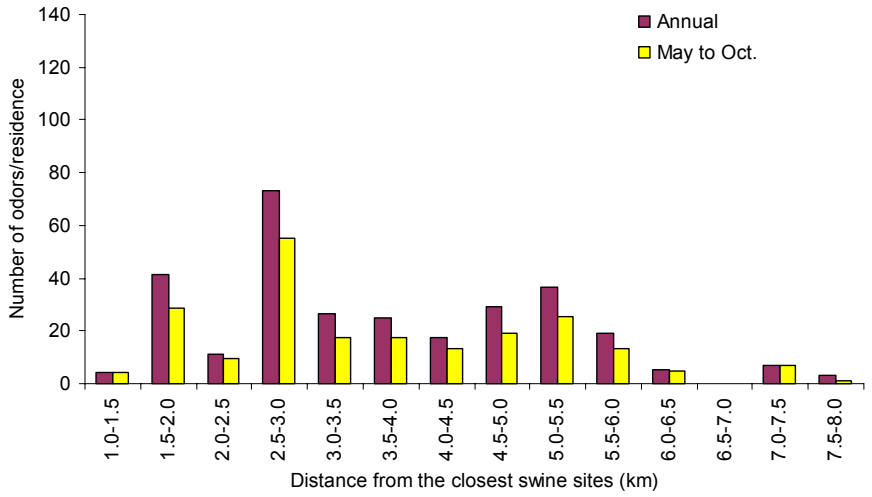
- Distance between the residence and the swine sites and direction of the residence from the odour source.
- Living style of the residents. When they went outside and how long they stayed outside, whether they were away from home a lot, etc.
- Olfactory sensitivity of the residents. Only one observer from one family among all the families reporting swine odours was a swine barn worker, but another observer from the same family was not. Some odour observers were involved in small cattle operations.

Some of the observers did not record the durations of the odour events or only recorded comments such as “morning,” “afternoon,” or “on and off,” which did not give sufficient information to calculate odour detection frequencies. The annual odour duration and detection frequencies of 16 locations which had reported durations are shown in Fig. 3-10, including the first, second, and fourth residences with the most odour events. The observer (L121) living 1.6

km from the farrowing site with the most odour events reported a total of 126 h or an annual odour detection frequency of 1.4%, which is the third highest. The observer (L90) living 2.7 km from the finishing site detected the second highest number of odour events (73) with a total duration of 260 h or annual odour detection frequency of 3.0%, which is the highest detection frequency of all observers. The observer living 4.1 km from the finishing site detected 28 odours; the detection frequency is 1.6%, which is the second highest. The other 13 observers had detection frequencies between 0.01 to 1.11%. The results indicated that only one residence had an odour free frequency of 97%; the other 15 residences had odour free frequencies between 98.40% and 99.99%. The four observers living 6.0 km or farther away from the closest swine site detected odours 3 to 7 times over the year and were odour free 99.88 to 99.97% of the time during the year.



(a) Total number of odour occurrences at various distances



(b) Number of odour occurrences per residence

Figure 3-6. Number of odour occurrences at various distances from the closest swine site

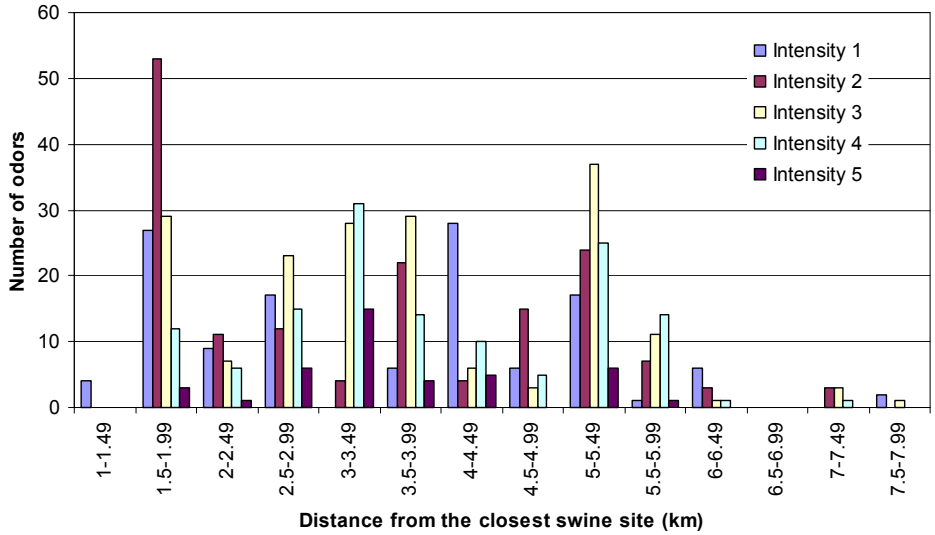


Figure 3-7. Odour intensity at various distances from the closest swine site

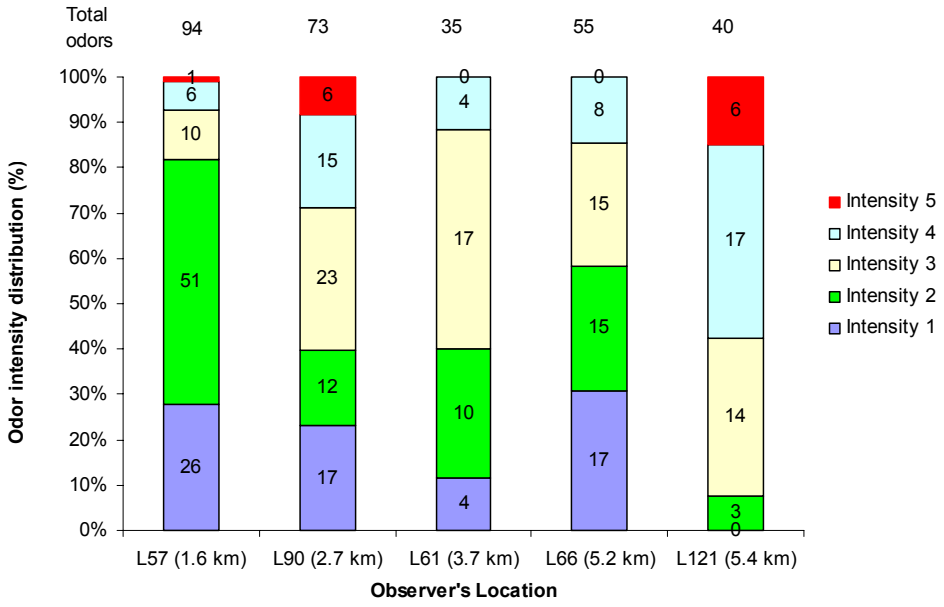


Figure 3-8. Odour intensity distribution at the five locations with most reported odours.

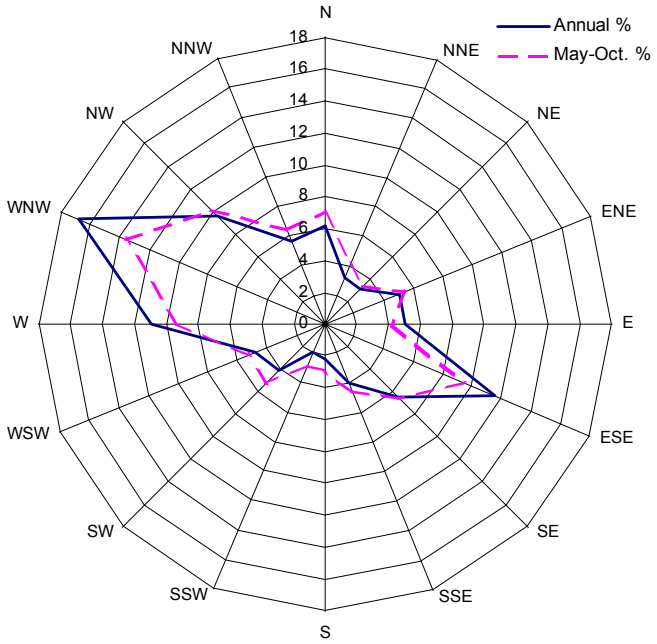


Figure 3-9. Annual and May-to-October wind frequencies

Table 3-3. Annual and May-to-October wind direction frequencies in the monitoring area

Direction	Annual percentage (%)	May-Oct. percentage (%)
N	6.1	7.1
NNE	3.2	4.0
NE	3.1	3.3
ENE	5.0	5.5
E	5.0	4.2
ESE	11.5	9.5
SE	6.4	6.6
SSE	3.9	4.5
S	2.2	2.9
SSW	2.0	2.9
SW	4.1	5.2
WSW	4.7	5.2
W	10.9	9.3
WNW	16.8	13.5
NW	9.5	10.1
NNW	5.6	6.3

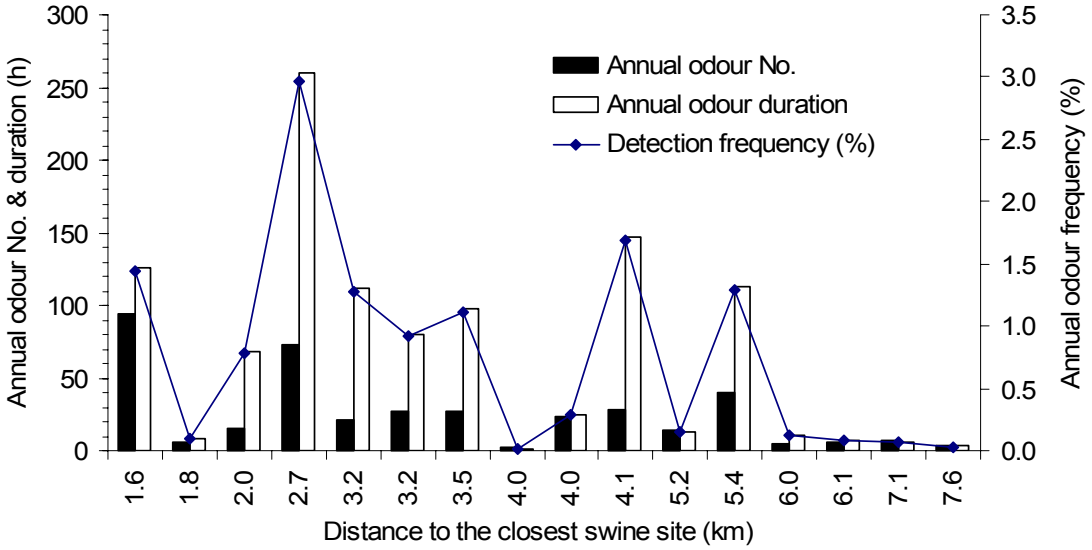


Figure 3-10. Annual odour duration and detection frequency of 16 residences

ODOUR OCCURRENCE AND WIND SPEED

The total number of odours at various wind speeds was plotted in Fig. 3-11. The total number of odours reported at different wind speeds had a linear relationship with the wind speed. The higher the wind speeds, the lower the reported numbers of odours.

Figure 1-12 gives the number of odours with different intensities at various wind speeds. High and low odour intensities were reported at all wind speeds. High odour intensities were reported even with high wind speeds. Twenty-eight odours were reported for wind speeds of 8.0 m/s or greater. Seven of them were reported from more than 5 km away from the swine sites and seven of them were reported as intensity 4 or 5 odours. This indicates that odour may travel long distances under high wind speeds and may still maintain high intensity.

IMPACT OF ATMOSPHERIC STABILITY ON ODOUR OCCURRENCE

Fig. 3-13 shows the diurnal average frequencies of various SC over the year. The stable weather mostly occurred during the early morning, evening, and night between 2000 to 0700h when observers were likely not outside to measure odours. The unstable weather occurred during the daytime when observers were more likely to be outside to observe odours. This might be the main reason that most odour events were detected during the daytime.

Table 3-4 gives the annual (May 2003 to April 2004) and May to October 2003 occurrence frequencies of various stability classes (SC), the number of odour events detected under various SC, and the frequency of odour detection under each SC. During the year, 62.9% of the odour events were detected under SC D, which is higher than the annual occurrence frequency of SC D (52.8%). No odour was detected under SC A. A total of 16.9% of odour events were detected under SC B and C, which was higher than the annual occurrence frequency of SC B and C (15.9%). A total of 20.2% of odour events were detected under SC E to G, which was much

lower than annual occurrence frequency of SC E to G (30.9%). The possible reason is that the odour observers were more available to conduct the measurements during the daytime when SC A to C or D occurred (Fig. 3-13) than during the night time when SC E to G or D occurred (Fig. 3-13). Another possible reason might be that atmospheric stability class did not have a significant impact on odour dispersion within the short distance of 8 km from the emission source. The results obtained from May to October 2003 were similar to the annual results.

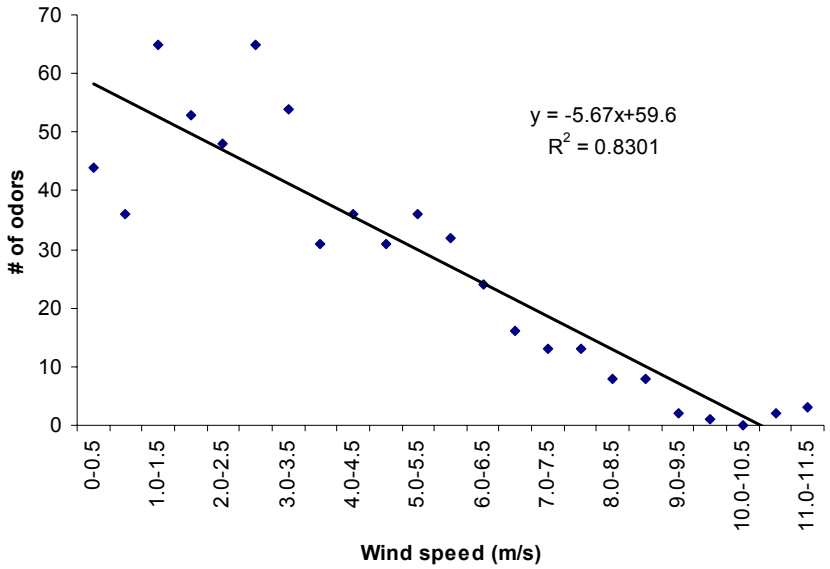


Figure 3-11. Wind speeds vs. number of detected odours

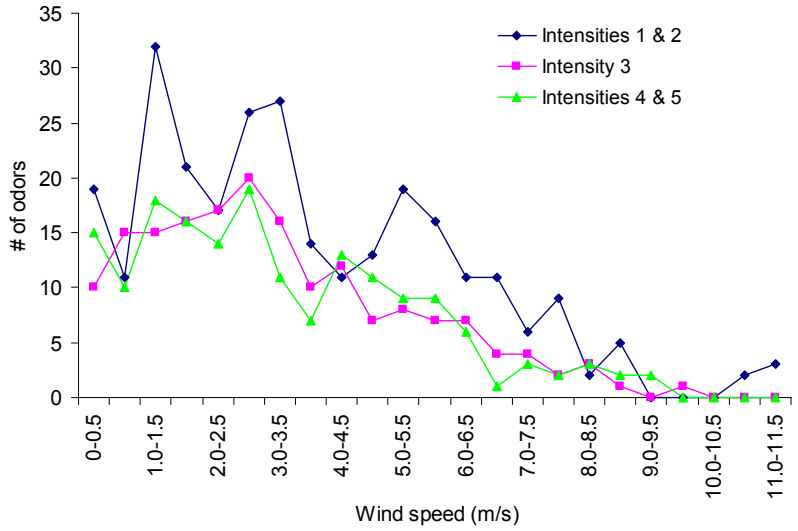


Figure 3-12. Wind speeds vs. number of odours with various intensities

Odour events with various intensities were reported under all SC B to G (Table 3-4). Figure 3-14 shows the odour occurrences at various distances under different SC. Odours were detected under SC B to G within 6.1 km from the closest swine site. The farthest detection distance under

SC B and C was 6.1 km because one intensity 1 odour event was reported by an observer living 6.1 km from the farrowing site under SC B and C, respectively. Under SC D, the farthest detection distance was 7.1 km from the finishing site; the observer reported a total of six odour events with intensities 2 to 4 between August and October 2003. The farthest detection distance under SC E and F was 7.6 km from the finishing site by one observer with a total of three events (two intensity 1 events and one intensity 3 event). The farthest detection distance under SC G was 5.7 km from the farrowing site.

Table 3-4. Odour occurrences under various atmospheric stability classes (SC)

SC	Annual (May 2003 to April 2004)								May to October 2003		
	Number of odour events by intensity					No. of odour events	% of odour events	% of SC (annual)	No. of odour events	% of odour events	% of SC (May-Oct.)
	1	2	3	4	5						
A	0	0	0	0	0	0	0.0	0.3	0	0	0.5
B	5	7	8	4	2	26	4.2	4.4	22	5.0	6.5
C	12	16	24	19	6	78	12.7	11.5	64	14.7	15.5
D	87	102	99	78	17	386	62.9	52.8	271	62.2	47.1
E	8	17	31	16	10	83	13.5	17.6	54	12.4	17.3
F	4	5	8	9	3	29	4.7	8.1	18	4.1	8
G	1	2	3	5	1	12	2.0	5.2	7	1.6	5.1

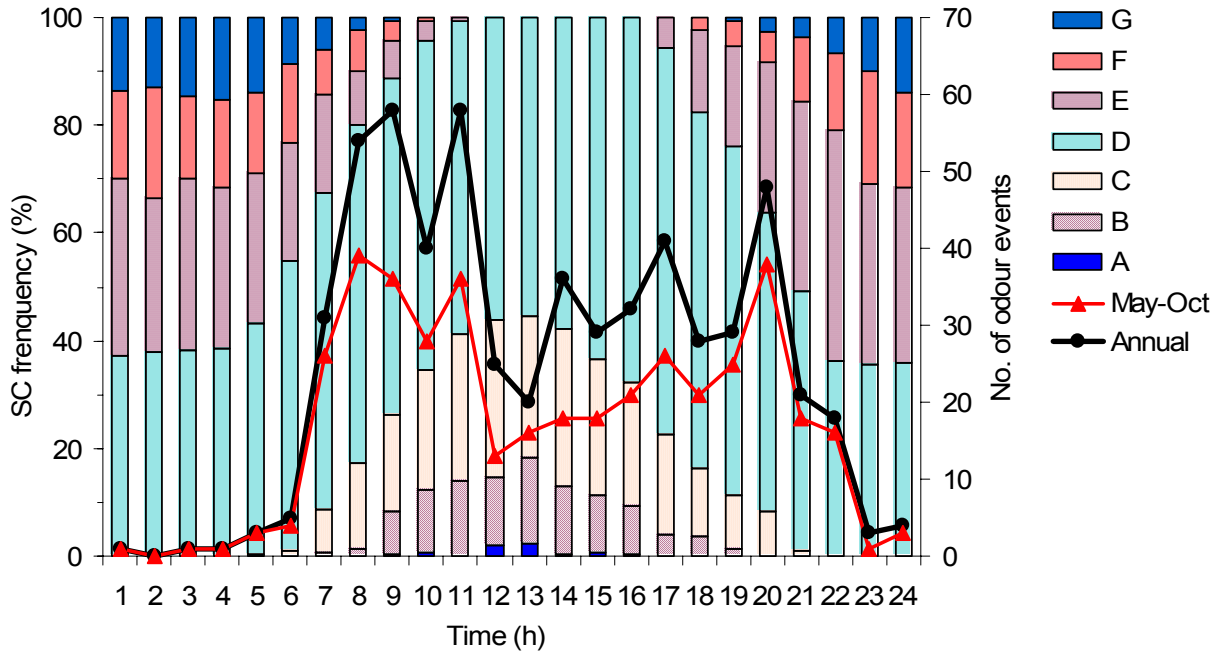


Figure 3-13. Diurnal average frequencies of various SC over the year

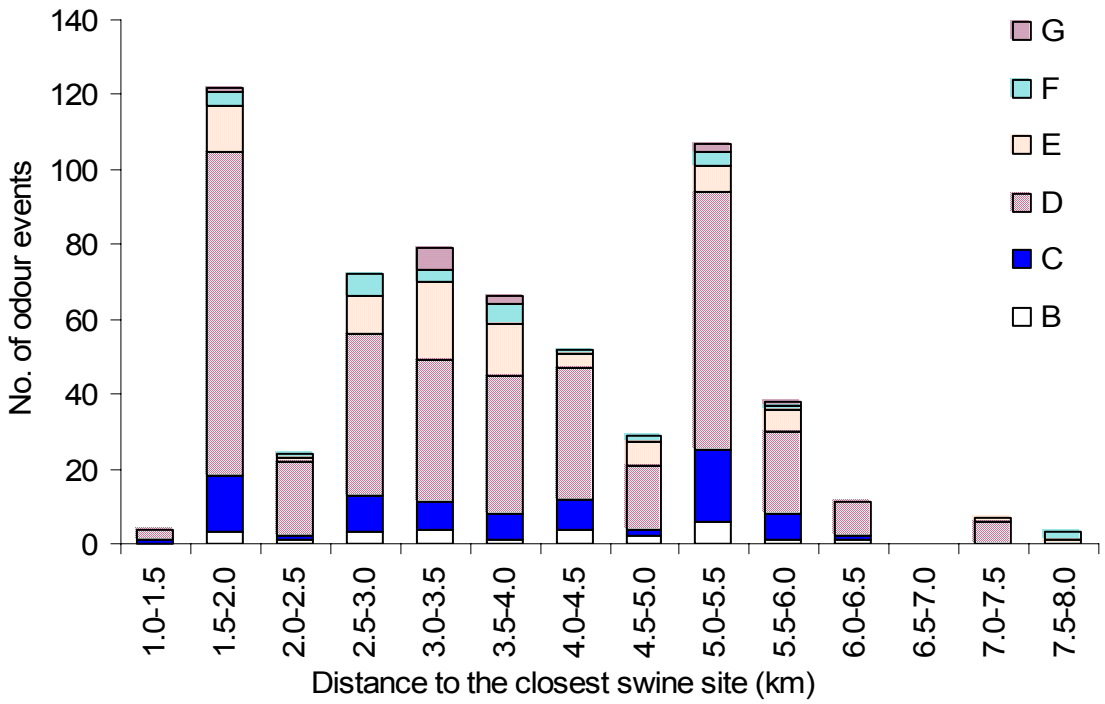


Figure 3-14. Number of odour events at various distances under different SC

CONCLUSIONS

a) The highest odour season was from May to October during May 2003 to April 2004.
b) 52.1% of annual odours and 57.0% of May-to-October odours were detected during the early morning, evening, and night.
c) Swine odour was detected up to 6 km downwind. Swine odours were also reported up to 7.6 km from the swine sites, although this rarely happened (in one year, 21 odours were reported by 4 families living 6.0 to 7.6 km away from swine sites), but whether these odours were swine odours and whether they originated from other sources needs to be further validated.
d) Sixteen families recorded detailed durations of the odour events while the information from the other families was insufficient to calculate the annual odour detection frequency. Annual odour detection frequencies for 15 families ranged from 0.01% to 1.60%. One family had the highest odour detection frequencies of 3.00% (2.7 km from the finishing site).
e) Of all swine odours, 44.3% were intensity 1 or 2 odours while 28.1% were intensity 3 odours, the other 27.5% were intensity 4 or 5 odours. This was very different compared with the Stage I results, where 3.3% and 13.3% of all odours reported were intensity 1 and 2 odours, but intensity 4 and 5 odours made up more than 50% of all odours. This result indicates that periodical nose calibration was indeed needed to ensure the quality of intensity rating.
f) Of all swine odours, 43.8% were assigned offensiveness 1 (not annoying) or 2 (somewhat annoying) and 27.5% were assigned offensiveness 4 (very annoying) or 5 (extremely annoying).

g) As rated by the observers, 77.2% of intensity 2 odours were considered not annoying or somewhat annoying regarding offensiveness. This finding may help in selecting acceptable odour intensity criterion for local communities.
h) Some odour observers may have overestimated the odour intensity of some odours due to their perception and sensitivity to swine odour characteristics.
i) The following factors may have affected the odour detection frequencies of the observers: distance from the swine site, direction from the swine site, living style/habit of the residents, and olfactory sensitivity of the residents.
j) Odour occurrence was inversely related to the wind speed. Under certain weather conditions, odour may travel a long distance and remain high in intensity even when wind speeds were high.
k) Most odour events were detected under SC D (62.9%) and no odour was detected under SC A. Stable weather SC E to G occurred mostly at night when observers were likely not outside to conduct measurement. Odours with varies intensities were observed under various stability classes except SC A, suggesting that stability class may have a limited effect on odour dispersion within the measurement distance (<8 km), which may be different than long distance air contaminant transportation.

Part 4. Stage II: Downwind Swine Odour Monitoring By Hired Trained Odour Assessors

OBJECTIVE

The objective of this study was for two hired trained odour assessors to monitor odours downwind of a 5,000-sow farrowing-to-finishing swine operation, located on the Canadian Prairies, to reveal odour occurrence profiles in the vicinity of swine operations.

MATERIALS AND METHODS

ODOUR MONITORING AREA AND THE SWINE OPERATIONS

This is identical to the description presented in Part 2.

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 20250 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., the 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.

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 (0.5 mile) 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, 5 days a week (including some weekends). Each trip took about 3 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. The detailed information is presented in Parts 5 to 7.

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., emptying the EMS, plug pulls, and 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 near 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 5,806 measurements, with the most measurements per month occurring in July (26 days; 1,139 measurements) and the least occurring in May (19 days) and October (814 measurements).

Of the 5,806 total measurements, 4,795 resulted in no odour detection, 90 in non-swine odour detection (e.g., smoke, chemicals, cattle manure, hay, or 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. In order 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 5,716: 4,795 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 the 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. 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 were 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 2 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 4-1 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 4-2 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 4-1 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 4-2). Figure 4-1 also gives the monthly odour events. The number of monthly odour events had a weaker logarithmic relationship with total barn odour emissions (r^2=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 4-1). 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 the EMS were not measured in October. Downwind odour occurrences are also determined by other factors such as weather conditions, which will be discussed later.

Table 4-1. Summary of monthly swine odour measurement results

Month (2003)	All odours	Detection frequency	Intensity 1		Intensity 2		Intensity 3		Intensity 4		Intensity 5	
	Events	(%)	Events	%	Events	%	Events	%	Events	%	Events	%
May	201	24.0	98	48.8	51	25.4	24	11.9	19	9.5	9	4.5
June	206	18.9	72	35.0	39	18.9	48	23.3	30	14.6	17	8.3
July	122	10.9	38	31.1	40	32.8	31	25.4	9	7.4	4	3.3
August	108	11.7	44	40.7	37	34.3	19	17.6	5	4.6	3	2.8
September	80	8.5	22	27.5	29	36.3	14	17.5	9	11.3	6	7.5
October	204	25.7	45	22.1	51	25.0	44	21.6	36	17.6	28	13.7
Total	921	16.1	319	34.6	247	26.8	180	19.5	108	11.7	67	7.3

Table 4-2. Odour emissions from barns and manure storages between May to October, 2003.

Odour source	Number of data	Odour concentration (OU/m^3)		Odour emission rate (OU/m^2-s)		Total odour emission (OU/s)	
		Mean*	S.D. †	Mean*	S.D. †	Mean*	S.D. †
Bred./gest. barn	12	429	215	10.4	3.1	106830	31736
Farrowing barn	12	832	755	23.4	17.3	121258	89606
Nursery barns	24	1260	778	25.4	17.3	198803	135542
Finishing barn	18	1220	695	49.2	28.4	469752	270753
Farrowing cell 1‡	2	390	22	5.5	0.3	16122	957
Farrowing cell 2‡	4	1526	1237	34.5	25.9	164434	123384
Nursery cell 1‡	3	1140	386	24.0	3.3	134804	18379
Nursery cell 2‡	5	619	1131	25.8	46.0	252811	450875
Finishing cell 1‡	4	1083	1513	48.1	84.2	270537	473552
Finishing cell 2‡	5	1680	1876	30.9	37.7	302732	369036
Farrowing site						474202	365021
Nursery site						1041742	342217
Finishing site						1068521	396619

*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.

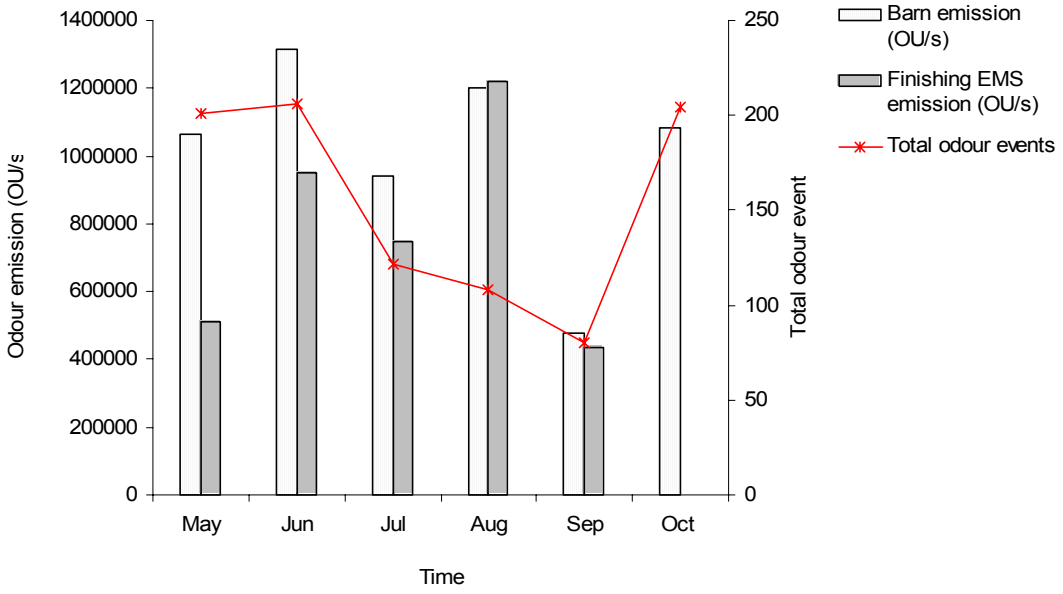


Figure 4-1. Monthly odour events and odour emissions from all building sources and manure storages of the finishing site

DISTRIBUTION OF ODOUR INTENSITY AND OFFENSIVENESS LEVELS

As given in Table 4-1, intensity 1 and 2 odours (very faint and faint odours) were reported the most and made up 34.6% and 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, accounting for 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 frequencies 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 4-3. A linear correlation exists between intensity and offensiveness (Offensiveness = 0.844 × Intensity + 0.331, $r^2 = 0.83$). For all odours with intensity 1, both assessors 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 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 would 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.

Table 4-3. Odour offensiveness rating of odours with different intensities

Offensiveness	Percentage of odour intensity (%)				
	1	2	3	4	5
1	80.2	8.7	1.7	0.0	0.0
2	19.8	81.0	29.8	1.0	0.0
3	0.0	10.4	63.5	27.2	0.0
4	0.0	0.0	5.1	65.0	23.0
5	0.0	0.0	0.0	6.8	77.0

DIURNAL ODOUR OCCURRENCE PROFILE

Figure 4-2 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 1,073 to 1,251 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 the 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 detection was only 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 4-3 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 as intensity 4 or 5 odours; it was also as high as 28.6% in the late evening from 2000 to 2100h with only 7 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. 4-4. Generally speaking, the closer the receptor's location to the source, the more frequently odours were detected (r^2=0.40). However, Figure 4-4 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.

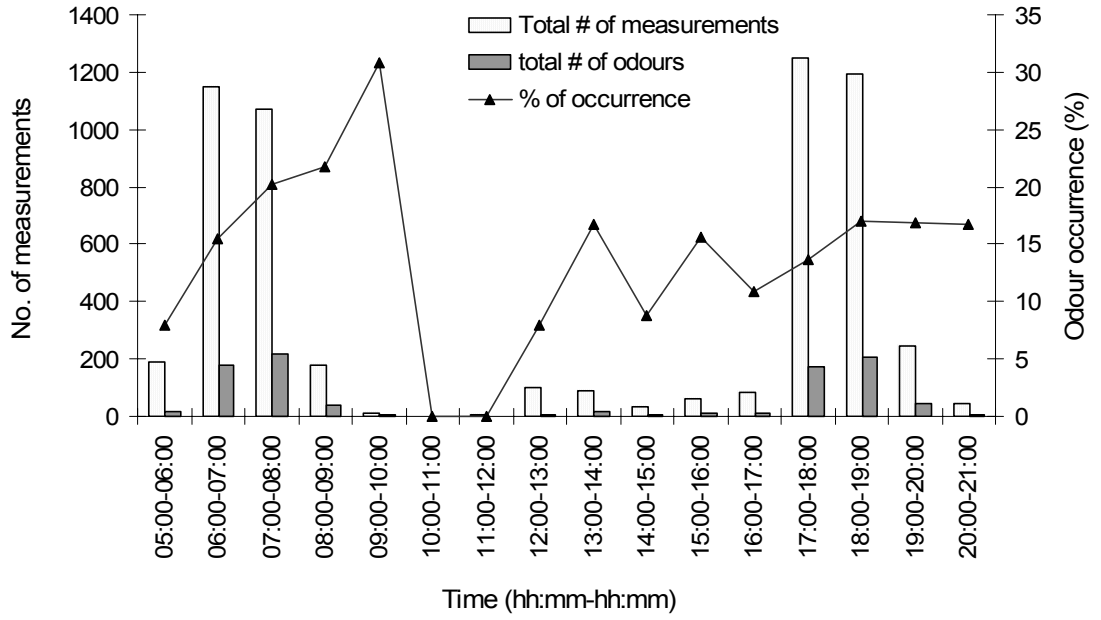


Figure 4-2. Diurnal odour occurrence profiles

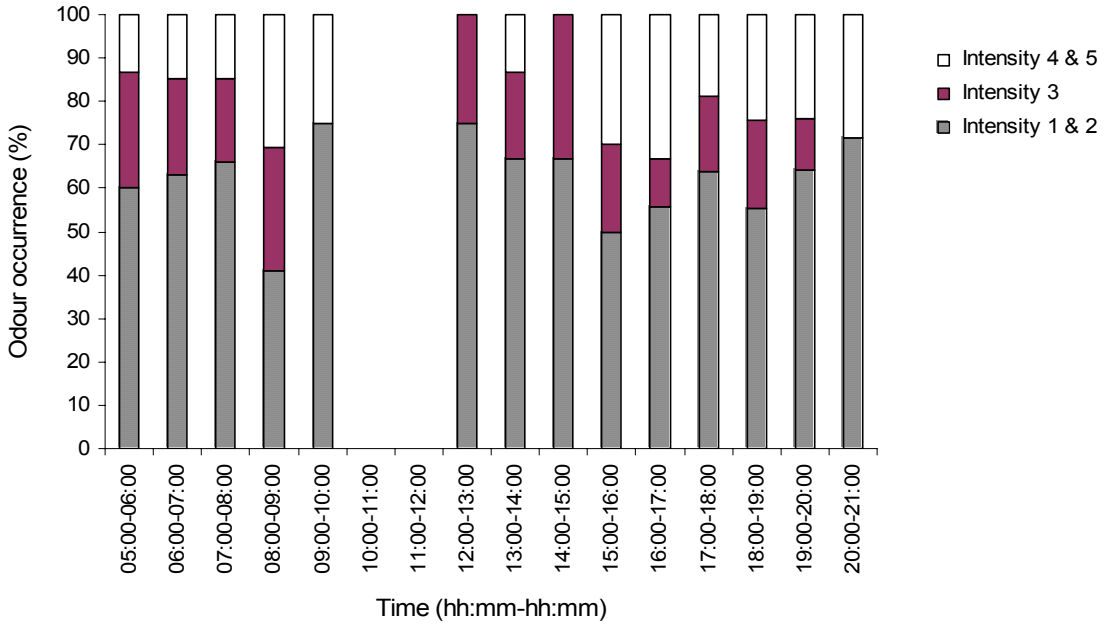


Figure 4-3. Diurnal percentages of odours with various intensities

The average number of odour measurements, odours detected, and detection frequencies per location at various distance ranges were summarized as shown in Fig. 4-5. 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 frequently 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 more of the locations within 5 and 6 km were leeward of the prevailing winds than the locations that were within 4 and 5 km.

Figure 4-6 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 4-7 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 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 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. 4-8. 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.

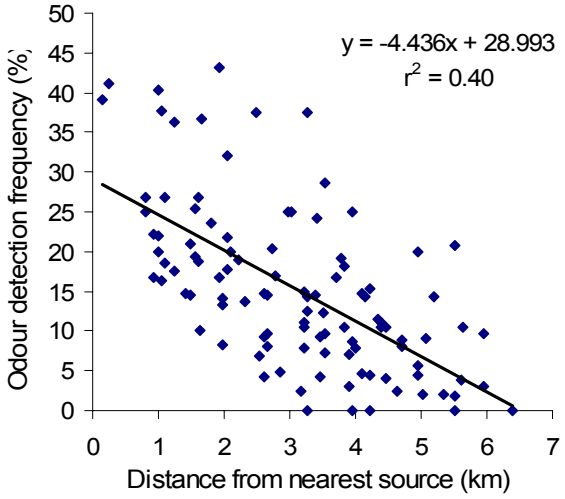


Figure 4-4. Odour detection frequencies at various distances from the closest swine site

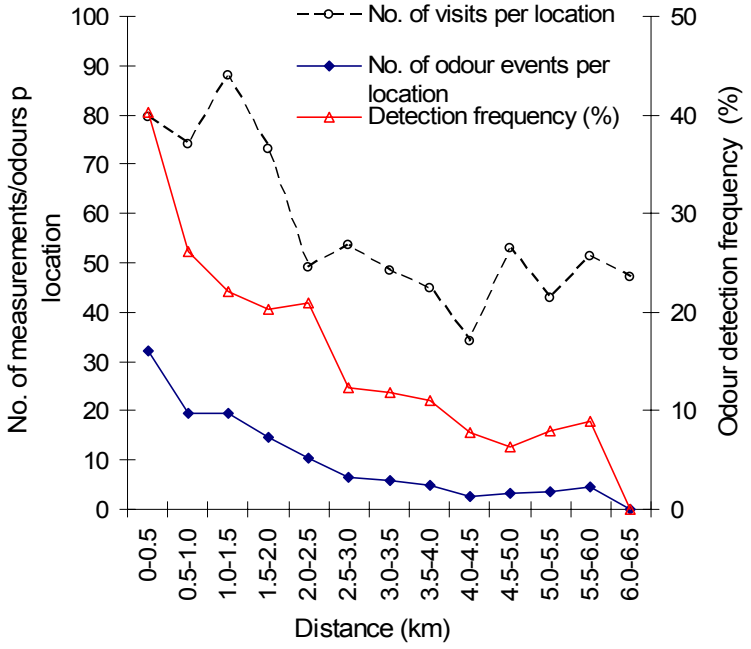


Figure 4-5. Average visits, number of odour events, and frequency of odour detection per location at various distances

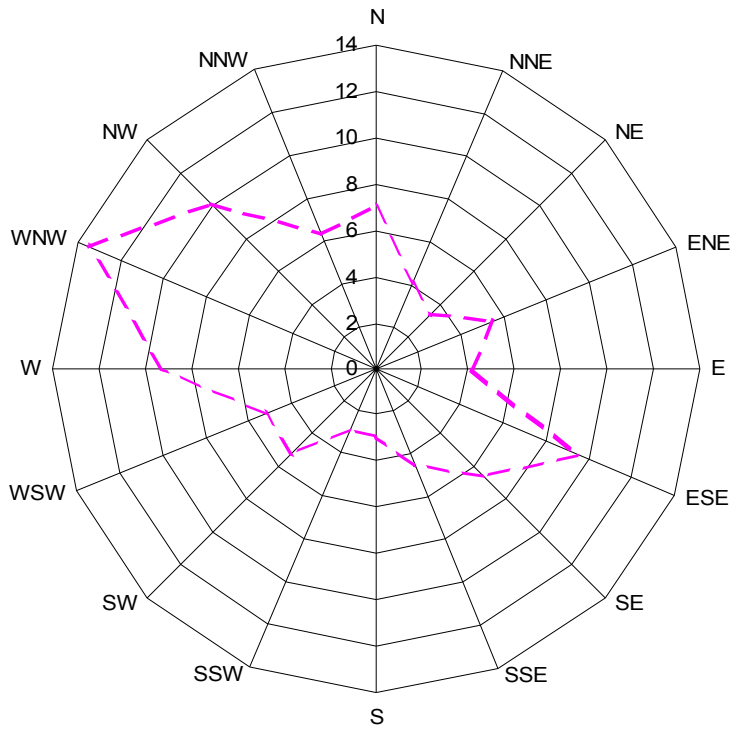


Figure 4-6. Wind rosette of the Rama area during May to October 2003 (unit: %)

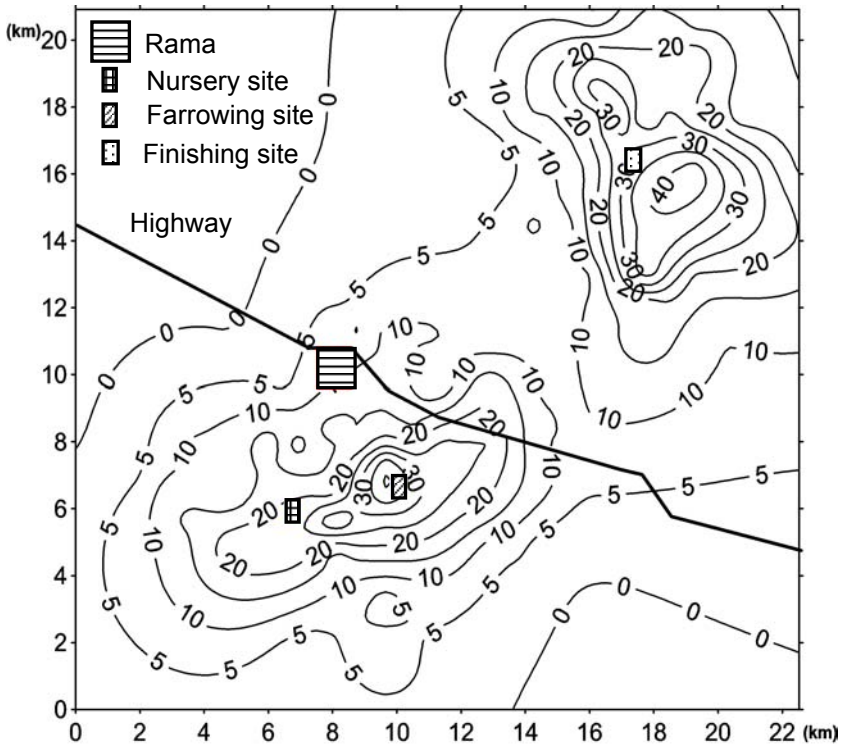


Figure 4-7. Odour detection frequency (%) downwind of the swine sites

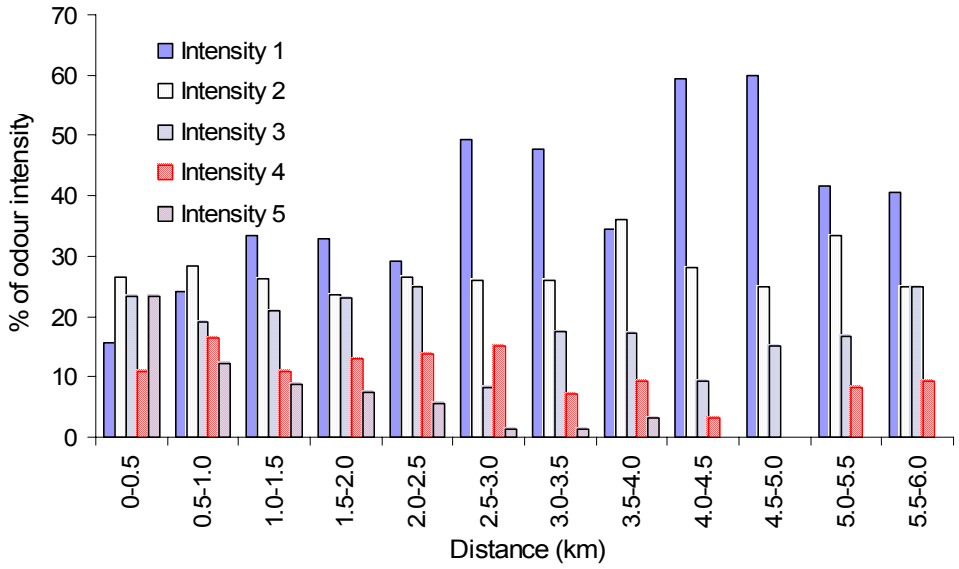


Figure 4-8. Average percentage of odours with different intensities detected at various distances

IMPACT OF WIND SPEED ON ODOUR OCCURRENCE

The total number of odour events with different intensities at various wind speeds is shown on Fig. 4-9. The number of odour events has an inverse linear relationship with the wind speed (r^2 = 0.52); the lower the wind speed, the more odours were reported except when wind speed was less than 1 m/s. Most odour events (81.7%) were detected when the wind speed was equal or less than 5 m/s (or 6.3 m/s at 10 m above the ground as measured by standard weather stations).

Odour events with an intensity of 1 to 4 were detected at all ranges of wind speeds while odours with intensity 5 were only detected when the wind speed was less than 6 m/s (Fig. 4-9). High odour intensities were reported even with high wind speeds. Nine of the 47 odour events reported when the wind speed was equal to or greater than 8.0 m/s were intensity 4 odours (19.1%). These nine events were reported at locations 0.9 to 3.6 km from the closest swine sites when the wind speeds were 8.2 to 12.3 m/s. Six of these events were detected from locations 0.9 to 3.6 km away from the swine manure application land during manure application. The other three events were detected from locations 0.9 to 1.2 km from the swine sites in the early morning and evening. This indicated that during the non-manure application periods, under high wind speeds greater than 8 m/s, odour would be diluted rapidly and might not travel further than 1.2 km. However, during the manure application, odour might travel up to 3.6 km and still retain high intensity (4) even with high wind speed.

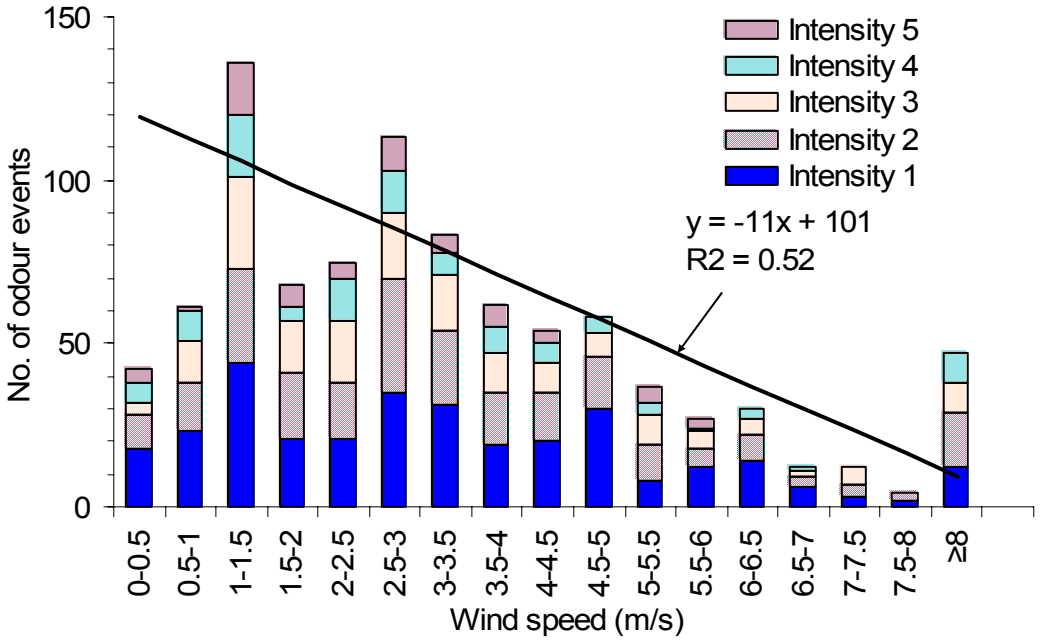


Figure 4-9. Number of odour events with different intensities at various wind speeds

IMPACT OF ATMOSPHERIC STABILITY ON ODOUR OCCURRENCE

IMPACT ON SEASONAL ODOUR OCCURRENCE

Atmospheric stability data from the Yorkton weather station was used in this study. Table 4-4 gives May to October 2003 occurrence frequencies of various stability classes (SC), the average SC frequencies during the field measurement periods, and the percentage of odour events under various SC. SC D had the highest annual occurrence frequency (47.0%) with monthly variations between 37.4% (August) and 54.4% (October). SC E occurred the second most frequently with an average of 17.3% (the lowest was 13.6% in June and the highest was 21.0% in October). SC C occurred the third most frequently with an average of 15.5% (the lowest was 7.8% in October and the highest was 22.8% in July). SC F occurred 8.0% with monthly variations (7.1% to 9.7%). SC G occurred 5.1% with monthly variation ranging from 3.9% (June) to 6.6% (October). For all stable weather conditions (SC E to G), the average frequency ranged from 24.8% in June to 35.8% in October with annual average of 30.4%. Unstable weather condition SC A to C had a lower annual occurrence frequency of 22.5% and the monthly variation was between 9.8% (October) and 31.0% (July).

Although the odour measurements were taken mainly in the early mornings and evenings and some afternoons, stable atmospheric conditions SC E to G during the field measurement periods were still lower than the six month averages (17.2% vs. 30.4%), as given in Table 4-4. This is because SC E to G mainly occurred during the night, as discussed later. The occurrence frequency of unstable atmospheric SC A to C during the field measurement periods was about the same as the average frequency of SC A to C over the six month period (22.2% vs. 22.5%). SC D occurred the most during field measurements (60.6%), which was higher than the average frequency of SC D over the six months (47.0%).

As given in Table 4-4, the frequencies of odour detection under various SC were about the same as the occurrence frequencies of the SC during the measurement periods. No odour was detected under SC A. Odour detection frequency under SC B was lower than the occurrence frequency of SC B during the measurement periods (2.1% vs. 3.2%). However, the odour detection frequency under SC C was higher than its occurrence frequency during the measurement periods (20.2% vs. 19.0%). A total of 22.3% of odour events were detected under unstable atmospheric conditions (SC A to C), which was the same as the occurrence frequency of SC A to C during the measurement periods. Fewer odour events were detected under stable weather conditions than expected. In fact, only 16.7% of all odour events were detected under stable atmospheric conditions (SC E to G), which was lower than the occurrence frequency of SC E to G during the measurement periods (17.2%). Table 4-4 indicates that 61% of odour events were detected under stability D. The results indicated that the atmospheric stability classes had little effect on the odour detection frequency. This is contrary to the commonly accepted air dispersion theory that stable weather would favour air contaminants, odour, or gas transportation for longer distance than unstable weather conditions. However, this is consistent with the conclusions made in Part 2 and 3 of this study.

As mentioned previously, 81.7% of odour events were detected when the wind speed was equal or lower than 5 m/s, which seems contrary to the fact that 61.0% of odours were detected under SC D, which included windy and overcast conditions. Table 4-5 gives the two dimensional frequency distribution of SC and wind speed during May to October 2003 for Yorkton. During this study period, when the weather conditions qualified as SC D, wind speed was lower than 5 m/s (ranging from 0 to 4.9 m/s) 39.2% of the time. Hence, wind speed is not the only factor for determining atmospheric stability class; other factors such as cloudiness, solar radiation, mixing height, etc. were all included when determining atmospheric stability classes.

Figure 4-10 shows the monthly odour events and the occurrence frequencies of various stability classes during the measurement periods. During May and June, unstable weather was at the highest occurrence frequency while stable and neutral weather conditions were at the lowest occurrence frequencies, which indicated that this period of time was least favourable for odour travel. However, this period had the highest number of odour events. The unstable weather frequency in July was similar to that of June but odour events dropped dramatically. August and September had low occurrence of unstable weather yet they also had the lowest number of total odour events. October had low frequency of unstable weather, which may be one reason for the high number of odour events detected during this month. Other reasons might be manure application and the high odour emission rates, as discussed previously.

The above result again indicated that atmospheric stability class was not the determining factor for odour dispersion. The main difference between livestock odour dispersion and industrial air contaminant dispersion, on which the air dispersion theory is based, is the transportation distance. Based on this study, the detection distance for livestock odours is 6 km or, possibly, up to 8 km. However, the air dispersion theory and industrial air dispersion models are intended to be used for distances beyond 10 km to more than 100 km. The result of this study indicated that the air dispersion models may not be applicable for odour dispersion within short distances. Also based on this study, wind direction and wind speed are determining factors for odour

dispersion whereas the effect of atmospheric stability on odour dispersion is very limited. Other factors, such as diurnal and seasonal variations of source odour emission rate, may also play a role in short distance odour dispersion.

Table 4-4. Odour occurrences under various atmospheric stability classes (SC)

Atmospheric SC	Number of odour events by intensity					No. of odour events by SC	% of odour events by SC	% of SC during measurement periods	% of SC (May-Oct.)
	1	2	3	4	5				
A	0	0	0	0	0	0	0.0%	0.1	0.5
B	10	2	4	3	0	19	2.1%	3.2	6.5
C	70	44	33	23	16	186	20.2%	19.0	15.5
D	183	157	113	66	43	562	61.0%	60.6	47.0
E	35	27	21	13	2	98	10.6%	10.5	17.3
F	17	15	7	2	6	47	5.1%	5.0	8.0
G	4	2	2	1	0	9	1.0%	1.7	5.1
Total	319	247	180	108	67	921	100%	100%	100%
Percent of odour events	34.6%	26.8%	19.5%	11.7%	7.3%	100%			

Table 4-5. Two-dimensional frequency distribution in percentage of stability classes and wind speeds during May to October 2003

Wind speed (m/s)	Stability class						
	A	B	C	D	E	F	G
<1.0	63.6	5.2	2.3	1.1	3.4	12.7	31.6
1.0–1.9	36.4	50.2	16.3	6.5	12.5	35.6	68.4
2.0–2.9	0	24.4	13.4	9.0	18.6	50.6	0
3.0–3.9	0	16.7	5.7	8.1	20.1	0.6	0
4.0–4.9	0	3.5	32.1	14.4	30.6	0.6	0
5.0–5.9	0	0	28.4	27.8	14.8	0	0
6.0–6.9	0	0	0.4	8.4	0	0	0
7.0–7.9	0	0	0.6	11.6	0	0	0
≥ 8.0	0	0	0.7	13.1	0	0	0
Total	0.5	6.5	15.5	47.0	17.3	8.0	5.1

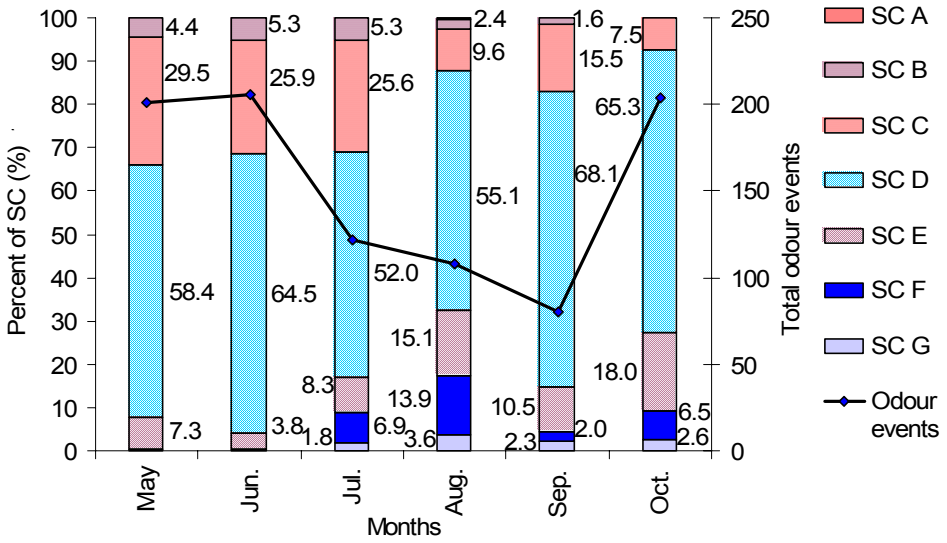


Figure 4-10. Atmospheric stability distributions during the measurement periods

IMPACT ON DIURNAL ODOUR OCCURRENCE

Figure 4-11 shows the diurnal mean cumulative occurrence frequency of each stability class during May to October, 2003. The data were obtained by cumulating the occurrences of each stability class during each hour period of every day over the six months and then calculating the percentage of each stability class during each hour. SC A to C occurred mostly between 0700 and 2000h and dominated the period from 1000 to 1400h with an occurrence frequency up to 53.3%. SC E to G occurred mostly between 1900 and 0700 h and dominated the period from 2100 to 0500h with the frequency ranging from 50.0% to 73.4%. The occurrence frequency of SC D ranged from 26.6 to 69.0% and was occasionally dominant during the day and night.

The field odour measurements were taken primarily during the transition periods between day and night. During the morning between 0500 and 1000h, the odour detection frequency gradually increased from 7.9% to 30.8% with the decrease in the frequency of stable weather SC E to G and the increase in the frequency of unstable weather SC A to C (Fig. 4-11). From the afternoon to the evening (1200 to 2100h), the odour detection frequency fluctuated between 7.9% and 16.7% and stabilized after 1800h at about 17%. The average odour detection frequency during the daytime between 0900 and 1700h was 15.1%, which is slightly lower than that during the morning between 0500 and 0900h (16.3%) and during the evening from 1700 to 2100h (16.1%). Hence, unstable weather did not reduce the odour detection frequency as compared to stable weather. Again, odour dispersion within a distance of 6 km may not comply with the air dispersion theory that is applicable to long distance air contaminant transportation.

IMPACT ON ODOUR INTENSITY

As indicated in Table 4-4, odour events with various intensities occurred under all SC B to G except that no intensity 5 odour events occurred under SC B and G. The observed results did not support the hypothesis that stable atmospheric conditions would favour odour travel, i.e., high intensity odours were expected to occur mostly under stable weather conditions rather than under neutral or unstable weather conditions. Under each individual stability class, odours with

intensity 1 occurred most frequently and the number of odour events decreased with the increase of odour intensity.

IMPACT ON ODOUR DETECTION DISTANCE

Figure 4-12 shows the number of odour events with various intensities detected at different distances under each atmospheric stability class. Swine odours were detected under SC C to G within 6.0 km from the production sites. The largest detection distance under SC B was 3.8 km (one odour event of intensity 1). With the increase of distance, total odour events decreased and high intensity odour events (intensity 4 and 5) decreased as well.

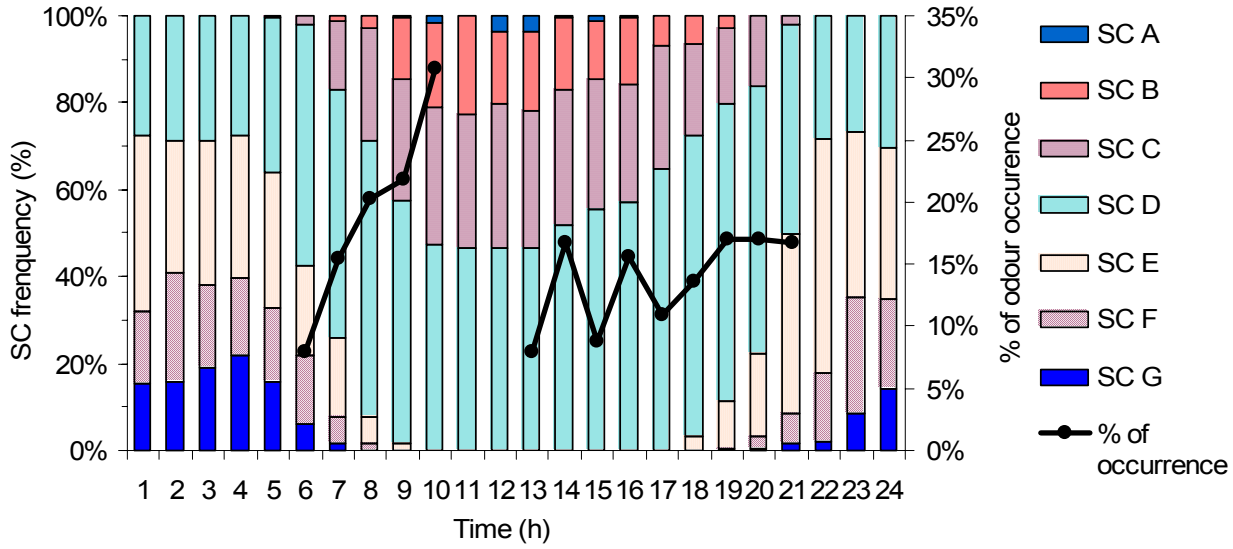


Figure 4-11. Diurnal atmospheric stability distribution and detected odour events

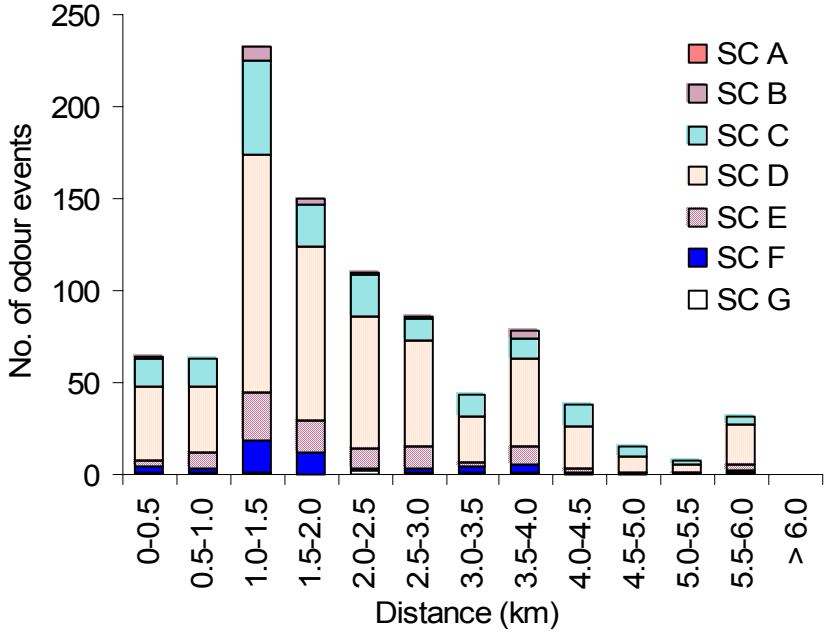


Figure 4-12. Odour events under various atmospheric stability classes at different distances.

CONCLUSIONS

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

a) Swine odours were detected in 16.1% of all downwind measurements on 105 locations, which resulted in a total of 921 swine odour events. The farthest detected location was 6.0 km from the closest swine site. At five of the locations, no odour was ever detected, including the farthest location (6.4 km) from the swine site.
b) October and May had the highest odour detection frequencies of 25.7% and 24.0%, respectively, which might be caused by frequent manure land applications. September had the lowest detection frequency of 8.5%.
c) 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%); they occurred most frequently in June and October but least frequently in July and August.
d) 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 ($r^2 = 0.83$**). All intensity 1 odours and 89.7% of intensity 2 odours were considered not annoying or somewhat annoying by the assessors. This may help set acceptable odour intensity criterion. Considering both the odour measurement by the resident observers and the hired odour assessors, odour intensity 2 may serve as odour annoyance free level in rural area around livestock operations.
e) Regarding diurnal odour occurrence, most measurements (81.7%) were taken during the hours of 0600 to 0800h and 1700 to 1900h and the odour detection frequencies were 13.7% to 20.2%, respectively. Odour detection frequency was the highest between 0800 and 1000h (21.8% to 30.8%). Intensity 4 and 5 odours were detected during each of the time periods during which measurements were taken.
f) The odour detection frequency at a receptor's location had a weak linear relationship with the distance from the odour source. The average detection frequency per location was the highest within 0.5 km (40.3%) and the lowest at a distance of 4.5 to 5.0 km (6.3%). Beyond 1 km, the higher the odour intensity, the lower its detection frequency was. Odours with all intensities were observed within 6 km except no intensity 5 odour was observed beyond 4.0 km from the source.
g) The number of odour events has an inverse linear relationship with the wind speed; the lower the wind speed, the more odours were reported except when the wind speed was less than 1 m/s. Most odour events (81.7%) were detected when the wind speed was equal to or less than 5 m/s.
h) (h) The majority of odour events (61.0%) were detected under SC D. A total of 22.3% of odour events were detected under unstable atmospheric conditions (SC A to C), which was the same as the occurrence frequency of SC A to C during the measurement periods. Only 16.7% of all odour events were detected under stable atmospheric conditions (SC E to G), which was lower than the occurrence frequency of SC E to G during the measurement periods (17.2%). Wind direction and wind speed are determining factors for odour dispersion whereas the effect of atmospheric stability on odour dispersion is very limited. The result of this study indicated that the air dispersion models may not be applicable for odour dispersion within short distance.

Part 5. Seasonal Odour Emission Profiles From Different Types Of Swine Barns

OBJECTIVE

The objective of this part of the study is to reveal the seasonal variations of odour concentrations and emission rates of different commercial swine production buildings (breeding/gestation, farrowing, nursery, and growing/finishing) under the Canadian Prairie climate.

MATERIALS AND METHODS

SWINE PRODUCTION FACILITIES

The information on the swine operation is presented in Part 2. Different types of building sources of the three sites were selected for this study including two breeding/gestation rooms, two farrowing rooms, four nursery rooms, and three finishing rooms. The specifications of the facilities are given in Table 5-1. These rooms were all mechanically ventilated by wall and ceiling mounted exhaust fans. The manure handling system of these rooms were the same, all with liquid manure stored in under-floor shallow pits and then removed to outdoor manure storage basins once every one to four weeks.

Table 5-1. Information on the selected swine buildings.

Facility	Number	Facility capacity	Size (length x width, area)
Gestation room (G1)	1	612 sows	18.3 x 63.8 m (1,167 m^2)
Gestation room (G2)	1	1200 sows	36.6 x 63.7 m (2330 m^2)
Farrowing room (F1 and F2)	2	32 farrowing sows	7.3 x 25.3 m (185 m^2)
Nursery room (N 1 to N4)	4	736 weaner pigs	14.3 x 17.1 m (245 m^2)
Finishing room (FN1 to FN3)	3	1250 feeder pigs	26.1 x 36.6 m (955 m^2)

ODOUR EMISSION MEASUREMENT

Odour emissions from the building sources were measured for one year from March 2003 to March 2004. It was measured once a month from March to November, 2003 and less frequently during the winter (January to March, 2004).

All measurements were taken during the day time between 0900 to 1600h. 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 and an air pump and Teflon® FEP tubing (Cole-Parmer Instrument Company, Vernon Hills, IL).

The sample bags were transported to the Olfactometry Laboratory, University of Alberta, Edmonton, Canada and measured for odour concentration, i.e., odour detection threshold, within 30 hours of collection. An eight-port olfactometer with eight trained panelists was used for odour concentration measurement. The triangular forced-choice method was

used to present samples to the panelists. The panelists were selected and re-evaluated periodically following the procedure of CEN (1999). For each olfactometry session, data were retrospectively screened by comparing panelists' individual threshold values with the panel average (CEN 1999).

Two methods were used for obtaining the ventilation rate of a room: the fan method, which tallies the airflow rates of all fans, and the CO_2 mass balance method (Albright 1990). For the fan method, the speed of all the fans and the vacuum pressure of the room were measured and then fan performance testing results from the manufacturers or fan testing organizations (PAMI Prairie Agricultural Machinery Institute) were used to obtain the air flow rates of the fans. The fan speed was measured by a SHIMPO DT-207L Tachometer (accuracy: ±1 rpm for 6 to 8300 rpm, Netech Corp. Hicksville, NY) and the static pressure was measured by VelociCalc® Plus (accuracy: ±1% of reading, TSI Inc. Shoreview, MN). For the CO_2 mass balance method, CO_2 concentration was measured directly from the air sample bags immediately after the samples were collected. CO_2 concentrations lower than 3000 parts per million (ppm) were measured by a Guardian Plus Infra-Red Gas Monitor (accuracy: ±2% for 0 to 3000 ppm, Edinburgh Sensors Ltd., Hingham, MA), and those over 3000 ppm were measured by gas chromatography in the Soil Science Laboratory, University of Saskatchewan. The number and the combined weight of pigs in a room were recorded. The total CO_2 loss from a room was the product of the CO_2 concentration and ventilation rate. The CO_2 gain of a room was the sum of the CO_2 coming from incoming supply air, which was assumed to be 345 ppm, and the CO_2 produced by pigs. Indoor and outdoor temperature and relative humidity were recorded. The odour emission rate of a room is the product of odour concentration and the ventilation rate.

NH_3 concentration was measured immediately after the air samples were taken using colorimetric tubes (Kitagawa, Matheson Gas Products, Secaucus, NJ, USA) and later using an infrared NH3 analyzer (CHLLGARD RT refrigerant monitor, measuring range of 0 to 100 ppm, accuracy ±1 ppm, MSA Instrument Division).

STATISTICAL ANALYSIS

The data were subjected to an analysis of variance using SAS (SAS Institute 1999). Data of individual barns were analyzed separately using the general linear models (PROC GLM) based on the completely randomized block experimental design. Correlation and regression analysis among measured variables were conducted using PROC CORR and REG procedures of SAS. Both treatment effects, correlation and regression coefficients, were considered as significant at $P<0.05$.

RESULTS AND DISCUSSIONS

ODOUR CONCENTRATIONS AND EMISSIONS

GESTATION ROOMS

Measurements for gestation rooms were taken in the morning between 0900 and 1200 h. Figure 5-1 shows the measurement results throughout the year for gestation room G1. As shown in Fig. 5-1 a), room temperature ranged from 17.0 to 26.3^{o}C while outside temperature was between -22.3 and 23.3^{o}C. CO_2 concentration showed large seasonal variation ranging between 720 ppm in August to 4435 ppm in January. Odour concentration followed a similar seasonal pattern with the lowest of 536 OU in May and the highest of 4993 OU in January. The warm season from May to October had low odour concentrations ranging between 536 to 891 OU, while during the cold season from November to April the odour concentrations were high, ranging between 1967 and 4993 OU.

Figure 5-1 b) gives the ventilation rate of room G1 obtained by the fan and CO_2 methods. The ventilation rates obtained by the fan method were much higher than those obtained by CO_2 method (annual means 22.4 and 5.3 m^3/s, respectively). Similar results were obtained from all the other rooms. The fan method may have an uncertainty of about 15% due to the dust buildup and power supply variations. The CO_2 method had an unknown uncertainty due to the fact that the CO_2 productions of animals were obtained in the late 1950's (ASAE standard 2001). Animal breeds, diets, and production systems have changed over the years; therefore, the CO_2 production rate may have also changed. The result from this study indicated that the CO_2 production data need to be updated. Hence, the ventilation rates obtained by the fan method were used by this study. The ventilation rate of room G1 varied between 5.6 m^3/s in January and 52.6 m^3/s in May when the measurements were taken.

Figure 5-1 c) and d) summarize odour concentrations and emission rates of both rooms. For room G2, there were missing data in April due to leaking bags and again in January because the wall mounted fans were not running due to the low ambient temperature (only the chimney fans were working), so the air samples could not be taken. Similar seasonal profiles of odour and CO_2 concentrations were observed in room G2; however, the odour concentration in room G2 was much lower than that in G1. CO_2 ranged from 640 ppm in May to 2935 ppm in November while odour concentration ranged from 71 OU (May) to 812 OU (October). The reason for the much lower odour concentration through out the year in room G2 than in room G1 could not be identified. The ventilation capacities of the two rooms were the same (0.85 m^3/s-pig) and the average pig weight was much higher in G1 (120 and 59 kg/m^2, respectively).

Odour emission rate in G1 varied over a large range and there was no apparent seasonal pattern. April had the highest value of 40.2 OU m^{-2} s^{-1} while October had the lowest value of 5.6 OU m^{-2} s^{-1}. Although summer temperature was high, which resulted in a high ventilation rate, the odour concentration was low; therefore, odour emission rates, as the product of ventilation rate and odour concentration, were not the highest of the year.

In the cold season from November to March, the ventilation rate was low although the odour concentration was high, which did not result in low odour emission rates. Odour emission rates in room G2 varied between 1.4 OU m^{-2} s^{-1} (March) to 15.1 OU m^{-2} s^{-1} (June), which was much lower than room G1. Again, no specific reason was found.

Table 5-2 gives the annual geometric means of odour concentrations and emissions of each room and the statistical analysis results for comparison of the rooms within each type of barn. It indicated these two rooms were significantly different in odour concentrations and emissions ($P<0.05$). It is also notable that the standard deviations were very large, which reflected the high variations of odour concentrations and emissions throughout the year. Table 5-3 gives the geometric means of the rooms in each type of barn at different measurements and the statistical comparison of the measurements taken throughout the year. It indicated that the odour concentrations and emissions of the gestation rooms were significantly different throughout the year ($P<0.05$). Odour concentration increased with decreasing ambient temperature but the rate of change for odour emission was random. The correlations of odour concentration and emissions with the ambient temperature and other related factors will be discussed later.

FARROWING ROOMS

Measurements for the farrowing rooms were also taken in the morning between 0900 and 1200h. Figure 5-2 shows the measurement results. The two rooms had similar indoor temperature ranging between 17.0 and 27.2^{o}C (Fig. 5-2 a). Similar seasonal patterns of odour and CO_2 concentrations as the gestation rooms were observed (Fig. 2 a)). For room F1, as shown in Fig. 5-2 a), odour concentration ranged from 457 OU in April to 4752 OU in January while CO_2 concentration varied between 620 ppm in June and 2750 ppm in January. Figure 5-2 b) shows the odour concentrations for both rooms F1 and F2. Odour concentrations of room F2 were similar to room F1. The ventilation rates of the two rooms varied from 1.8 (January) to 5.8 (April and July) m^3/s. Figure 5-2 c) depicts the odour emission rates of the rooms. In contrast to odour concentration, it did not show an obvious seasonal pattern. Its lowest value was 10.2 OU m^{-2} s^{-1} in June and September and it peaked in October and January at 57.6 OU m^{-2} s^{-1}. Statistical analysis indicated that there are no significant difference between the two rooms for odour concentrations and emission rates (Table 5-2, $P>0.05$). Table 5-3 indicated that the odour concentrations and emissions of the farrowing rooms were significantly different throughout the year ($P<0.05$).

NURSERY ROOMS

Measurements for the nursery rooms were also taken in the early afternoon between 1200 and 1400h. The weights and ages of pigs in different nursery rooms at different times of the year were usually different and the required room temperatures were different according to the ages of pigs. Figure 5-3 a) shows measured results for room N1 over the year. The temperature varied from 18.5 to 30.9^{o}C. Seasonal variations of odour and CO_2 concentrations were also observed as high in winter and low in summer (Fig. 5-3 a). The odour concentration ranged from 707 OU (July and September) to 8605 OU (March) while CO_2 varied between 685 ppm (July) to 7340 ppm (October). The other three rooms

had similar results. Figure 5-3 b) pools the data for all four nursery rooms for odour concentration.

The ventilation rate of the rooms varied from 0.8 m^3/s in winter and 12.5 m^3/s in summer. Figure 5-3 c) pools the odour emission rates of all four nursery rooms. The odour emission rate of room N1 did not show an obvious seasonal pattern. Its lowest value was 7.7 OU m^{-2} s^{-1} in September and it peaked in April at 93.2 OU m^{-2} s^{-1}. The other three rooms showed similar values except that room N2 had a very high odour emission rate of 269.2 OU/m^2-s in April as compared with the second highest value of all rooms during the year, which was 93.2 OU m^{-2} s^{-1} from room N1 in April. As given in Table 5-2, there were no significant differences between the other four rooms for odour concentrations and emissions ($P>0.05$). The odour concentrations and emissions of the nursery rooms throughout the year were significantly different (Table 5-3, $P<0.05$).

FINISHING ROOMS

Measurements for the nursery rooms were also taken in the early afternoon between 1400 and 1600h. The age of pigs in different finishing rooms at different times of the year were also usually different and the temperature requirements were also different. Figure 5-4 describes the measurement results for the finishing rooms. Seasonal patterns of odour and CO_2 concentrations were observed as being high in winter and low in summer for room FN3 (Fig. 5-4 a). The other rooms showed similar results. For all finishing rooms, room temperature varied from 15.0 to 32.1^oC while the ambient temperature ranged from -19.8 to 30.3^oC. Figure 5-4 b) pools all the odour concentrations from the three finishing rooms. Odour concentration ranged from 446 OU (July) to 7797 OU (March) while the CO_2 concentration varied between 475 ppm (August) to 3856 ppm (January). The ventilation rate of the rooms varied from 6.5 m^3/s in winter to 46.6 m^3/s in summer. Figure 5-4 c) pools all the odour emission rates from the three finishing rooms. The odour emission rate did not show an obvious seasonal pattern. Its lowest value was 12.0 OU m^{-2} s^{-1} in November and it peaked in June at 137.7 OU m^{-2} s^{-1}. The results given in Table 5-2 indicated that the odour concentration of room FN3 were significantly lower than that of the other two rooms ($P<0.05$) but no significant difference was found for odour emission rates of the three rooms ($P>0.05$), which was caused by the great variation of the data. The results in Table 5-3 also indicated that the odour concentrations and emissions of the finishing rooms varied significantly throughout the year ($P<0.05$).

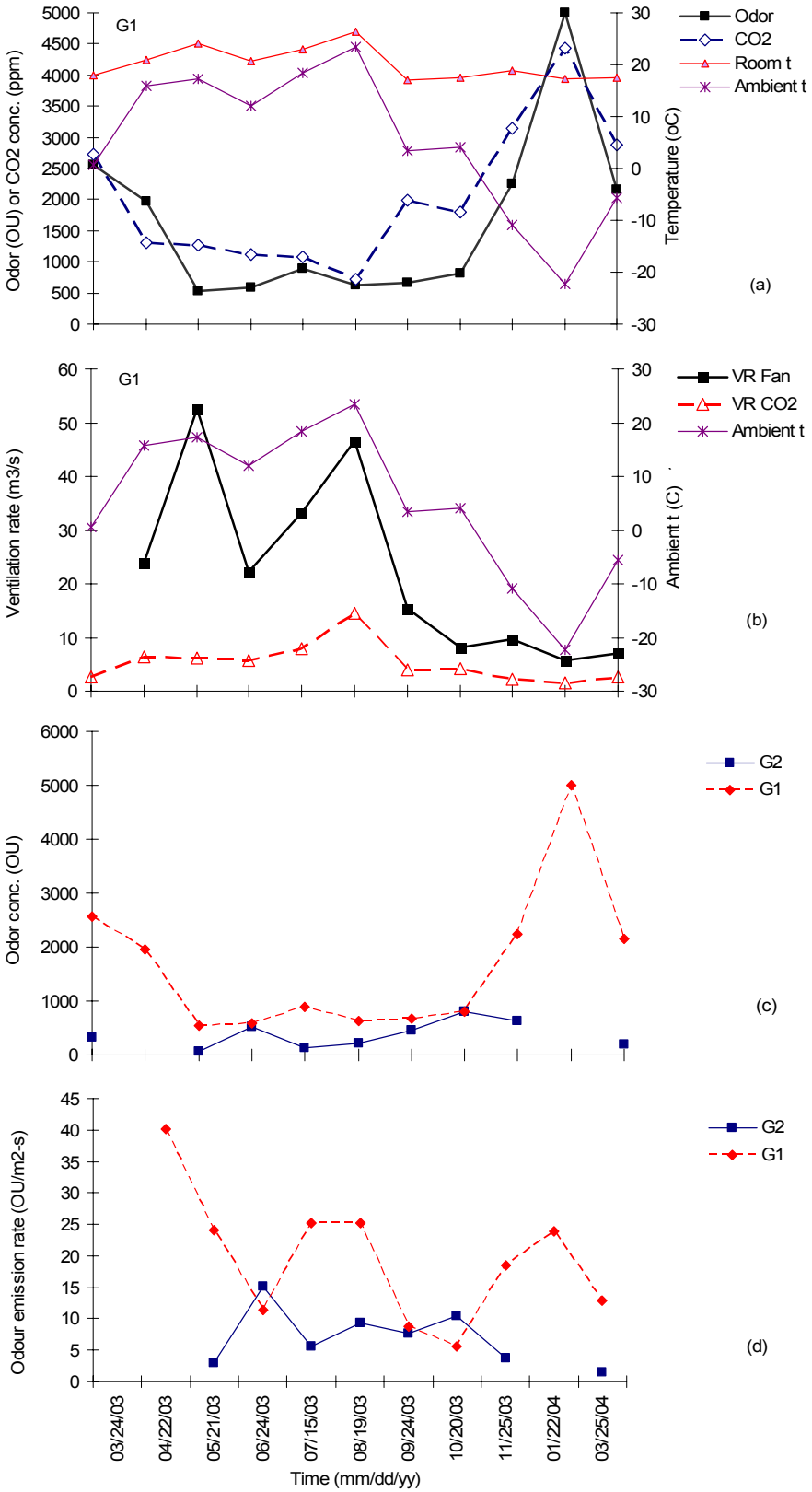


Figure 5-1. Odour concentration and emissions of gestation rooms

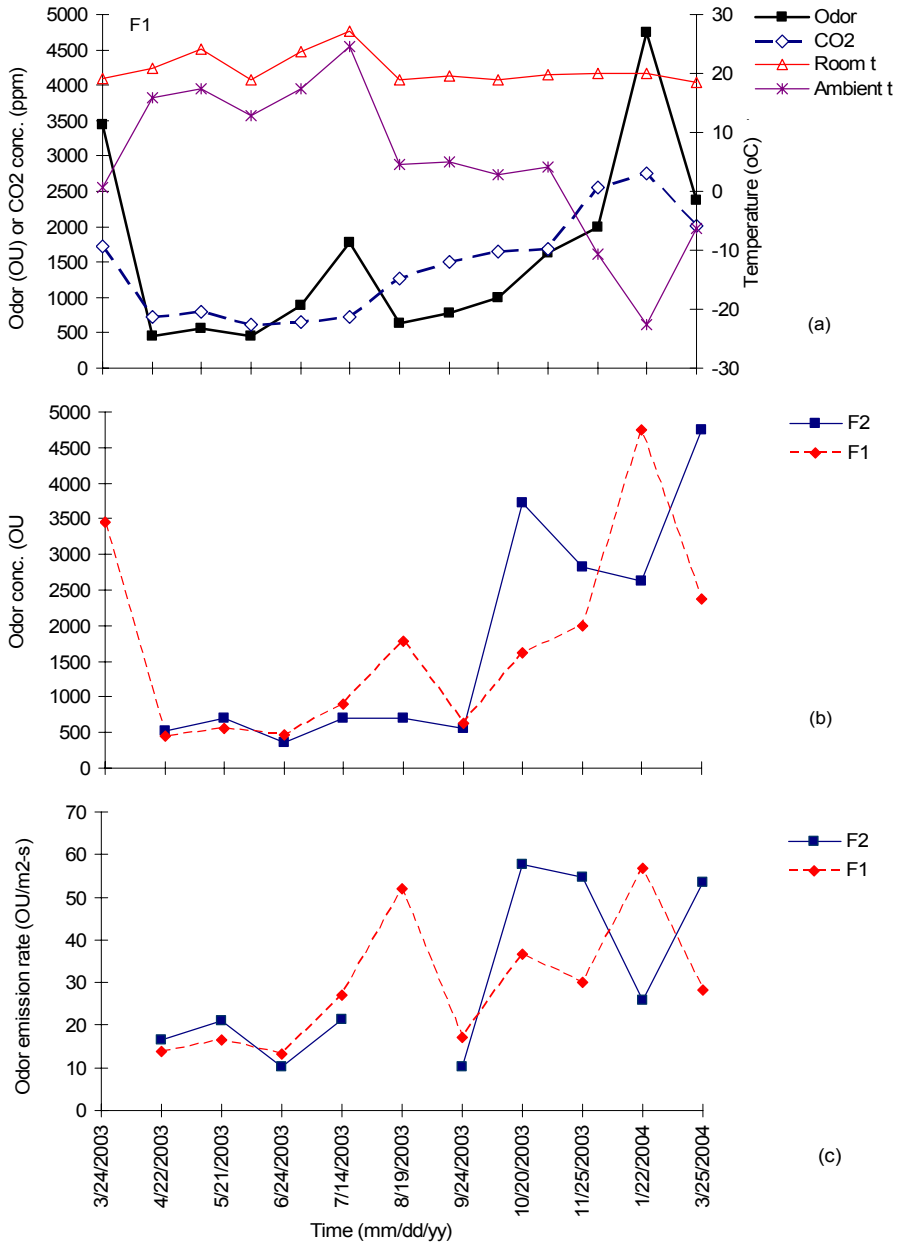


Figure 5-2. Odour emissions for farrowing rooms

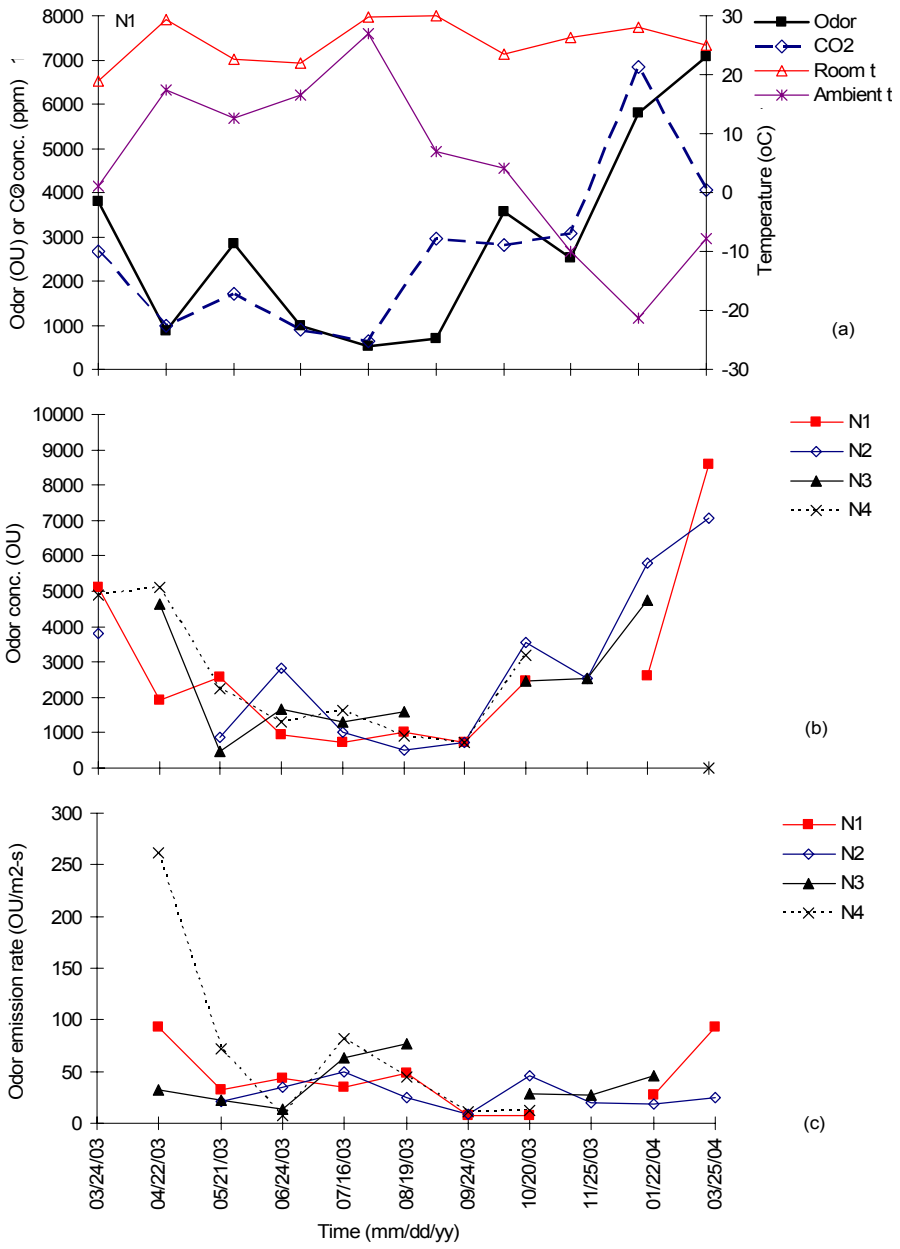


Figure 5-3. Odour measurement results of all four nursery rooms

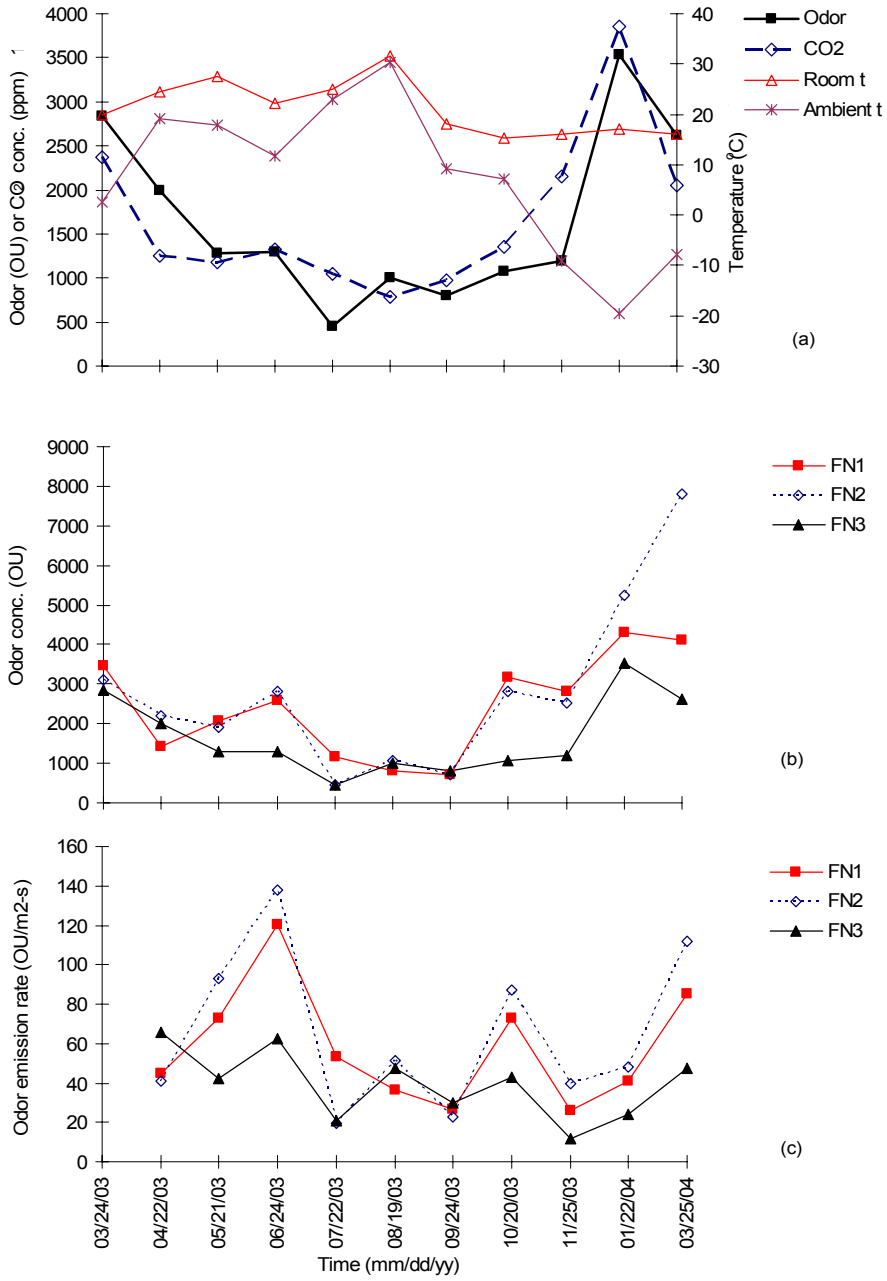


Figure 5-4. Annual odour concentration and emission rates of all 3 finishing rooms

Table 5-2. Comparison of the same type of rooms for room temperature, animal units, and annual odour concentrations and emission rates*

Room	Indoor t (C)	Animal Unit	Odour concentration (OU)				Odour emission rate (OU m^{-2} s^{-1})			
			Geometric mean	S.D.	Max.	Min.	Geometric mean	S.D.	Max.	Min.
G1	20.1a	197.4b	1252a	1355	4993	536	17.0a	10.3	40.2	5.6
G2	20.8a	558.6a	294b	264	812	71	5.7b	4.5	15.1	1.4
F1	20.0a	14.3a	1278a	1382	4752	457	25.8a	15.4	56.7	13.1
F2	21.1a	14.5a	1171a	1598	4752	354	24.6a	19.6	57.6	10.2
N1	23.8a	24.8a	1914a	2480	8605	707	31.8a	31.5	93.2	7.7
N2	25.6a	21.3a	2038a	2245	7062	512	24.7a	13.3	49.4	9.0
N3	26.1a	17.4a	1968a	1543	4752	476	33.6a	21.9	77	13.4
N4	24.9a	16.1a	1983a	1734	5123	707	35.5a	89.5	261.3	7.7
FN1	20.8a	160.1a	2052a	1283	4304	707	51.7a	29.8	120.5	26.3
FN2	21.8a	183.8a	2106a	2127	7797	446	54.3a	39.8	137.7	19.4
FN3	20.8a	155.3a	1397b	971	3530	446	35.3a	17.7	65.8	11.7

*Means followed by the same letter in a column of each type of barn are not significantly different at P<0.05 according to Duncan's multiple range tests.

Table 5-3. Seasonal variations of room temperature and odour concentration and emissions of the four types of rooms*

Time	Ambient	Odour detection threshold (OU)				Odour emission rate (OU m^{-2} s^{-1})			
(mm/dd/yy)	T (^oC)	Gestation	Farrowing	Nursery	Finishing	Gestation	Farrowing	Nursery	Finishing
03/24/03	1.3	907b	3448a	4564b	3128ab				
(S.D.)		1585	N/A	700	303				
04/22/03	17.2	1967b	490b	3563bcd	1841bc	40.2a	15.1bc	92.5a	49.5bc
(S.D.)		N/A	49	1737	412	N/A	1.8	118.5	13.3
05/21/03	17.5	195b	630b	1239efg	1720bc	8.6b	18.6bc	31.9ab	65.8abc
(S.D.)		329	103	1022	422	14.9	3.1	24.2	25.6
06/24/03	12.1	559b	403b	1557defg	2119bc	13.1b	11.6c	19.9ab	101.3a
(S.D.)		49	74	815	825	2.7	2.0	16.9	39.3
07/22/03	19.9	346b	794b	1107fg	613c	11.9ab	24.1abc	54.7a	27.9c
(S.D.)		535	130	400	412	13.9	3.9	20.0	19.2
08/19/03	25.9	375b	1122ab	922fg	944c	15.3ab	52.1a	45.1ab	44.4bc
(S.D.)		288	760	445	139	11.3	N/A	21.5	7.7
09/24/03	5.6	546b	594b	707g	735c	8.2b	13.2c	9.2b	26.4c
(S.D.)		157	49	0	50	0.8	5.0	1.8	3.6
10/20/03	5.3	812b	2462ab	2878cde	2127bc	7.7b	46.0b	18.8ab	64.8abc
(S.D.)		0	1491	547	1127	3.5	14.8	17.4	22.5
11/25/03	-10.3	1189b	2378ab	2520def	2039bc	8.4b	40.6abc	22.9ab	23.0c
(S.D.)		1142	585	0	871	10.4	17.4	5.0	13.8
01/22/04	-21.6	4993a	3531a	4164bc	4304a	24.0ab	38.3abc	28.7ab	36.3bc
(S.D.)		N/A	1505	1616	860	N/A	21.9	14.3	12.4
03/25/04	-6.8	656b	3360a	7795a	4375a	4.3b	39.0abc	48.2a	76.7ab
(S.D.)		1380	1680	1091	2666	8.2	17.8	47.8	32.3

*Means followed by the same letter in a column of each type of barn are not significantly different at P<0.05 according to Duncan's multiple range tests.

COMPARISON OF THE FOUR TYPES OF BUILDINGS

Great seasonal variations of odour concentrations and emission rates were found in all the rooms, ranging from 71 to 8605 OU for odour concentrations and 1.4 to 261.3 OU m^{-2} s^{-1} for odour emission rates ($P<0.05$). It indicates that using the randomly measured odour emission rate for odour dispersion modeling or setback modeling may result in great uncertainty.

Table 5-4 summarizes the geometric means of odour concentrations and emission rates of each type of rooms. Gestation rooms had the lowest odour concentration of 677 OU, which was significantly lower than that of nursery and finishing rooms ($P<0.05$). Farrowing rooms did not show significant differences compared with the other types of rooms ($P>0.05$). The nursery rooms had the highest odour concentrations, followed by the finishing rooms. High standard deviations reflected the high variations of odour concentrations through the year.

Significant differences in odour emission rates were found between the four types of rooms ($P<0.05$). The gestation rooms had the lowest value of 10.4 OU m^{-2} s^{-1} while the finishing rooms had the highest value of 45.9 OU m^{-2} s^{-1}. High standard deviations also reflected the high variations of odour emissions throughout the year.

Table 5-4. Comparison of different types of rooms for room temperature, animal units, and annual odour concentrations and emission rates*

Room	Indoor t* (C)	Animal Unit	Odour concentration (OU)				Odour emission rate (OU m^{-2} s^{-1})			
			Geometric Mean*	S.D.	Max.	Min.	Geometric Mean*	S.D.	Max.	Min.
Gestation	20.4b	378.0	677b	1207	4993	71	10.4c	10.3	40.2	1.4
Farrowing	20.6b	14.4	1226ab	1451	4752	354	25.2b	17.0	57.6	10.2
Nursery	25.0a	20.5	1975a	1996	8605	476	30.8b	46.2	261.3	7.7
Finishing	21.3b	166.4	1830a	1544	7797	446	45.9a	31.1	137.7	11.7

*Means followed by the same letter in the column are not significantly different at $P<0.05$ according to Duncan's multiple range tests.

In order to compare the total odour emissions from the barns of the three sites, the annual average odour emission rates were summarized in Table 5-5. It also gives the total animal units of each barn and odour emission rates based on animal units; the order from the highest to the lowest was as follows: nursery, finishing, farrowing, and gestation. The finishing barn had the highest total odour emission which was followed by nursery, farrowing and gestation barns. The total emission from the farrowing site, adding the emissions of gestation barn and farrowing barns together, was the lowest while the finishing barn had the highest odour emission. It must be noted that this finishing site was one of four finishing sites in this swine operation. The other three sites were located 16 km away from this area.

Table 5-5. Annual mean odour emission rates based on animal units and total emissions from the barns of each site.

	Barn			
	Gestation	Farrowing	Nursery	Finishing
Mean animal units (AU)	2321	469	671	1525
(S.D.)	(121)	(37)	(62)	(474)
Geometric mean of odour emission rate (OU AU^{-1} s^{-1})	46	279	359	287
(S.D.)	(45)	(188)	(538)	(195)
Mean odour emission of each site (OU/s)	106753	130773	240864	437882
(S.D.)	(105290)	(88218)	(361123)	(296691)

The odour emissions from the barns during the warm season of May to October were given previously in Table 4-2. The finishing barn had the highest odour emission rate, followed by the nursery, farrowing, and gestation barns. To compare the odour emissions from the barns and manure storages, Table 4-2 also gives the odour emissions from the manure storages. Combining the two cells on each site, the finishing EMS had the highest odour emissions, followed by the nursery EMS, and the farrowing EMS had the lowest emissions. Comparing the barns and EMSs, the odour emissions from the farrowing EMS was lower than those from the farrowing barns (which included the farrowing and gestation barns) by 21%; however, the odour emissions from the nursery and finishing barns were lower than those from the nursery and finishing EMSs by 95% and 22%, respectively. It must be noted that the EMSs were applied with straw covers one to three time from March to July, which reduced the odour emissions as the odour emissions from the straw covered areas were considered to be 20% of the uncovered areas. This indicated that a) during the warm season, both the barns and the EMS were major odour sources, and b) straw covers on the EMS were effective to reduce odour emissions. Without straw covers, the EMS would be a much larger odour source than the barns. Comparing the three sites, the finishing site had the highest odour emission rate; the emission rates of the nursery and farrowing sites were 56.2% and 39.2% of that of the finishing site, respectively.

The results obtained by this study were compared with those of the other studies. Zhang et al. (2005) measured odour emissions from two swine farrowing farms for two summers in Manitoba, Canada, which was on also on the Canadian Prairies as were the farms in this study. The geometric means of the odour emission rates were 7.6 and 11.6 OU m^{-2} s^{-1} for the gestation barns and 22.7 and 23.0 OU m^{-2} s^{-1} for the farrowing barns, which were in the same ranges as the results obtained from this study. Large variations of odour concentration and emissions were also observed (Zhang et al. 2005). Zhang et al. (2003) also measured odour emissions from 10 swine farms in Manitoba, Canada during May to October. Each farm was measured three times. The average odour concentrations from barn exhaust ranged from 131 to 1842 OU/m^3 (ranging from 79 to 4635 OU) and the average odour emission rates ranged from 12 to 39 OU m^{-2} s^{-1} (ranging 2 to 70 OU m^{-2} s^{-1}). The odour concentration in nursery barns was found to be higher than that in the gestation barn, but there was no significant difference between the farrowing and nursery

barns nor between the farrowing and gestation barns. Odour emission rates from the farrowing and nursery barns were higher than those from gestation barns ($P<0.05$) and there was no difference between the emission rates in the farrowing and nursery barns ($P>0.05$). No comparisons of finishing barns with the other types of barns were made. The results were consistent with those obtained from the current study. Zhou and Zhang (2003) also found the odour concentrations increased significantly as the ambient temperature decreased ($P<0.05$), which was also observed by the current study. The maximum odour concentration and emissions obtained in this study were higher than those reported by Zhou and Zhang (2003). The reason is that Zhou and Zhang's measurements were taken between May and October, and the highest odour concentration occurred during the coldest month of January as measured by this study.

Wood et al. (2001) summarized the odour emission rates of swine barns as reported by researchers in the U.S. and the Netherlands (Zhu et al. 1999; Verdoes and Ogink 1997; Klarenbeek 1985). The ranges for the odour emission rates for the gestation, farrowing, nursery, and finishing barns were 4.8-21.3, 3.2-47.7, 6.7-47.7, 1.4-19.2 OU m^{-2} s^{-1}, respectively. The results obtained from the current study fell in the same ranges except the results from the finishing barns were higher than those in these references. Wood et al. (2001) also summarized the odour emissions measured in Minnesota from 6 to 28 swine farms over three years from 1998-2001 and concluded that the odour emissions varied greatly, the mean and range of odour emissions from the four types of barns were 12.6 (1.2-192), 4.8 (0.1-16.7), 8.7 (1.5-97.1), and 6.9 (0.1-745) OU m^{-2} s^{-1}, respectively.

Heber *et al*. (1998) measured odour emission rates from four mechanically ventilated swine finishing barns between April and August The buildings had long term manure storage beneath fully slatted floors. The mean odour concentration of 109 measurements was 142 OU/m^3, and the odour emission rate was 5.0 OU m^{-2} s^{-1}. Odour emission rates from two nursery rooms in Indiana were measured from March to May (Lim *et al*., 2001). The rooms were mechanically ventilated with long-term manure storage pits under wire floors. The mean odour concentration was 199 OU/m^3. The mean net odour emission rate from the two nursery rooms was 34 OU AU^{-1} s^{-1} or 1.8 OU m^{-2} s^{-1}. The results were lower than the results obtained by the current study. The different odour concentrations and emission rates that exist between the results obtained in the cold Canadian Prairies in the current study and the results obtained by Heber et al. (1998) and Lim et al. (2001) may be mainly due to the climate differences and other factors such as the differences between building systems, manure management, and odour measurement methods in the field and olfactometory laboratories.

CORRELATION OF ODOUR CONCENTRATIONS AND EMISSIONS WITH THE RELATED FACTORS

As discussed above and shown in the seasonal comparison results given in Table 5-3, seasonal variations of odour concentration were observed in all rooms. Many factors contributed to the odour concentrations and emissions of a room including ambient and indoor temperatures, ventilation rate, animal number and weight, manure handling, and the cleanliness of a room, etc. Among these factors, ambient air temperature is the main

climate parameter that determines the ventilation rate of a room and the indoor temperatures. Animal number and weight can be represented by the number of animal units or the animal mass per area unit (kg/m^2). The inside temperature is dependent on ambient temperature and animal age. For each type of barn, the manure handling and cleanliness of all rooms were similar under the same management. Hence, the possible correlation between the odour concentration and emission of each type of barn with the ambient air temperature, indoor temperature, and animal unit in the room were analysed using the PROC CORR procedure of SAS (SAS institute, 1999). The results were given in Table 5-6.

Table 5-6. Correlation of odour concentration and emission with related factors.

Odour concentration or emission	Barn	P value		
		Ambient t (C)	Indoor t (C)	Animal Unit
Odour concentration	Gestation	<0.01	0.05	0.02
	Farrowing	<0.01	0.22	0.02
	Nursery	<0.01	0.30	0.21
	Finishing	<0.01	0.03	0.06
Odour emission	Gestation	0.54	0.49	0.01
	Farrowing	0.07	0.97	0.02
	Nursery	0.17	0.34	0.04
	Finishing	0.78	0.53	0.21

According to Table 5-6, odour concentration was significantly affected by the ambient temperature for all four types of barns ($P<0.01$), which is consistent with the conclusion of Zhou and Zhang (2003). It was also significantly affected by indoor temperature for gestation and finishing barns ($P\leq0.05$), but the indoor temperature effect was not significant for farrowing and nursery barns ($P>0.05$). It was also significantly affected by the number of animal units for gestations and farrowing barns ($P<0.05$) but not for the nursery and finishing barns. The odour emission rate was not significantly affected by ambient and indoor temperatures but was affected by the number of animal unit except the finishing barn ($P<0.05$). Zhou and Zhang also found that the odour emission rate was not affected by ambient temperature (2003).

Using the PROC REG procedure of SAS (SAS institute, 1999), the relationship between odour concentration and the three related factors takes the form of:

$$OC = a + b\, t_o + c\, t_i + d\, AU \qquad (1)$$

where OC = odour concentration, OU/m^3
t_o = ambient temperature, ^oC
t_i = indoor temperature, ^oC
AU = animal unit of the room, 1 AU = 500 kg of pig weight
a, b, c, d = constants generated from the measured data using SAS PROC REG (SAS Institute 1999) and listed in Table 5-7.

Table 5-7. Regression of odour concentration with related factors.

	Barn	a	b	c	d	r^2
Odour Concentration (OU/m^3)	Gestation	-218.2	-82.5	139.7	-3.0	0.67
	Farrowing	-5328.2	-69.9	77.7	399.3	0.63
	Nursery	4593.4	-79.8	-36.0	-27.6	0.41
	Finishing	-1057.9	-113	156.5	5.2	0.58
Odour emission (OU/m^2-s)	Gestation	5.63	-0.05	1.07	-0.04	0.48

As given in Table 5-7, odour concentration was inversely related to ambient temperature for all the four barns. The lower the ambient temperature was, the higher the odour concentration would be due to the reduced ventilation rate. The odour concentration was positively linearly related to indoor temperature except in the nursery barn. The effect of animal units on odour concentration was not conclusive for the four barns. The r^2 of the regression equations were between 0.41 (nursery barn) and 0.67 (finishing barn).

Because the ambient temperature is the main determining variable for odour concentration, further non-linear regression between odour concentration and ambient temperature was performed for each individual room and each type of barns. A second-order polynomial relationship was found for all four types of rooms.

$$OC. = a\, t_o^2 + b t_o + c \qquad (2)$$

Where OC = odour concentration, OU
t_o = ambient temperature, ^oC
a, b, c = constants, listed in Table 5-8.

Table 5-8. Constants in equation 2 obtained by using geometric means of odour concentration of individual barns.

Barn	Parameters for odour concentration				
	a	b	c	r^2	r^2 for individual room
Gestation	3.91	-77.82	740.4	0.76	0.32, 0.80
Farrowing	-0.10	-72.10	2145.2	0.63	0.52, 0.70
Nursery	-1.31	-79.85	3613.5	0.38	0.25-0.62
Finishing	0.39	-72.61	2621.1	0.65	0.50-0.70

Great variations existed for the fitness of equation 2 for individual rooms ranging from 0.25 to 0.80 (Table 5-8). Four rooms including three nursery rooms and gestation room G2 showed poor correlation (r^2 between 0.25 and 0.38). The other seven rooms show relatively good correlation between odour concentration and ambient temperature (r^2

between 0.50 and 0.80). Figure 5-5 a) shows the odour concentrations as affected by ambient temperatures for finishing room FN1. The parameters a, b, c given in Table 5-8 were obtained using the geometric means of odour concentrations of all rooms of the same type of barn. Again, the nursery barn did not have a strong correlation between odour concentration and ambient temperature. The reason might be that the great difference between the outdoor temperature and the temperature of the nursery rooms (average 25.0°C and 7.9°C, respectively) required a very low ventilation rate, which made the ventilation rate rely less on the ambient temperature. The average indoor temperatures of the gestation, farrowing, and finishing barns were 20.5, 20.6, and 21.3°C, respectively.

Odour emission rates did not have a second-order polynomial relationship with ambient temperature except in three rooms (F1, N3, and FN1) that had a correlation coefficient r^2 greater than 0.6. Figure 5-5 b) shows the odour emission rates as affected by ambient temperatures for farrowing room F1. Odour emission rate was high when ambient temperature was either high or low, while it was low when the ambient temperature was moderate.

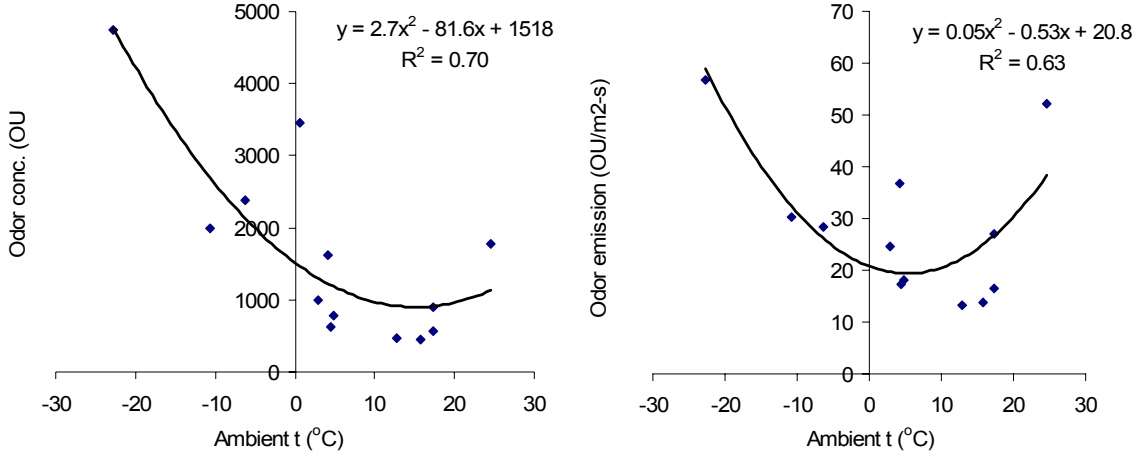


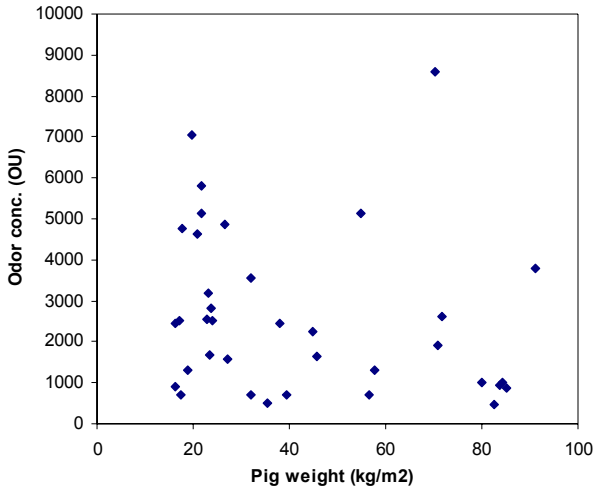
Figure 5-5. Ambient temperature and odour concentrations and emission rates of F1

EFFECT OF PIG DENSITY ON ODOUR CONCENTRATION AND EMISSIONS

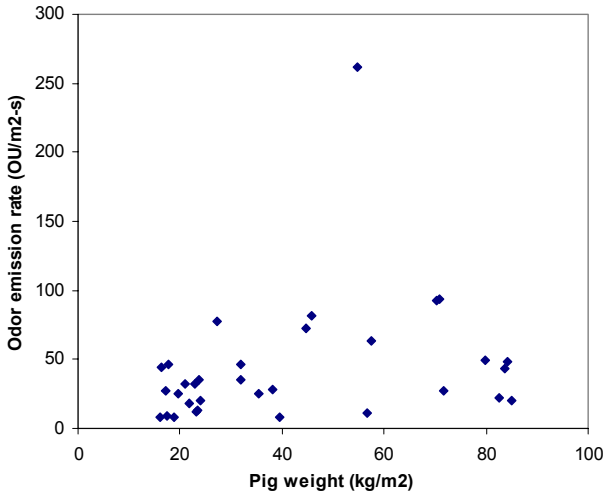
It is a general assumption that the higher the pig density, i.e., number and size of animals in a specific room in terms of kg/m^2, the higher the odour production, thus the higher the odour emission rate. This assumption was used by most setback distance guidelines developed by researchers and governments. As given in Table 5-5, the effect of animal units on odour concentration was not conclusive for the four barns. Animal units had a significant effect on the odour concentrations and emissions of the gestation and farrowing barns ($P<0.05$). However, the effect on gestation rooms was mainly caused by the large capacity difference between the two rooms (G1 had 610 sows while G2 had 1200 sows). The animal units did not have a significant effect on odour concentrations and emissions for the finishing rooms or the odour concentrations of the nursery rooms ($P>0.05$), but it affected odour emissions of the nursery rooms ($P<0.05$). The animal units of the farrowing rooms changed in a small range between 11 and 16 AU year round.

The animal conditions in the nursery and finishing rooms varied greatly depending on the number and age of the animals. The nursery room varied from 8 to 45 AU (mean 20.5 AU, standard deviation 12.2 AU) while the finishing rooms ranged from 11 to 264 AU (mean 164 AU, standard deviation 68 AU). Table 5-7 indicated that the odour concentrations of the nursery rooms had an inverse relationship with animal units, the odour concentration was reduced when the number of animal units increased, while the opposite was found for finishing rooms.

To further examine the effect of animal number and weight on the odour concentrations and emissions of the nursery and finishing rooms, the animal density of a room was plotted against the odour concentrations and emissions as shown in Figs. 5-6 and 5-7. In the nursery rooms, the average pig density varied from 16 to 91 kg/m^2, while that of finishing rooms ranged between 6 and 138 kg/m^2. No correlation was found between odour concentration or odour emission rate and pig density for either type of room ($P>0.05$). Low odour concentration and emissions occurred when pig densities were high, and high odour emissions were found when pig densities were low. Therefore, animal units or animal density of nursery and finishing barns may not represent the odour concentrations and emissions.



(a) Odour concentration



(b) Odour emission rate

Figure 5-6. Odour emissions vs. pig density for nursery Rooms

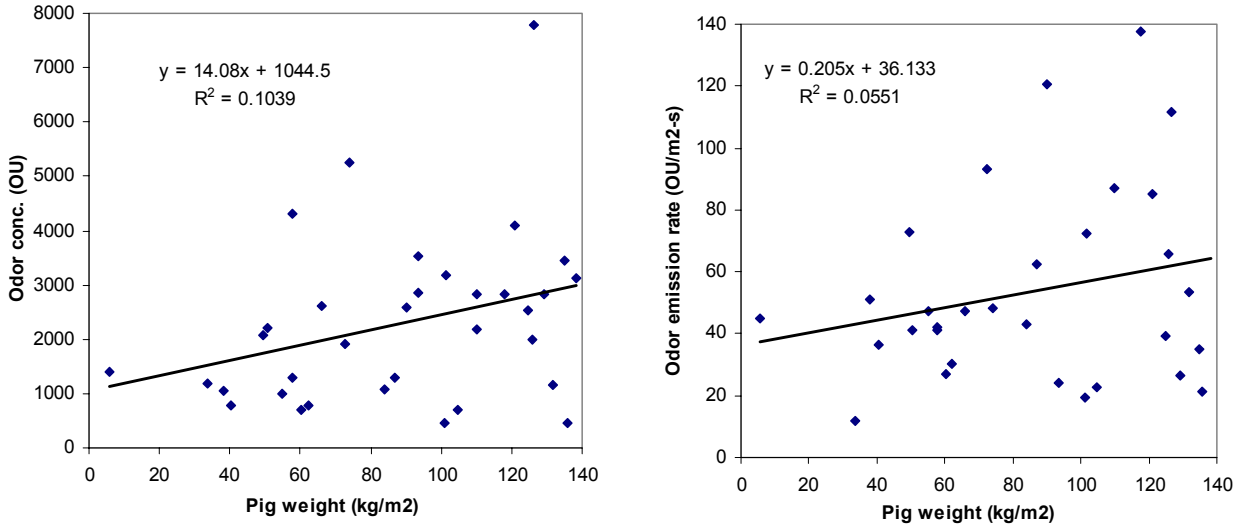


Figure 5-7. Odour emissions vs. pig density for finishing rooms

CORRELATION BETWEEN ODOUR AND CO_2 CONCENTRATION

CO_2 is often used as an indicator for air quality in livestock housing systems. The correlation between odour and CO_2 concentrations was explored using the data obtained from this study. Figures 5-8 show the correlation between odour and CO_2 concentrations for finishing rooms. A second-order polynomial relationship between odour and CO_2 concentrations was found for all four types of rooms.

$$OC = a\,C^2 + bC + c \qquad (3)$$

where OC = odour concentration, OU

C = CO_2 concentration, ppm

a, b, c = constants generated from measured data, listed in Table 5-9 for each type of rooms.

Table 5-9 also gives the correlation coefficient of the regression equations for individual rooms. Room G1 had the highest r^2 of 0.88 while nursery room N4 had the lowest r^2 of 0.25. If the data from all rooms of each animal type are pooled together, the gestation rooms would have the highest r^2 of 0.75, followed by the farrowing rooms (r^2=0.56), the finishing rooms (r^2=0.51), and the nursery rooms (r^2=0.43). The regression equations were different for the different types of rooms. The very low constant suggests that a linear relationship between odour concentration and ambient temperature may also be used; however, the r^2 would be lower. The results indicate that CO_2 may be used as an odour indicator in swine barns.

Table 5-9. Parameters in equation 2 for individual barns.

Barn	Parameters for odour concentration				
	a	b	c	r^2	r^2 for individual room
Gestation	0.0004	-0.8875	965.5	0.75	0.54, 0.88
Farrowing	-0.0003	2.4535	-823.0	0.56	0.58, 0.64
Nursery	-0.0002	2.0766	-448.9	0.43	0.25-0.63
Finishing	-0.0003	2.4915	-901.9	0.51	0.51-0.74

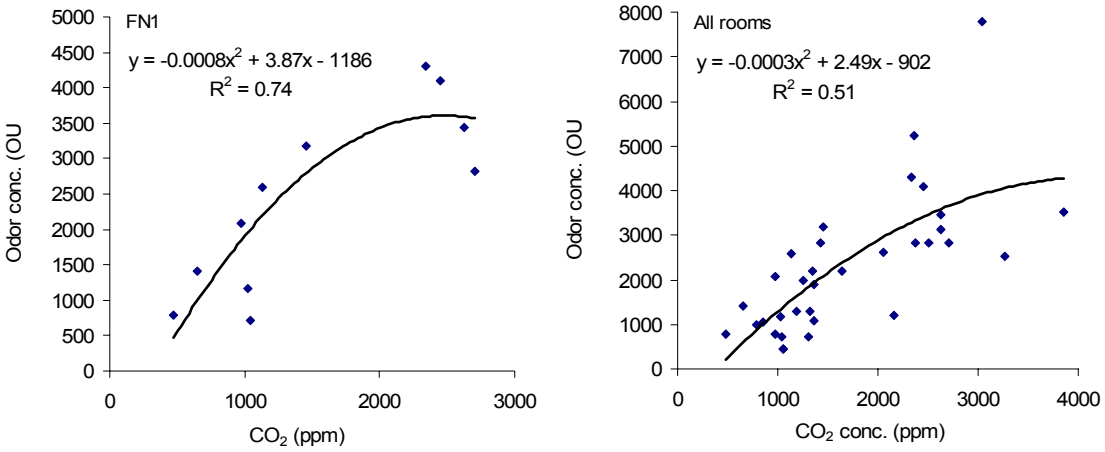


Figure 5-8. Odour vs. CO_2 concentration for finishing rooms

CONCLUSIONS

a) Odour concentrations from all types of swine barns varied seasonally ($P<0.05$); these concentrations were high in winter and low in summer. Odour emission rates also varied throughout the year but did not show a specific seasonal pattern ($P<0.05$). This might explain why swine odours were detected throughout the year including during the winter when the manure storage basins were frozen. The geometric mean of odour emission rates measured in different seasons may be used to represent the typical odour emission condition of an odour source for setback determination or odour dispersion modeling, but the maximum odour emission rate measured would represent the worst case scenario.

b) Odour concentration was the highest in the nursery rooms, followed by the finishing, farrowing, and gestation rooms. The odour emission rate from the finishing rooms was the highest, followed by the nursery, farrowing, and gestation rooms. Comparing total odour emission rates from the barns on the three sites, the finishing site had the highest odour emission rate followed by the nursery site which had slightly higher emission rate than the farrowing site.

c) During the warm season of May to October, the finishing barn had the highest odour emission rate, followed by the nursery, farrowing, and gestation barns. Comparing the barns and EMSs, the odour emissions from the farrowing EMS were lower than those from the farrowing barns (which included the farrowing and gestation barns) by 21%; however, the odour emissions from the nursery and finishing barns were lower than those from the nursery and finishing EMSs by

95% and 22%, respectively. This indicated that a) during the warm season, barns and the EMSs were all major odour sources, b) straw covers on the EMSs were effective for reducing odour emissions. Without straw covers, the EMSs would be much greater odour sources than the barns. Comparing the three sites, the finishing site had the highest odour emission rate; the emission rates of the nursery and farrowing sites were 56.2% and 39.2% of the finishing site emission rate, respectively.

d) Odour concentration in all types of barns was affected mainly by ambient temperature ($P<0.01$). Indoor temperature and number of animal units might have affected odour concentrations and emissions to a lesser extent. Odour concentrations could be predicted by regression equations using indoor and ambient temperatures and animal unit ($r^2 = 0.58$ to 0.67 for all rooms except nursery). The odour emission rate could not be predicted by using the indoor and ambient temperature and animal unit.
e) Odour concentration could also be predicted by ambient temperature using a second-order polynomial relationship generated by this study ($r^2 = 0.63$ to 0.76 for all rooms except nursery).
f) Animal density in the nursery and finishing rooms had no significant effect on odour concentrations and emission rates ($P>0.05$).
g) Odour concentration might have a second order polynomial relationship with CO_2 concentration ($r^2= 0.51$ to 0.75 for all rooms except nursery).
h) The ventilation rate estimation based on the CO_2 mass balance method was much lower than the actual values. Swine CO_2 production rates used in ASAE Standards may be lower than the actual value and need to be updated.

Part 6. Diurnal Odour Emission Profiles Of Different Types Of Swine Production Buildings

OBJECTIVE

The objective of this study was to reveal diurnal odour emission profiles of different swine production facilities in Saskatchewan.

MATERIALS AND METHODS

THE SWINE PRODUCTION FACILITIES

The information on the three swine production sites is presented in Part 2. The measured sources for diurnal odour emissions are one breeding/gestation room (BG1), one farrowing room (F25), one nursery room (N29), and one finishing room (FN1). The specifications of these rooms are given in Table 6-1. These rooms were all mechanically ventilated by wall and ceiling mounted exhaust fans. The manure handling systems for these rooms were all the same, with liquid manure stored in under-floor shallow pits and then removed to outdoor earthen manure storage basins once every one to four weeks. In order to observe odour and gas conditions during normal operation, the manure pits were not emptied during the measurement of the four rooms.

Table 6-1. Information on the swine rooms.

Source	Facility capacity	Size (length x width, area)
Breeding/gestation room (BG1)	1200 sows	36.6 x 63.7 m (2330 m^2)
Farrowing room (F25)	32 farrowing sows	7.3 x 25.3 m (185 m^2)
Nursery room (N29)	736 weaner pigs	14.3 x 17.1 m (245 m^2)
Finishing room (FN1)	1250 feeder pigs	26.1 x 36.6 m (955 m^2)

ODOUR EMISSION MEASUREMENT

Each room was measured for two consecutive days between July and September 2003. Each day, the measurement period started at 0600h and ended at 2000h to cover the main odour detection period measured by the neighbouring odour observers. Air samples were taken once every two hours by continuously pumping the exhaust air from an exhaust fan into two 10-L Tedlar® sample bags (SKC Inc. Eighty Four, PA) using a peristaltic pump and Teflon® FEP tubing (Cole-Parmer Instrument Company, Vernon Hills, IL). Seven samples were taken each day from each room.

The sample bags were transported to the Olfactometry Laboratory, University of Alberta, Edmonton, Canada and measured for odour concentration, i.e., odour detection threshold, within 30 hours of collection. An eight-port olfactometer with eight trained panelists was used for odour concentration measurement. The triangular forced-choice method was used to present samples to the panelists. The panelists were selected and re-evaluated periodically following the procedure of ASTM Standard E679-97 (ASTM, 1997) and

CEN (1999). For each olfactometry session, data were retrospectively screened by comparing panelists' individual threshold values with the panel average (CEN 1999).

Two methods were used to obtain the ventilation rate of a room, the fan method, which tallies the airflow rates of all fans, and the CO_2 mass balance method (Albright 1990). For the fan method, the speed of all fans and the vacuum pressure of the room were measured and then fan performance testing results from the manufacturers or fan testing organizations (PAMI Prairie Agricultural Machinery Institute) were used to obtain the air flow rates of the fans. The fan speed was measured hourly by a SHIMPO DT-207L Tachometer (accuracy: ±1 rpm for 6 to 8300 rpm, Netech Corp. Hicksville, NY) and the static pressure was measured hourly by VelociCalc® Plus (accuracy: ±1% of reading, TSI Inc. Shoreview, MN). For the CO_2 mass balance method, CO_2 concentration was measured directly from the air sample bags immediately after the samples were collected. CO_2 concentrations lower than 3000 parts per million (ppm) were measured by a Guardian Plus Infra-Red Gas Monitor (accuracy: ±2% for 0 to 3000 ppm, Edinburgh Sensors Ltd., Hingham, MA), and those over 3000 ppm were measured by gas chromatography in the Soil Science Laboratory, University of Saskatchewan. The number and the combined weight of pigs in the rooms were recorded. The total CO_2 loss from a room was the product of the CO_2 concentration and the ventilation rate. The CO_2 gain of a room was the CO_2 coming from incoming supply air, which was assumed to be 345 ppm, and the CO_2 produced by the pigs (ASAE Standards 2003). The odour emission rate of a room is the odour concentration multiplied by the ventilation rate.

Indoor and outdoor temperature and relative humidity were recorded. Ammonia concentration was measured immediately after the air samples were taken using colorimetric tubes (Kitagawa, Matheson Gas Products, Secaucus, NJ, USA) and later using an infrared ammonia analyzer (CHLLGARD RT refrigerant monitor, measuring range of 0 to 100 ppm, accuracy ±1 ppm, MSA Instrument Division).

A weather station was installed near the finishing site. Weather data including wind speed and direction, temperature, relative humidity, and solar radiation were monitored once every minute and the average of every10 minutes was recorded.

RESULTS AND DISCUSSIONS

DIURNAL ODOUR CONCENTRATIONS AND EMISSIONS

GESTATION ROOM

Odour concentrations and emissions from room BG1 were measured on July 14th and 15th. As shown in Fig. 6-1 a), the ambient temperature was quite different for the two days during the measurement periods (average ambient temperature 16.8^{o}C for July 14th and 24.1^{o}C for July 15th), and the temperature varied from 14.0 to 27.2^{o}C. As a result, the room temperature for the two days fluctuated between 19.0 and 30^{o}C with averages of 20.6 and 26.6^{o}C for day 1 and 2, respectively.

Figure 6-1 b) gives the ventilation rates obtained by the fan and CO_2 methods. The ventilation rates obtained by the fan method were much higher than those obtained by the CO_2 method with averages for the two days of 94.5 and 48.7 m^3/s for the former and later methods, respectively. Similar results were obtained from the other three rooms. This result is consistent with that obtained in the seasonal odour emission study in Part 5. The fan method may have an uncertainty of about 15% due to the dust buildup and power supply variations. The CO_2 method had an unknown uncertainty due to the fact that the CO_2 production rates for animals were obtained in the late 1950's (ASAE standard 2001). Animal breeds, diets, and production systems have changed over the years; therefore, the CO_2 production rates may have also changed. The result from this study indicated that the CO_2 production data need to be updated. Hence, the ventilation rates obtained by the fan method were used by this study. Due to the high ambient temperature, the ventilation rate of the room was close to or at maximum capacity with an average of 96.0 m^3/s for day 1 and 93.1 m^3/s for day 2.

Figure 6-1 a) also shows the CO_2 concentration variations during these two days. Due to the higher ambient and room temperatures for day 2 than day 1, the CO_2 concentration for day 2 was higher than that of day 1 (averaged 619 ppm for day 1 and 725 ppm for day 2). On both days, the CO_2 concentration was the highest during the early morning (0600-0800h), and gradually reduced to the lowest at the end of the day (1600-2000h). The high CO_2 in the first measurement period (0600–0800h) might be caused by a lower ventilation rate due to the lower ambient temperature before 0600h and the lower temperature during this period than during the rest of the measurement periods. With a higher temperature during the remainder of the daytime, the total heat production of the animals decreased and the total CO_2 production of the animals decreased as well. With the constant ventilation rate, CO_2 concentration decreased. There was no other peak during the day. It is difficult to explain the higher CO_2 concentration on day 2 compared to day 1. The main difference between these two days was the higher room temperature on day 2, which would have led to a lower CO_2 concentration on day 2 than day 1; however, the measured result was the opposite. One possible reason is the CO_2 production from the manure increased on day 2 due to the higher room temperature.

As shown in Fig. 6-1 c), odour concentration varied dramatically during the two days ranging from 120 OU to 500 OU. On day 1, with a constant ventilation rate, odour concentration started low (154 OU), increased and peaked during the period from 1400-1600h (500 OU), then decreased to the lowest concentration between 1800-2000h (120 OU). On day 2, the odour concentration had a similar trend as the CO_2 concentration. Due to the low ventilation rate during the first measurement period (0600-0800h), odour concentration was the highest in the early morning and lower during the day. It had another peak during the period between 1400-1600h (211 OU). On both days, there was a peak during the measurement period from 1400-1600h. This is consistent with the report by Zhu et al. that there was a peak odour concentration at 1700h in a gestation room. Zhu et al. explained that this was possibly caused by an increase in animal activity during the sampling period. A similar explanation might apply to the current study. On the contrary, CO_2 seemed to be unaffected by animal activities because its variations could be explained by changing ambient temperature and ventilation rate. Although CO_2

concentrations were higher on day 2 than day 1, the odour concentration was lower on day 2 than day 1 (geometric mean 259 OU for day 1 and 175 OU for day 2).

The ammonia concentration did not vary greatly on day 1 (ranging from 1.5 to 3.5 ppm), but the variation increased on day 2 (1.5 to 6.0 ppm). The daily average NH3 concentration was higher for day 2 than day 1 (2.6 and 2.2 ppm, respectively), possibly due to the higher room temperature on day 2. It followed a trend similar to odour on day 1, but it followed a trend similar to CO_2 on day 2 (Fig. 6-1 d).

Due to the almost constant ventilation rate during the two days, with the exception of the first measurement period on day 2, odour and ammonia emission rates were determined by odour concentration; therefore, they followed the same patterns as odour and ammonia concentrations. As shown in Fig. 6-1 b), the odour emission rate fluctuated, and it was higher on day 1 than on day 2 (daily geometric mean 6.9 vs. 5.1 OU m^{-2} s^{-1}). On both days, the odour emission peaked during the period between 1400-1600h (geometric mean 20.5 and 8.9 OU m^{-2} s^{-1} for days 1 and 2, respectively). The odour emission rate varied in a smaller range on day 2 than on day 1 (5.0 to 20.5 OU m^{-2} s^{-1} for day 1 and 5.6 to 9.0 OU m^{-2} s^{-1} for day 2. On day 2, although the odour concentration between 0600-0800h was much higher than during the rest of the day, it did not result in a much higher odour emission rate because the odour emission rate was the product of odour concentration and the ventilation rate, and the ventilation rate during this measurement period was the lowest of the day. In fact, the odour emission rate was similar to that of 1400-1600h ((9.0 and 8.9 OU m^{-2} s^{-1}, respectively). The ammonia emission rate varied between 47.5 and 128.0 mg m^{-2} s^{-1} and that of day 2 was higher than that of day 1 (average 69.2 and 75.1 mg m^{-2} s^{-1}, respectively).

In summary, odour and gas concentrations varied during the day. Statistical analysis results indicated that there is no significant difference in odour and NH_3 concentrations and emissions between the seven measurement periods ($P>0.05$). The two days' odour concentrations and emission rates were not significantly different ($P>0.05$).

FARROWING ROOM F25

Odour and gas emissions from Room F25 were measured on September 28th and 29th (Fig. 6-2). Odour and gas were not measured for the last measurement period (1800-2000h) of day 2 due to the sample shipping time limit. The ambient temperature was much lower during these two days than in July. As shown in Fig. 6-2 a), the ambient temperature varied from -0.3 to 8.6°C but the average temperatures of the two days were similar (average 5.9°C for day 1 and 4.5°C for day 2). The room temperature during the two days was kept stable (mean 19.3°C for day 1 and 19.0°C for day 2). Also shown in Fig. 6-2 a), the ventilation rate during the two days varied between 3.2 and 4.7 m^3/s with changing ambient temperature but the averages of the two days were similar with that of day 1 slightly higher than that of day 2 due to the higher ambient temperature on day 1 (4.2 and 3.9 m^3/s for days 1 and 2, respectively).

With averages of 1441 and 1610 ppm for days 1 and 2, respectively, the CO_2 concentration was much higher in the farrowing room than in the gestation room, mainly

due to the lower ventilation rate and ambient temperature (Fig. 6-2 c). During these two days, the CO_2 concentration showed a similar trend (Fig. 6-2 c). Ranging between 960 and 2210 ppm, it decreased with increasing ventilation rate due to increasing ambient temperature. It was the highest during the early morning (0600-0800h), gradually reducing to its lowest value during the period from 1400-1600h (day 1) or 1200-1400h (day 2) when the ambient temperature was high, which resulted in a high ventilation rate, and then increased again afterwards. Similar to what observed in the gestation room, the change in CO_2 concentration was not affected by animal activities.

As shown in Fig. 6-2 b), odour concentration showed the same pattern as CO_2 for day 1. For day 2, odour concentration fluctuated during the day and had two peaks, possibly due to increased animal activities. The ranges of odour concentrations for the two days were very similar with a range of 580 to 1122 OU for day 1 and 630 to 1122 OU for day 2. The average odour concentrations of the two days were similar (geometric means 792 and 874 OU, respectively), which were much higher than those of the gestation rooms. Lower odour and CO_2 on day 1 than on day 2 was possibly caused by higher ambient temperature on day 1 than on day 2. Ammonia concentration was not measured for this room.

Figure 6-2 b) also shows the odour emission rate. Although the daily geometric means of the odour emission rate of the two days were similar (18.3 and 19.3 OU m^{-2} s^{-1} for day 1 and day 2, respectively), the two days did not show the same trend. Large variations existed from a low of 12.0 to a high of 28.3 OU m^{-2} s^{-1}. On day 1, odour emission was the highest in the early morning and was the lowest during the period from 1400-1600h. On day 2, the odour emission rate started low, varied during the day, and peaked during the last measurement period (1600-1800h).

In summary, odour and CO2 concentrations and odour emissions varied during the two days. Statistical analysis results indicated that there is significant difference diurnally for CO2 concentration ($P<0.05$) but there is no significant difference diurnally for odour concentration and emission ($P>0.05$). The two days' odour concentration and emission rates were not significantly different ($P>0.05$).

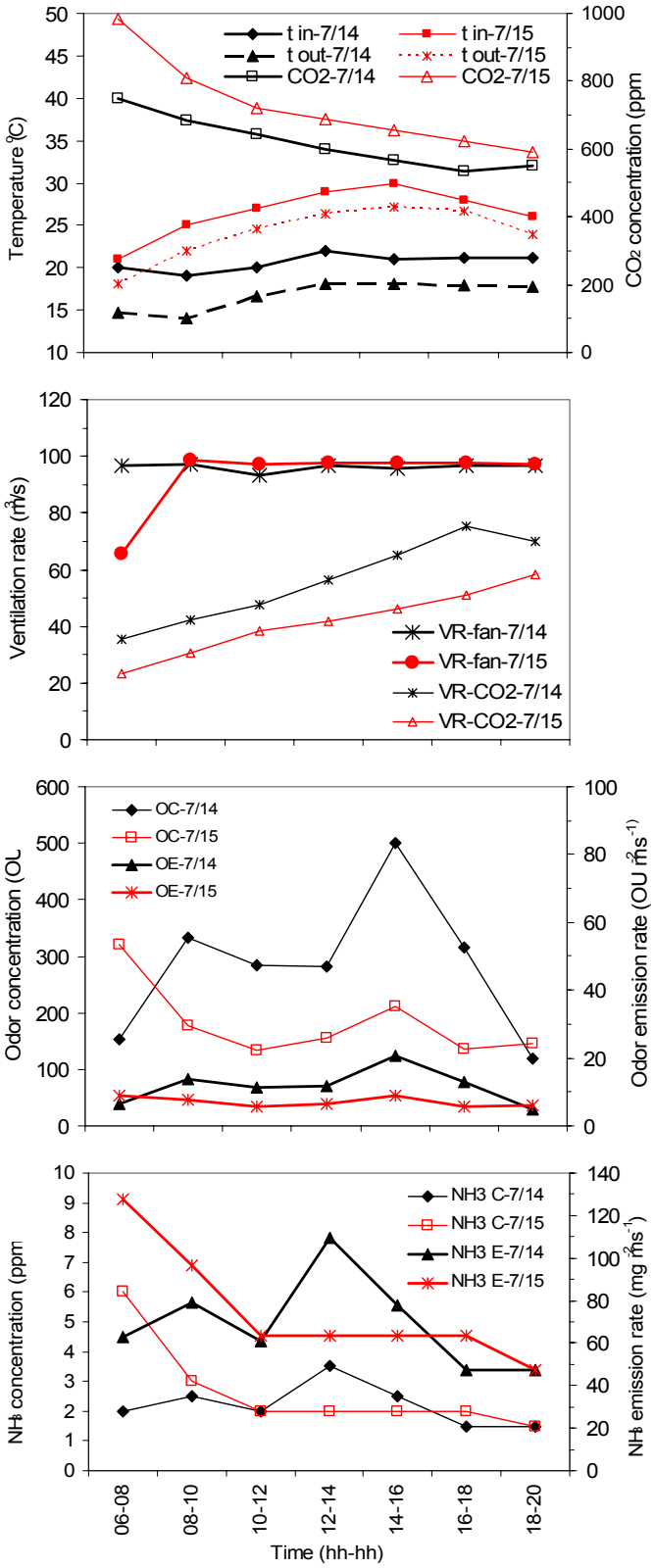


Figure 6-1. Diurnal odour concentration and emissions of room BG1

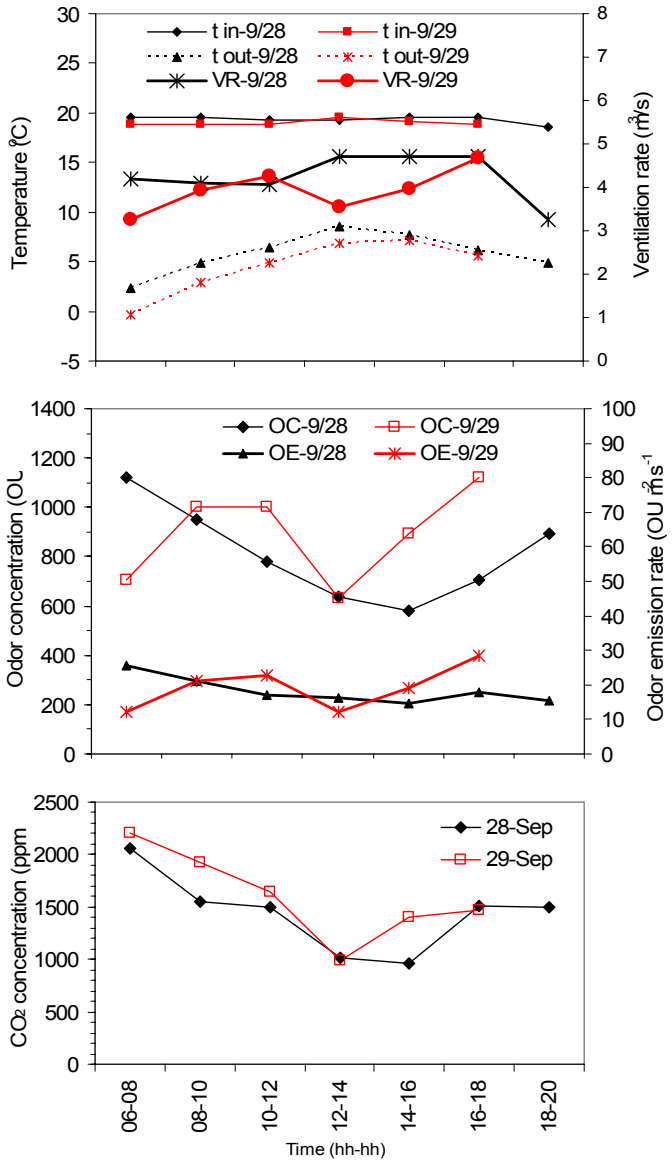


Figure 6-2. Diurnal odour concentration and emissions for farrowing room F25

NURSERY ROOM N29

The odour and gas emissions from Nursery room N29 were measured on July 16th and 17th (Fig. 6-3). As shown in Fig. 6-3 a), the ambient temperature of day 1 was slightly lower than day 2 (average ambient temperature 19.9°C and 21.1°C for days 1 and 2, respectively). The ventilation rate was kept at maximum capacity except during the early morning (average 11.5 m^3/s for the two days). The room temperature varied with the ambient temperature from 2.4 to 6.7°C higher than ambient temperature. The average room temperatures of the two days were almost the same (25.1°C and 25.2°C, respectively).

On these two days, the CO_2 concentrations had a similar trend (Fig. 6-3 d) as the gestation room. It was the highest during the early morning (0600-0800h) and it

maintained a similar range during the day for the two days. The daily averages of the two days were almost the same (856 ppm for day 1 and 832 ppm for day 2), which were higher than those of the gestation room but lower than those of the farrowing room. Again, CO_2 concentration was not affected by the animal activities because its changing course could be explained by changing ambient temperature and the resultant change in ventilation rate. As shown in Fig. 6-3 b), odour concentration fluctuated during the two days ranging from 841 to 1640 OU with a daily geometric means of 1052 OU for day 1 and 1299 OU for day 2, which were much higher than those of the gestation and farrowing rooms. The odour concentration was the highest in the early morning on day 1, and it was lower during the rest of the day. It was also high in the early morning on day 2, but it peaked again during the period from 1000-1200h. Changing animal activities was the possible cause of the change in odour concentrations. As shown in Fig. 6-3 c), the ammonia concentration was fairly low with little variation through out the two days (2 to 3 ppm).

With a constant ventilation rate, except during the first measurement period (0600-0800h), odour and ammonia emission rates followed the same pattern as odour concentration as it was determined by the odour or ammonia concentrations. The odour emission rate for this room is depicted in Fig. 6-3 b). Day 2 had a higher geometric mean than day 1 (49.8 and 58.0 OU m^{-2} s^{-1} for day 1 and day 2, respectively). For day 1, odour emission was in a relatively narrow range (43.0 to 57.4 OU m^{-2} s^{-1}), and it peaked during the period from 1600-1800h. Large variations existed during day 2 (37.9 to 81.6 OU m^{-2} s^{-1}). The odour emission rate was the lowest in the early morning, increased during the day, and peaked during the period from 1000-1200h. As shown in Fig. 6-3 c), the ammonia emission rate varied from 55.6 to 116.3 mg m^{-2} s^{-1} with averages of 81.7 and 85.5 mg m^{-2} s^{-1} for days 1 and 2, respectively.

Statistical analysis results indicated that there is significant difference among the diurnally measured CO2 concentrations ($P<0.05$) but no difference diurnally for odour and NH_3 concentrations and emissions ($P>0.05$). The two days' odour concentration and emission rates were not significantly different ($P>0.05$).

FINISHING ROOM FN1

The emissions from finishing room FN1 were measured on July 21st and 22nd. As shown in Fig. 6-4 a), the ambient temperature was different for these two days (an average of 19.4°C for day 1 and 22.9°C for day 2). As a result, the mean room temperatures for the two days were also different (23.9°C and 26.6°C, respectively). Because of the high ambient temperature, the ventilation rate was kept at maximum capacity on both days (44.7 and 44.2 m^3/s for days 1 and 2, respectively). The variation in the ventilation rate was caused by the variations in the static pressure of the room, which were caused by changing wind direction and speed. During the measurement period, the wind speed varied from 0.0 to 5.1 m/s and wind direction changed up to 70 degrees.

As shown in Fig. 6-4 d), the CO_2 concentration did not have large variations during either day (day 1 range: 770-1010 ppm, day 2 range: 970-1050 ppm); however, day 2 had a higher daily average than day 1 (873 ppm for day 1 1021 ppm for day 2). This was

similar to what was observed in the gestation room: higher ambient and room temperature resulted in higher CO_2 concentration, which is difficult to explain considering the very limited difference in the ventilation rate for these two days (1.2%). The elevated room temperature on day 2 compared to day 1 might have increased CO_2 production from other sources such as the manure stored in the pit or on the floor, but the extent of this CO_2 production increase was unknown.

The odour concentration showed high variations during both days, ranging from 268 OU to 1160 OU (Fig. 6-4 b). The odour concentration began low on day 1 and peaked during the last measurement period (1800-2000h), while it peaked during the period from 1400-1600h on day 2. Again, the fluctuation could only be explained by the decrease or increase of animal activities. The daily geometric mean of odour concentrations was 397 OU for day 1 and 655 OU for day 2. With the same ventilation rate, the increase of odour concentration might have been caused by elevated room temperature on day 2, which might resulted in higher odour production.

The ammonia concentration had a similar trend as the CO_2 concentration for day 1 but stayed constant for day 2, and the averages of the two days were the same (10.1 and 10.0 ppm for days 1 and 2, respectively). Elevated room temperature increased the CO_2 and odour concentration but not the ammonia concentration.

Similar to the gestation and nursery rooms, with an almost constant ventilation rate, odour and ammonia emission rates followed the same patterns as the odour and ammonia concentrations. As shown in Fig. 6-4 b), the odour emission rate of day 2 had a higher geometric mean than day 1 (18.6 and 30.3 OU m^{-2} s^{-1} for day 1 and day 2, respectively). Average ammonia emission rates of the two days were about the same (360.0 and 350.9 mg m-2 s-1 for days 1 and 2, respectively, Fig. 6-4 c). Elevated room temperature increased the odour emissions but not the ammonia emissions.

Statistical analysis results indicated that there is no significant difference among the diurnally measured CO_2, odour, and NH_3 concentrations and emissions ($P>0.05$). The two days' odour concentration and emission rates were not significantly different ($P>0.05$).

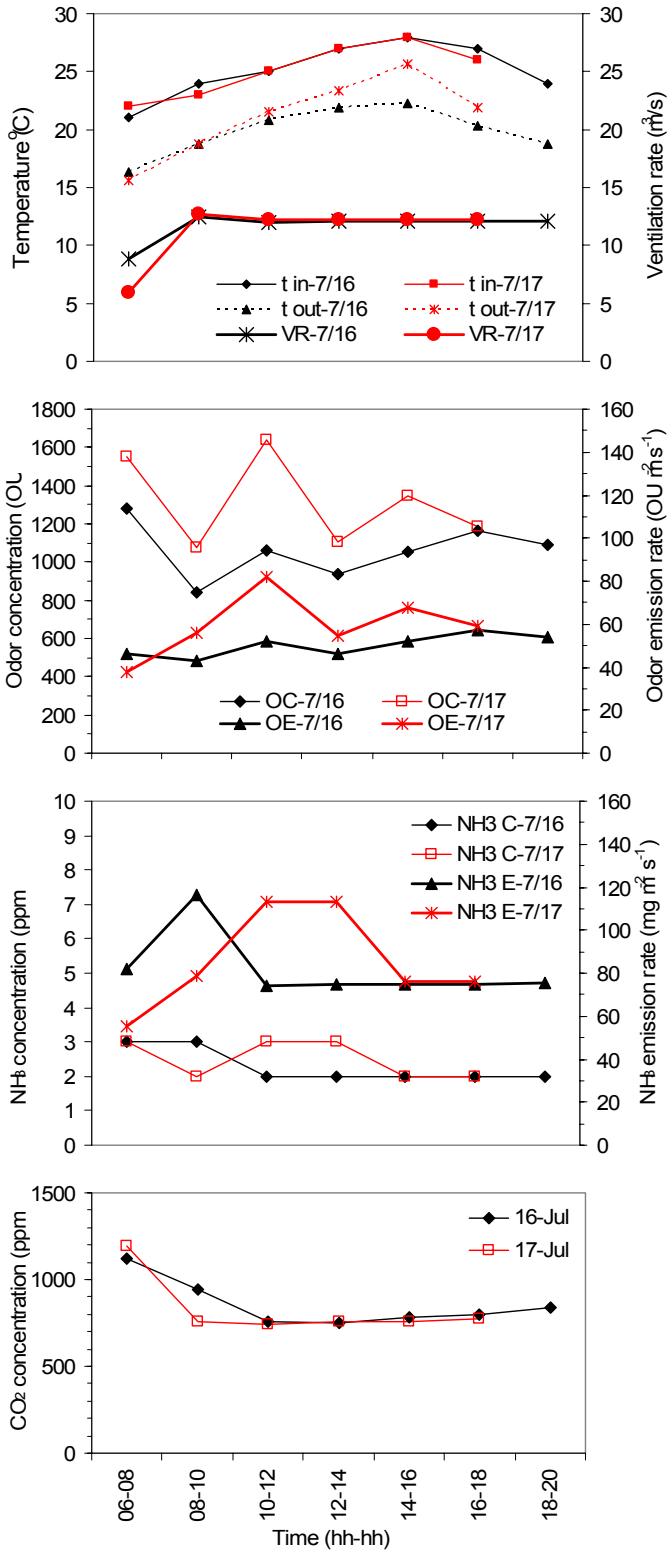


Figure 6-3. Diurnal odour concentration and emissions of room N29

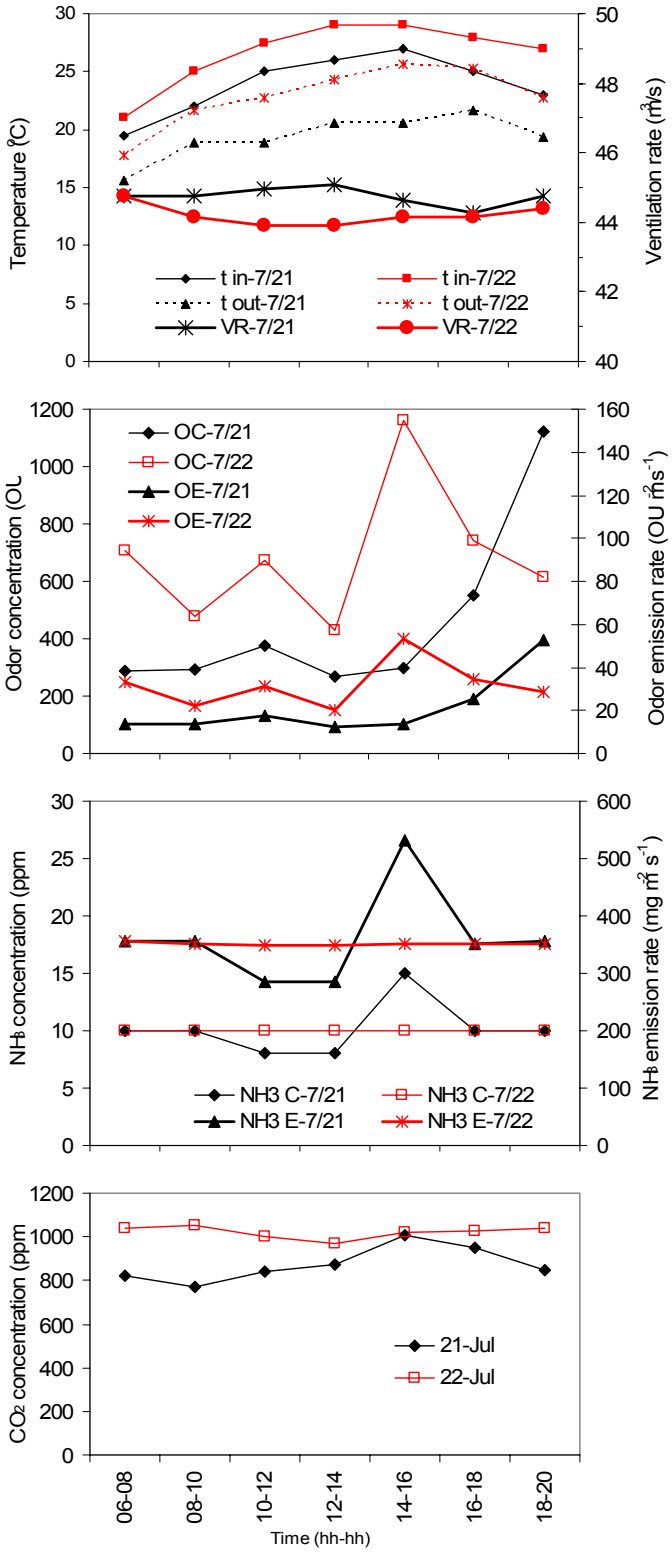


Figure 6-4. Diurnal odour concentration and emissions for finishing room FN1

COMPARISON OF ODOUR AND GAS CONCENTRATIONS AND EMISSIONS OF THE FOUR ROOMS

Table 6-2 summarizes the ambient and room temperatures, animal conditions, and odour concentrations and emission rates of these four rooms. The three rooms measured during July had similar ambient and room temperatures. Animal density was much higher in the finishing and gestation rooms than in the farrowing and nursery rooms. Odour concentrations in different rooms were quite different ranging from 213 to 1159 OU for geometric means ($P<0.05$). Nursery room N29 had the highest value, followed by the farrowing room, finishing room, and breeding/gestation room S1. Odour emission rates were also different in different rooms and varied in a large range from 8.6 to 53.5 OU m^{-2} s^{-1} for geometric means ($P<0.05$). Again, nursery room N29 had the highest value, followed by FN1 and F25, and BG1 was the lowest. Figure 6-5 shows the geometric means of odour concentration and emission rate for different periods of all rooms. It must be noted that the farrowing room was not measured during the same period. The ambient temperature in September was much lower than July. This might be the reason for the higher odour concentration found in this room compared with FN1 and BG1. If the farrowing room was measured under the same ambient temperature as the other rooms, the result might be different. Table 6-2 also gives the odour emission rate on the basis of animal units (AU, 1 AU = 500 kg of animal mass), which varied from 34 to 585 OU AU^{-1} s^{-1} for the different rooms with the highest rate from nursery room, followed by the farrowing, finishing, and gestation rooms ($P<0.05$).

Table 6-2. Summary of odour measurement results†.

Room (Time)		Inside T (C)	Outside T (C)	Animal density (kg m^{-2} s^{-1})	Ventilation rate (m^3/s)	Odour conc.* (OU)	Odour emission* (OU m^{-2} s^{-1})	Odour emission* (OU AU^{-1} s^{-1})
BG1	Mean	23.6a	20.4a	126.2	94.5	213d	8.6d	34d
(7/14 -	SD	3.8	4.5		8.4	110	4.4	17
7/15)	Min	19.0	14.0		65.6	120	5.0	20
	Max	30.0	27.2		98.7	500	20.5	81
F25	Mean	19.2b	5.2b	48.0	4.1	829b	18.8c	190b
(9/28 -	SD	0.3	2.4		0.5	187	4.9	51
9/29)	Min	18.6	-0.3		3.2	580	12.0	125
	Max	19.6	8.6		4.7	1122	28.3	295
N29	Mean	25.2a	20.4a	45.7	11.5	1159a	53.5a	585a
(7/16 -	SD	2.3	2.8		1.9	227	11.2	123
7/17)	Min	21.0	15.6		6.0	841	37.9	415
	Max	28.0	25.6		12.7	1640	81.6	893
FN1	Mean	25.3a	21.1a	131.6	44.5	510c	23.7b	90c
(7/21-	SD	3.0	2.9		0.4	292	13.5	51
7/22)	Min	19.5	15.6		43.9	268	12.7	48
	Max	29.0	25.6		45.1	1160	53.6	204

* Geometric means.

†Means followed by the same letter in a column are not significantly different at $P<0.05$ according to Duncan's multiple range tests.

Table 6-3 summarizes the CO_2 and NH_3 conditions of the four rooms. The mean CO_2 concentration was the highest in the farrowing room as a result of the low ventilation rate caused by low ambient temperature, followed by the finishing, nursery, and gestation

rooms. This is different than the odour concentration, which was higher in the nursery room than the farrowing room. Ammonia concentration was much higher in the finishing room than in the nursery and gestation rooms. Similarly, the ammonia emission rate in the finishing room was much higher than in the nursery and gestation rooms.

Table 6-3. Summary of gas conditions of the four rooms*

	Time (m/dd)		CO_2 (ppm)	NH_3 (ppm)	NH_3 emission (mg m^{-2} s^{-1})	NH_3 emission (mg AU^{-1} s^{-1})
BG	7/14 -	Mean	672c	2.4b	72.1b	286c
	7/15	SD	120	1.2	24.2	96
		Min	535	1.5	47.1	186
		Max	985	6.0	128.0	507
FR	9/28 -	Mean	1519a	N/A		
	9/29	SD	388	N/A		
		Min	960	N/A		
		Max	2210	N/A		
NS	7/16 -	Mean	845b	2.4b	83.4b	913b
	7/17	SD	149	0.5	18.6	203
		Min	745	2.0	55.6	608
		Max	1195	3.0	116.3	1273
FN	7/21-	Mean	947b	10.1a	355.4a	1350a
	7/22	SD	97	1.6	56.0	213
		Min	770	8.0	285.6	1085
		Max	1050	15.0	531.3	2018

*Means followed by the same letter in a column are not significantly different at $P<0.05$ according to Duncan's multiple range tests.

SUMMARY OF DIURNAL ODOUR AND GAS EMISSION PATTERNS

The above results indicated that odour concentration and emissions and CO_2 concentrations usually varied greatly during the measurement periods from 0600 to 2000h for all rooms. Ammonia concentrations and emissions also varied greatly for the gestation and finishing rooms; however, with very low ammonia concentration, less variation was observed in the nursery rooms. The large diurnal odour and gas variations were represented by the large standard deviations of the measured parameters as given in Tables 6-2 and 6-3. Any activities taking place in the buildings, such as workers disturbing animals by entering and working in the building or the running of the feeding system, may significantly affect the odour production and result in changing the odour and possibly the ammonia concentration and emission rates but may not affect CO_2 concentrations. This result indicated that a snapshot measurement of odour and gas concentrations and emissions will likely not give the representative or average conditions of a building. Using snapshot measured odour or gas emissions in odour and gas dispersion modeling will likely result in large errors. The results obtained by this study are consistent with the two other studies conducted by Hartung et al. (1998) and Zhu et al. (2000b).

For the three rooms measured in July, the ventilation rates were at the maximum capacity most of the time, except during the first measurement period (0600-0800h) for both days on which the nursery room was measured and the second day on which the gestation room was measured. Under such conditions, room temperatures were 3.2, 4.7, and 4.2^{o}C

higher than the ambient temperatures for the gestation, nursery, and finishing rooms, respectively. For the farrowing room, under cooler ambient conditions, the ventilation rate changed with changing ambient temperature and maintained a constant room temperature. Generally, CO_2 concentration was high during the period from 0600-0800h, possibly due to the lower ventilation rate and ambient temperature prior to this period, and lower during the rest of the day.

As shown in Fig. 6-5, odour concentrations in all rooms fluctuated during the day and did not show a consistent pattern. Duncan's multiple range tests for each and all rooms did not show a significant difference between the seven measurement periods for odour concentration ($P>0.05$) and days 1 and 2 are not significantly different ($P>0.05$). However, it peaked in the early morning (day 2 of gestation room, both days of nursery rooms, day 2 of finishing room), and then went down, and peaked again in the afternoon (1400-1600h for gestation rooms and day 2 of the finishing room; 1600-1800h or 1800-2000h for day 1 of the nursery and finishing rooms). However, as discussed before, any activities taking place in the room that disturb the animals may increase odour concentration, because some high odour concentrations were observed during the other measurement periods (e.g., 1000-1200h in nursery room). Odour concentration of the farrowing room was high in the early morning and evening due to the lower ventilation rate and ambient temperature and lower during the daytime, which might represent a typical pattern for all buildings during the cooler season when the ventilation system does not run at maximum capacity.

As for the NH_3 concentrations, large fluctuations occurred on both days in the gestation room (1 to 6 ppm) and day 1 of the finishing room (8 to 15 ppm). NH_3 in the nursery room did fluctuate much (2 to 3 ppm) and the NH_3 concentration of the finishing room on the day 2 stayed flat at 10 ppm. Generally, NH_3 was high in the early morning and lower during the day (the nursery room and day 2 of the gestation room), but higher concentrations also occurred during the rest of the day (day 1 of the gestation room, day 2 of the nursery room, and day 1 of the finishing room).

In summary, odour and gas concentrations are likely to be high in the early morning and early evening but lower during the rest of the daytime; however, peak odour and NH_3 concentrations will likely occur in the afternoon or anytime when animals are disturbed.

As also shown in Fig. 6-5, odour emission rates in all rooms fluctuated during the day and did not show a consistent pattern. Duncan's multiple range tests for each and all rooms did not show a significant difference between the seven measurement periods for odour emission rates ($P>0.05$). The high odour concentration in the early morning or early evening did not necessarily result in a high odour emission rate because the ventilation rate was low during that time due to the low ambient temperature. Odour emission rates fluctuated during the day and generally one or two peaks were observed, which were possibly related to an increase in animal activities. NH_3 emission rates followed a similar pattern. As given in Tables 6-2 and 6-3, the large range of odour and NH_3 emission rates in all rooms suggested that a snapshot measurement will not likely give representative emission data for a building. The emission measurement needs to be

taken during the interested dispersion modeling period or multiple measurements are needed to get the average emission rates of a building.

The odour and gas conditions in the farrowing room may represent the typical patterns for cold seasons in the swine buildings.

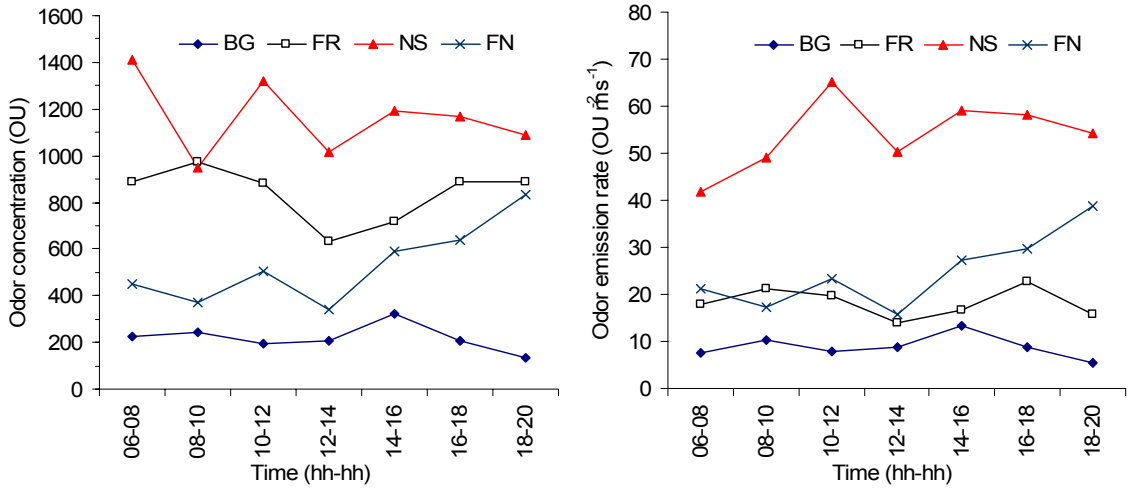


Figure 6-5. Comparison of diurnal odour concentrations and emission rates in all rooms

CORRELATION OF ODOUR CONCENTRATION AND EMISSIONS WITH RELATED VARIABLES

Besides animal conditions, room cleanliness, and manure handling in the room, odour and gas concentration and emissions were determined by room and ambient temperatures, and ventilation rate. Statistic analysis indicated that there was no correlation between odour or NH_3 concentrations and room and ambient temperature and ventilation rate for each room ($P>0.05$). Odour emission rate was also not significantly affected by room and ambient temperatures for each room ($P>0.05$). Odour emission rate was also not significantly affected by ventilation rate for all rooms ($P>0.05$) except the farrowing room ($P<0.05$) due to the lower ambient temperature. NH_3 emissions were not significantly affected by room and ambient temperatures and ventilation rate ($P>0.05$) except that the gestation room was significantly affected by ventilation rate (farrowing room not measured) ($P<0.05$).

CO_2 concentration was determined by the room temperature (that determines CO2 production by animals) and ventilation rate (which determines CO_2 gain and loss from the room by ventilation), if the CO_2 production and loss through other sources are ignored. When the ambient temperature was high, the ventilation rate was kept constant at the maximum capacity; therefore, the CO_2 concentration should only be determined by the room temperature. However, the correlation of CO_2 and room temperature from the three rooms measured during July was not strong ($P>0.05$, linear regression $r^2 = 0.13$, 0.56, and 0.30 for the gestation, nursery, and finishing rooms, respectively). CO_2 and room temperature in the nursery room showed a polynomial relationship ($r^2=0.74$), but the other two room did not show such a relationship.

CONCLUSIONS

a) Large diurnal variations of odour concentrations and emissions were observed in each of the four types of rooms. Therefore, it is unlikely that representative odour concentration and emission rate (e.g. daily mean) can be obtained from instantaneous measurements. Odour and gas concentrations are likely to be high in the early morning and late afternoon but the odour emission rate did not show any diurnal pattern. Odour and NH_3 concentration and emissions were affected by animal activities whereas CO_2 concentration was not. Statistical analysis indicated that there were no significant differences among the seven measurement periods ($P>0.05$) for all rooms.

b) Measured in July, nursery room N29 had the highest geometric mean of odour concentration and emission rate, followed by finishing room FN1, while breeding/gestation room BG1 had the lowest value. Farrowing room F25 was measured in September. Its odour concentration was lower than N29 but higher than FN1 and BG1, and its emission rate was lower than room N29 and FN1 but higher than BG1.

c) No correlation was found between odour or gas concentration or emissions and room and the ambient temperature and ventilation rate except the odour emission rate of the farrowing room was significantly affected by the ventilation rate ($P<0.05$) and the NH_3 emission rate from the gestation room was also significantly affected by ventilation rate ($P<0.05$).

Part 7. Seasonal and Diurnal Odour Emissions From Manure Storage Basins

OBJECTIVE

The objective of this part of the study was to reveal the seasonal and diurnal odour emission profiles of different swine production facilities in Saskatchewan.

MATERIALS AND METHODS

MANURE STORAGE BASINS

The information on the three swine production sites is presented in Part 2. For seasonal odour emission measurement, all the six earthen manure storage (EMS) basins were measured once a month from May to October 2003. From November to April, the cells were frozen and odour emission was eliminated, so no measurements were taken. Diurnal odour emissions were measured from Cell 1 and Cell 2 of the finishing site (FN-EMS1 and FN-EMS2). The specifications of the facilities are described in Table 7-1. Straw covering information was recorded by the swine farms.

Table 7-1. Information on the manure storages.

Source	Number	Facility capacity	Size (Length x width, area)
FR-EMS cell 1	1	For the Farrowing site (5000 sows)	54 x 54 m (2,916 m^2)
FR-EMS cell 2	1		69 x 69 m (4,761 m^2)
N-EMS cell 1	1	For the Nursery site (19,200 weaner pigs)	75 x 75 m (5,625 m^2)
N-EMS cell 2	1		99 x 99 m (9,801 m^2)
FN-EMS cell 1	1	For the Finishing site (11,550 feeder pigs)	75 x 75 m (5,625 m^2)
FN-EMS cell 2	1		99 x 99 m (9,801 m^2)

ODOUR EMISSION MEASUREMENT

Air samples were taken using the wind tunnel method for seasonal odour emission measurements when exposed liquid areas were available and also for all diurnal odour emission measurements. A wind tunnel using the design by Schmidt et al. (2002) was used to collect air emissions from the manure storage surface with an average surface speed of 0.3 m/s; the wind tunnel covered an area of 0.32 m^2. Exhaust air from the outlet of the wind tunnel was collected 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). The odour emission rate was the odour concentration multiplied by the air flow rate of the wind tunnel.

When the cells were partially covered by barley straws, air samples were from the exposed liquid areas using a wind tunnel and also at the edge of straw cover downwind of the cells by surface sampling. Only surface air samples were taken when the cells were fully covered with straw or the manure level was too low to access.

For diurnal emission measurement, each source was measured for two continuous days. The measurement period started at 0600 h and ended at 2100 h. Air samples were taken once every 3 hours by continuously pumping the exhaust air from the wind tunnel into the sample bags using a peristaltic pump.

The sample bags were transported to the Olfactometry Laboratory, University of Alberta and analyzed for odour concentration, i.e., odour detection threshold, and hedonic tone within 30 hours of collection using a dynamic dilution olfactometer. The odour detection threshold in OU is defined as the concentration at which the panelists first detect a difference in the air sample when comparing it to two clean samples; it was measured in accordance with ASTM Standard E679-97 (ASTM, 1997) using eight trained panelists.

RESULTS AND DISCUSSION

SEASONAL ODOUR EMISSION RESULTS

Barley straw was applied to the cells one to three times from March to July. For the October measurement, the surface sampling method was used for all cells because the liquid surface was low due to the recent manure removal from the cells. A total of 22 odour measurements using the wind tunnel method were obtained. Surface sampling measurements were conducted 15 times. Each cell was measured 2 to 5 times using the wind tunnel method and 1 to 4 times using the surface sampling method.

Figures 7-1 to 7-6 give odour concentrations and emission rates and air temperatures for each cell at different times of during the experimental period. Table 7-2 gives the odour concentrations and emission rates from all the six cells using the wind tunnel method. Table 7-3 gives the odour concentration measured by the surface sampling method. Odour emission rates obtained by the surface sampling method were not presented because further work is needed to confirm the calculation method.

The ambient air temperature varied from 8.3 to 29.1^{o}C for the six measurements taken between May and October. As shown in Figs. 7-1 to 7-6, there was no apparent seasonal profile for either odour concentrations or odour emission rates for all cells. One important reason for the lack of a pattern for seasonal odour emissions might be that the straw cover was applied to the cells at different times.

FARROWING EMS CELLS

Figure 7-1 a) indicates that farrowing cell 1 was only measured twice using the wind tunnel method in May and August when liquid areas were available. The odour concentrations obtained in May and August were similar (375 and 406 OU, respectively) although the air temperatures were different (17.9^{o}C and 8.5^{o}C, respectively). The August odour emission rate was higher than that of May due to a higher airflow rate in the wind tunnel. As shown in Table 7-2, farrowing cell 1 had the lowest geometric mean odour concentration (390 OU) and emission rates (28 OU m^{-2} s^{-1}) among all the six cells.

For the other four months, the surface sampling method was used (Table 7-3). Although the air temperatures in September and October were low, the odour concentrations were much higher compared with those of June and July. October's high odour concentration may be due to the recent removal of manure from the cell. The odour concentrations that were measured at the edge of the cell down wind were much higher than those obtained by the wind tunnel method.

For farrowing cell 2, June had the highest odour concentration and emission while May had the lowest. As given in Table 7-2, the geometric mean odour concentration and emission rate of all four measurements for cell 2 using the wind tunnel were much higher than the measurements taken from farrowing cell 1 (1526 OU vs. 390 OU for concentration and 98 vs 28 OU m^{-2} s^{-1} for emission rate). Considering the available paired data for the two cells in May and August, as given at the bottom of Table 7-2, the odour concentration and emission rate of cell 2 were reduced to 887 OU and 64 OU m^{-2} s^{-1}, but the difference between the two cells was still very high.

As given in Table 7-3, odour concentrations as measured by the surface sampling method varied greatly and were lower than those measured by the wind tunnel method. Cell-1 odour concentrations were much higher than cell 2, which was the opposite of the results obtained by the wind tunnel method.

NURSERY EMS CELLS

For Nursery cell 1, using the wind tunnel method, August had higher odour concentrations and emission rates than June and July. Surface sampling results showed that October had the highest odour concentration which may be due to the recent manure removal from the cell, while those of May, June, and September were lower In particular, the June surface sampling results were lower than those obtained by the wind tunnel method.

For Nursery cell 2, June had the highest odour concentration and emission rate, followed by August, while those of May, July and September were much lower. Surface air samples were taken only once for the October measurement and the odour concentration obtained was higher than those obtained by the wind tunnel method during the earlier measurements, which may be also due to the recent removal of manure from the cell. As for the geometric mean of odours of these two cells, as given in Table 3-7, if all data are considered, cell 1 had a higher odour concentration and emission rate than cell 2 (1140 OU vs. 619 OU, 80 vs. 45 OU m^{-2} s^{-1}). However, if only the 3 paired measurements are considered, the odour concentration and emission rates would be almost the same (1140 vs. 1117 OU, and 80 vs. 79 OU m^{-2} s^{-1}).

FINISHING EMS CELLS

For finishing cell 1, of the 4 measurements taken using the wind tunnel method, August had the highest odour concentration and emission rate, followed by May, September, and July (Table 7-2). Using the surface sampling method, October had a higher odour concentration than June.

For finishing cell 2, there were four measurements using the wind tunnel method (Table 7-2). The highest odour concentration was obtained in June, followed by August, September, and May. The single surface measurement in October gave a high odour concentration of 4490 OU, which was lower than that of August but higher than that of the other months.

Based on the above results, no apparent seasonal pattern for odour concentration and emission rate was found for the six cells. Odour concentration varied in a large range for every cell with the ratio of high and low values up to 16 times (nursery cell 2) except for farrowing cell 1 which only had two observations. All three cell 2s had the highest odour concentrations and emissions on June 26th while all three cell 1s had peaks on August 26th. There was only one measurement on August 26th that measured all 6 cells with wind tunnel method. In this measurement, FN-cell 1 had the highest odour emissions, followed by FN-cell 2, F-cell 2, N-cell 1, N-cell 2, and again F-cell 1 had the lowest values. If all the data obtained by the wind tunnel method are considered, finishing cell 2 had the highest geometric means for odour concentration and emission rates, followed by F-cell 2, N-cell 1, FN-cell 1, N-cell 2, and F-cell 1 had the lowest values (Table 7-2). Considering the geometric mean of the two cells on each site, the finishing EMS had the highest odour concentration and emission rate, followed by the farrowing EMS and the nursery EMS (Table 7-2).

Tables 7-4 and 7-5 summarize the odour concentration and emission rates of all cell 1s, all cell 2s and all six cells at different measurement times. All cell 1s had the highest odour concentration in August and had similar values for the other months ranging from 641 to 952 OU. All cell-2s had high odour concentrations and emissions in June and August but had low values in the other three months ranging from 341 to 806 OU. Considering all six cells, June and August had the highest odour concentrations (2594 OU and 1569 OU, respectively) while the other three months had much lower values ranging from 451 OU to 730 OU and the monthly values were significantly different ($P<0.05$). The geometric means of odour concentrations were fairly similar with 1009, 878, and 1111 OU for all cells, cell 1s, and cell 2s, respectively, but the standard deviations were large indicating the large variations in the data (Table 7-4). The odour emission rates had geometric means of 74, 67, and 79 OU m^{-2} s^{-1} for all cells, cell 1s, and cell 2s, respectively (Table 7-5). The odour emission rate varied significantly from month to month ($P<0.05$) for all the cells (Table 7-5).

Table 7-6 summarizes the odour concentrations of different types of cells using the surface sampling method. The geometric means of odour concentrations were quite similar for cell 1s and cell 2s (877 OU and 998 OU, respectively), and for all six cells, the value was 916 OU. The odour concentrations were very similar compared to the odour concentrations obtained using the wind tunnel method, but they were a little lower.

The result of t tests for odour concentration and emissions indicated that there was no significant difference between cells 1 and 2 on all three sites ($P>0.05$). The results of Duncan's multiple range test for odour concentration and emissions also indicated that there was no significant difference among monthly emission measurements using the

wind tunnel method for F-cells and FN-cells ($P>0.05$); however, there was significant difference among the measurements of the N-cells ($P<0.05$).

As previously presented in Table 4-2, odour emissions from each cell and each site were summarized. Comparing EMSs on the three sites, the finishing EMS had the highest odour emissions, followed by the nursery EMS, and the farrowing EMS had the lowest emissions.

Table 7-2. Odour concentration (OC) and odour emission rates (OER) of the EMS cells obtained using the wind tunnel method.

Time	F-cell 1		F-cell 2		N-cell 1		N-cell 2		FN-cell 1		FN-cell 2	
(m/dd)	OC (OU)	OER (OU/m^2-s)	OC (OU)	OER (OU/m^2-s)	OC (OU)	OER (OU/m^2-s)	OC (OU)	OER (OU/m^2-s)	OC (OU)	OER (OU/m^2-s)	OC (OU)	OER (OU/m^2-s)
5/22	375	21	421	24			167	9	1260	73	561	32
6/26			3448	199	952	55	2829	164			4876	282
7/15 or 23			2000	116	958	55	325	19	457	48		
8/26	406	36	1866	166	1624	170	1516	159	3732	309	2143	191
9/21							391	41	641	67	1357	142
Geomean*	390	28	1526	98	1140	80	619	45	1083	92	1680	125
(S.D.**)	22	11	1237	76	386	66	1131	77	1513	124	1876	104
Geomean*	Both F-cells		969	64	Both N-cells		778	56	Both FN-cells		1349	108
(S.D.**)	Both F-cells		1246	78	Both N-cells		882	68	Both FN-cells		1623	108

# of paired data	F-cell 1 vs. F-cell 2				N-cell 1 vs. N-cell 2				FN-cell 1 vs. FN cell 2			
	2				3				3			
Geomean*	390	28	887	64	1140	80	1117	79	1444	115	1177	96
(S.D.**)	22	11	1021	100	386	66	1252	82	1636	138	791	81

*geometric mean.
**standard deviation.

Table 7-3. Odour concentration (OU) sampled from the EMS surface

Time	F-cell 1	F-cell 2	N-cell 1	N-cell 2	FN-cell 1	FN-cell 2
5/22/2003			89			
6/26/2003	2593	71	707		132	
7/23/2003	781					
9/21/2003	5124	944	391			
10/19/2003	4000	891	2000	3694	1000	4490
Geomean*	2538	391	471	3694	363	4490
(S.D.**)	1874	489	841		614	

*geometric mean.
**standard deviation.

Table 7-4. Odour concentration (OU) of the EMS cells obtained using the wind tunnel method.

Time	All cells			Cell-1s			Cell-2s		
(m/dd)	No. of data	Geomean*	S.D.**	No. of data	Geomean*	S.D.**	No. of data	Geomean*	S.D.**
5/22	5	451b	418	2	688	625	3	341	200
6/26	4	2594 a	1627	1	952	N/A	3	3623	1050
7/15 or 23	4	730 a	761	2	662	354	2	806	1184
8/26	6	1569a	1084	3	1350	1683	3	1823	315
9/21	3	698a	502	1	641	N/A	2	728	684
May to Sep.	22	1009	1275	9	878	1053	13	1111	1407

*geometric mean. Means followed by the same letter in a column are not significantly different at P<0.05 according to Duncan's multiple range tests.
**standard deviation.

Table 7-5. Odour emission rates (OU/m^2-s) of the EMS cells obtained using the wind tunnel method.

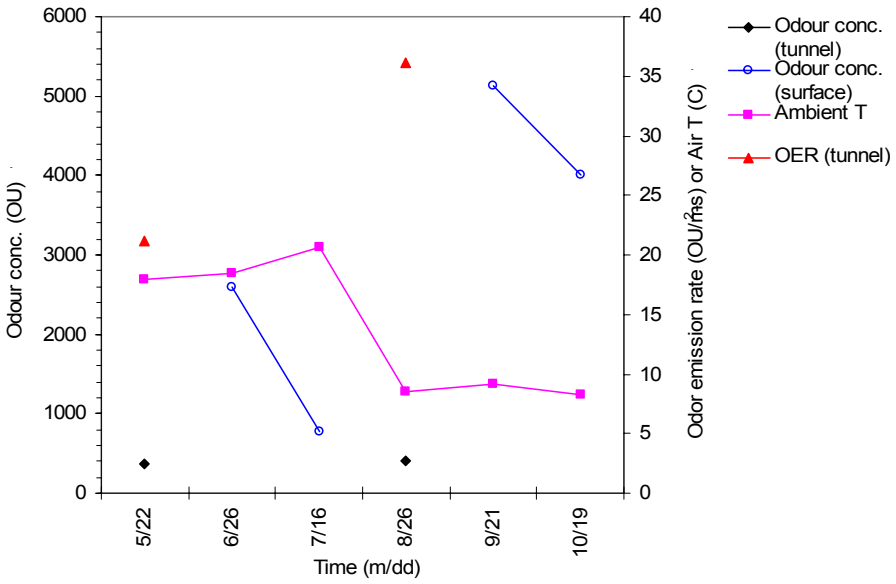
Time	All cells			Cell 1s			Cell 2s		
(m/dd)	No. of data	Geomean*	S.D.**	No. of data	Geomean*	S.D.**	No. of data	Geomean*	S.D.**
5/22	5	26c	24	2	39	37	3	20	12
6/26	4	150 a	94	1	55	N/A	3	209	61
7/15 or 23	4	49bc	41	2	51	5	2	47	68
8/26	6	146ab	87	3	124	136	3	171	17
9/21	3	73bc	53	1	67	N/A	2	76	72
May to Sep.	22	74	87	9	67	92	13	79	86

*geometric mean. Means followed by the same letter in a column are not significantly different at P<0.05 according to Duncan's multiple range tests.
**standard deviation.

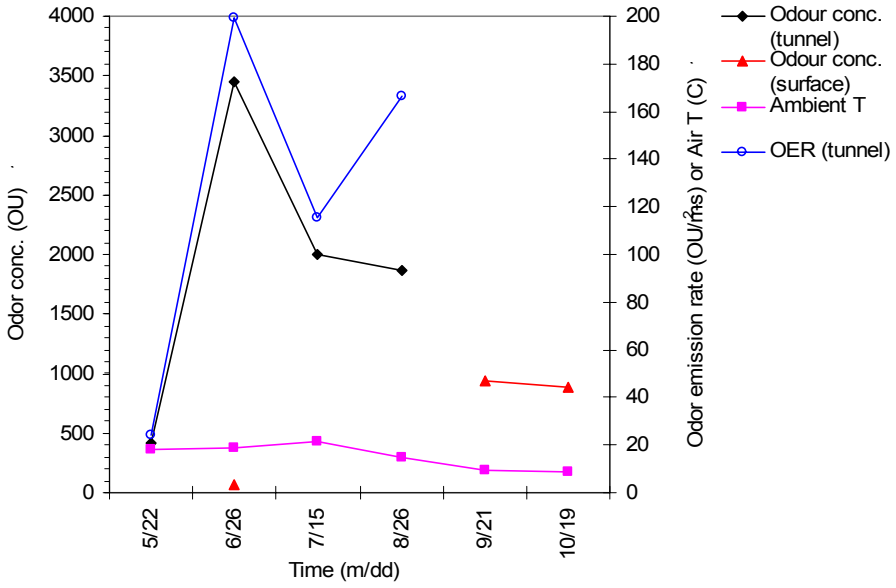
Table 7-6. Odour concentration sampled from the EMS surface

Time	All cells			Cell 1s			Cell 2s		
(m/dd)	No. of data	Geomean*	S.D.**	No. of data	Geomean*	S.D.**	No. of data	Geomean*	S.D.**
5/22	1	89		1	89		0		
6/26	4	362	1180	3	623	1287	1	71	
7/23	1	781		1	781		0		
9/21	3	1236	2588	2	1415	3347	1	944	
10/19	6	2216	1583	3	2000	1527	3	2454	1890
May to Sep.	15	916	1742	10	877	1732	5	998	1945

*geometric mean.
**standard deviation.

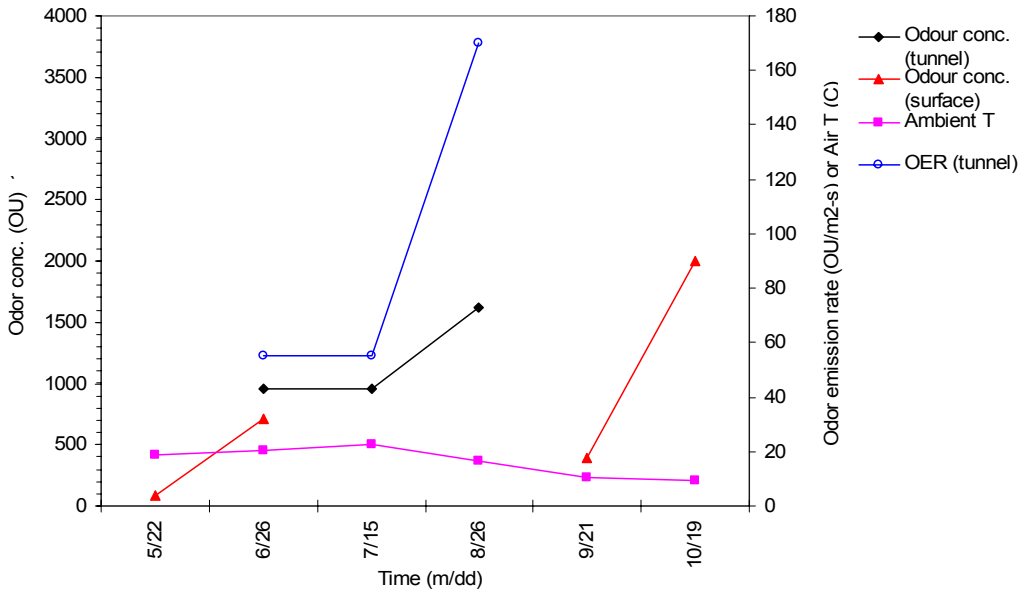


(a) Cell 1

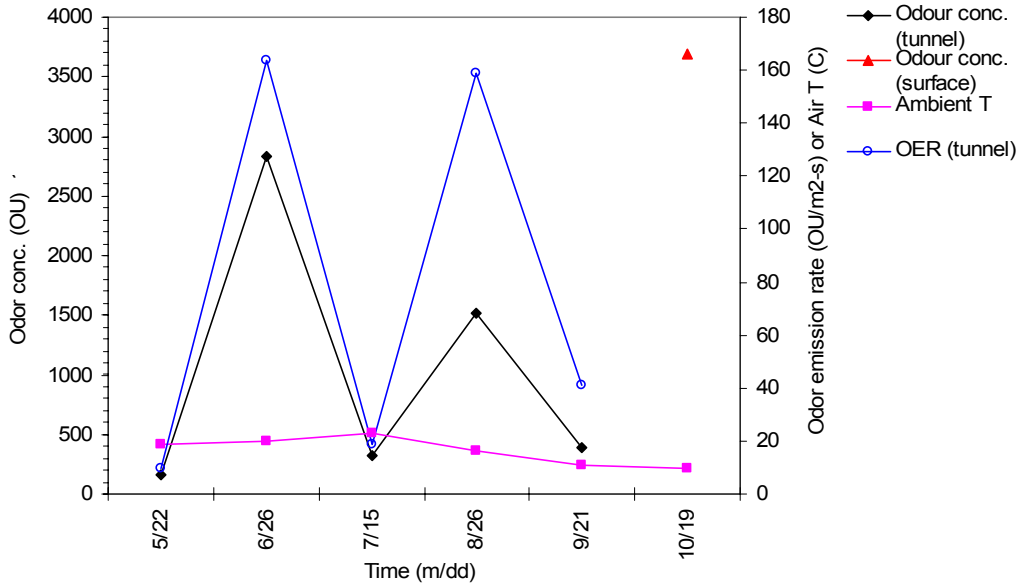


(b) Cell 2

Figure 7-1. Odour concentrations and emission rates from Farrowing Cells

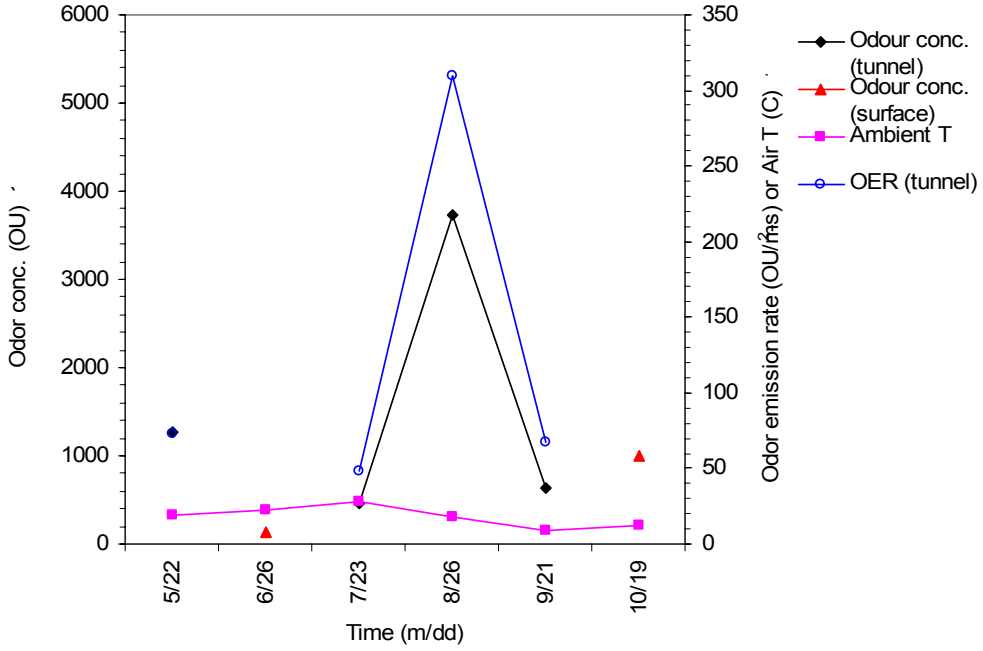


(a) Cell 1

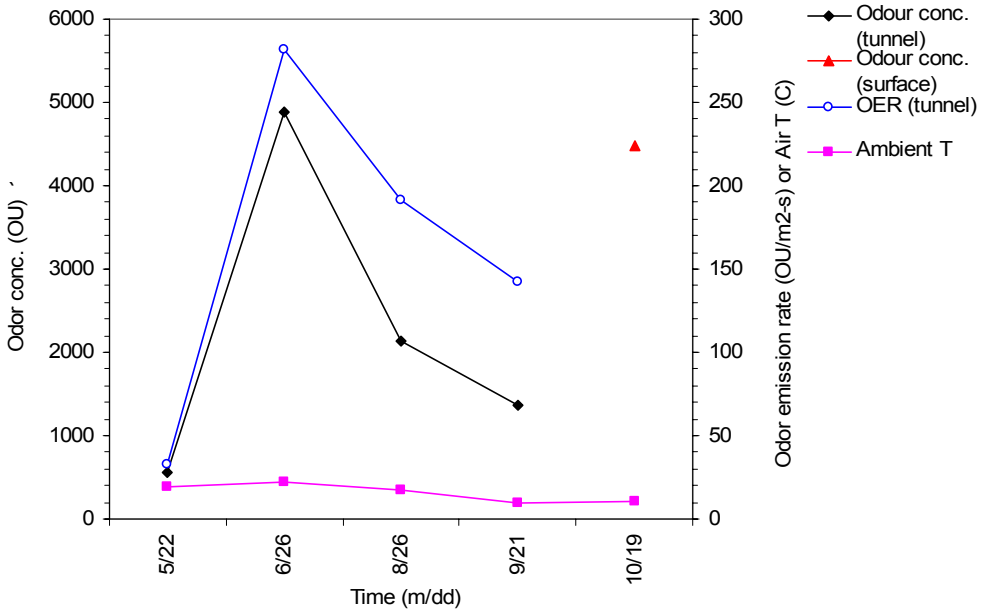


(b) Cell 2

Figure 7-2. Odour concentrations and emission rates from Nursery Cells



(a) Cell 1



(b) Cell 2

Figure 7-3. Odour concentrations and emission rates from Finishing Cells

ODOUR EMISSION VS. AMBIENT AIR TEMPERATURE AND WIND SPEED

Figure 7-4 shows all the odour concentrations and emission rates obtained using the wind tunnel method at various ambient air temperatures measured during the sampling times. There was little correlation between the odour concentration and air temperature ($P>0.05$)). There was also little correlation found between odour concentration and air

temperature for individual cells (P>0.05). Similarly, little correlation was found between the odour emission rate and air temperature (P>0.05).

Figure 7-5 a) shows the odour concentration and ambient air temperature obtained from all cells using the surface sampling method. Again, there was little correlation between odour concentration and air temperature (P>0.05). By using the wind tunnel method, the covered liquid surface air speed was always 0.3 m/s. However, the actual surface wind speed ranged from 0.07 to 0.94 m/s during these measurements. Little correlation was found between odour concentration measured by surface sampling method and surface wind speed, as shown in Fig. 7-5 b) (P>0.05).

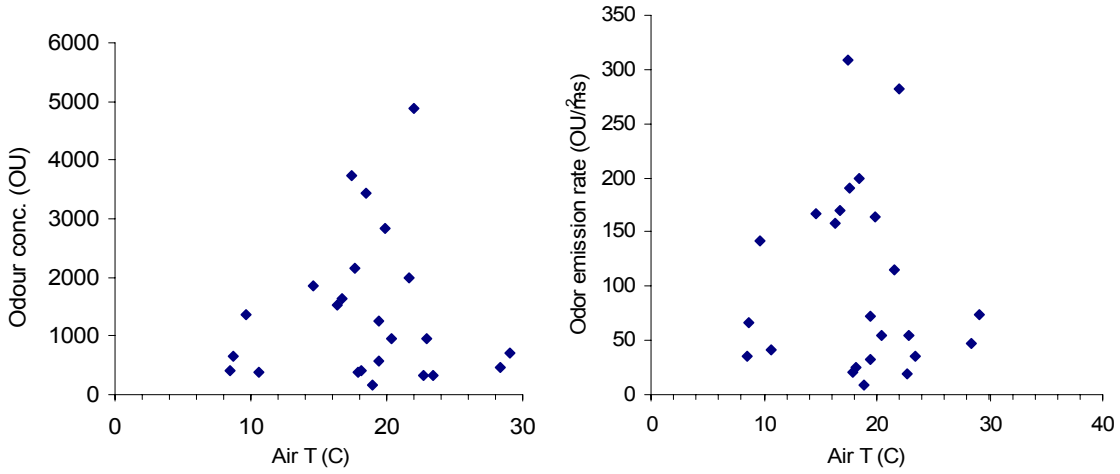
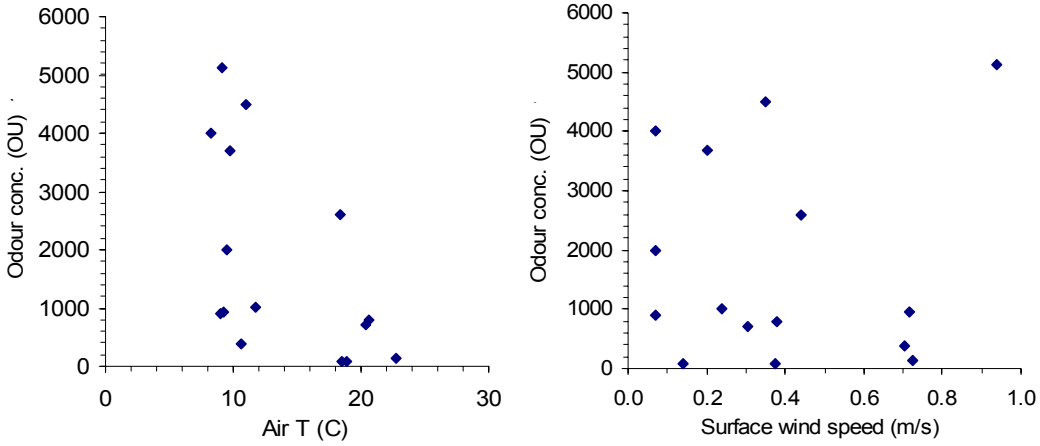


Figure 7-4. Odour emissions obtained using the wind tunnel method at various ambient air temperatures



(a) Odour concentration vs. air T (b) Odour concentration vs. surface wind speed

Figure 7-5. Odour concentration obtained using the surface sampling method at various air temperatures and surface wind speeds

DIURNAL EMISSION MEASUREMENT RESULTS

FINISHING CELL FN-CELL 1

The emissions from the finishing EMS FN-cell 1 were measured on July 23rd and 24th. Figure 7-6 a) shows the diurnal air and manure temperatures. The ambient temperatures of the two days were quite similar (mean ambient temperature 26.5 and 25.8°C for days 1 and 2, respectively). The liquid temperature data was not complete. The available two pairs of data indicated that day 1 had a higher liquid temperature than day 2. The odour concentration showed diurnal variations between 250 OU and 630 OU for day 1 and between 410 OU and 1542 OU for day 2. The odour concentrations were low in the morning and higher in the afternoon. The daily geometric mean of odour concentration on day 2 was much higher than that of day 1 (428 OU for day 1 vs. 793 OU for day 2). The odour emission rate followed the same trend as odour concentration. There was no apparent reason for the higher odour emissions on day 2 when the manure temperature was lower.

FINISHING CELL FN-CELL 2

The emissions from the finishing EMS FN-cell 2 were measured twice. The first time was on August 13th and 14th. Due to a transportation incident, the samples from August 14th did not arrive at the Odour Lab on time. Three of the samples were analyzed 72 hour after they were collected. The results given in Fig. 7-7 b) for the August 14th measurements did show they were similar to the values obtained on August 13th. Due to this incident, the emissions from this cell were measured again on September 7th and 8th.

Figure 7-7 a) shows the diurnal air and manure temperatures of all four days. The ambient temperatures of the two days in August were quite similar (mean ambient temperature 25.9 and 26.3°C for days 1 and 2, respectively). However, the liquid manure temperatures were much higher on day 2 than day 1 (mean manure temperature 19.9°C for day 1 and 23.5°C for day 2). The odour concentration variations on these two days were very small ranging between 268 OU and 436 OU, if the results of August 14th were considered. Similarly, the odour emission rates did not show large variations (between 28.1 and 45.6 OU m^{-2} s^{-1}). The geometric mean of the odour concentrations and emission rates of these two days were almost the same (346 OU vs. 341 OU, 36.2 and 35.7 OU m^{-2} s^{-1}).

For the September measurements, as also shown in Fig. 7-7, the diurnal ambient temperatures of the two days were different (mean 19.9 and 24.8°C for days 1 and 2). As a result, the liquid manure temperatures were much higher on day 2 than day 1 (mean 18.3°C for day 1 and 21.9°C for day 2). The odour concentrations in day 2 were also much higher than day 1 (geometric mean 341 OU for day 1 and 556 OU for day 2). Small diurnal variations were observed (day 1 between 305 OU and 421 OU, and day 2 between 478 OU and 707 OU). Similarly, the odour emission rates showed some variations and day 2 had higher emissions than day 1 (35.7 OU m^{-2} s^{-1} for day 1 and 58.3 OU m^{-2} s^{-1} for day 2). The odour emissions in September were higher than August (geometric mean 424 OU vs. 343 OU, geometric mean 44.4 vs. 35.9 OU m^{-2} s^{-1} for September and August, respectively).

Table 7-7 summarizes the diurnal odour emission results from these manure storage facilities. Due to the uncertain diurnal patterns of the odour emissions from the manure storage cells, using the geometric means of the diurnal measurement results is recommended. More samples from of similar research work will be needed to confirm the findings from this study.

Duncan's multiple range tests for odour concentration and emission rate for FN-cell 1 showed no significant difference among the five measurement periods or between the two days. The statistical result on odour concentration and emissions for FN-cell 2 for the four days' data also indicated that there was no significant difference among the five diurnal measurement periods but the four days' results were different ($P<0.05$) as given in Table 7-7.

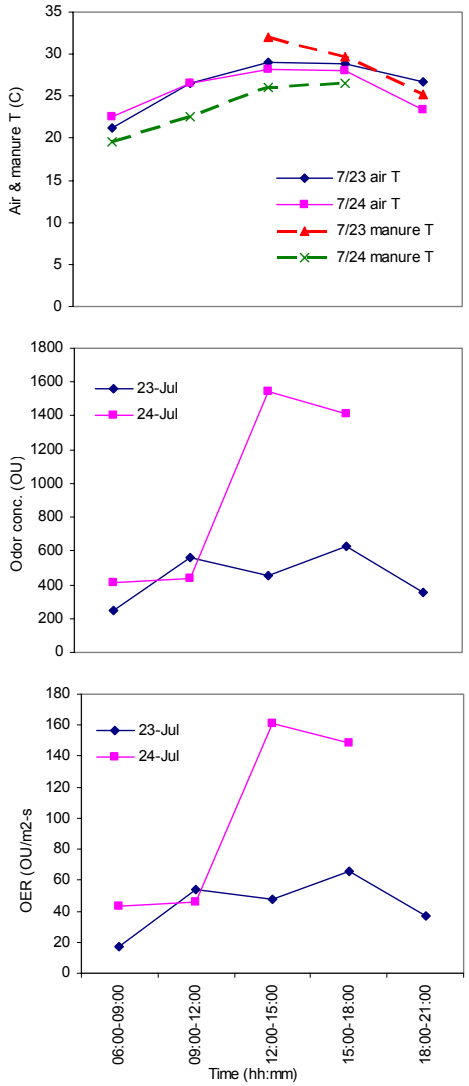


Figure 7-6. Finishing cell 1 diurnal air and manure temperatures and odour concentrations and emission rates

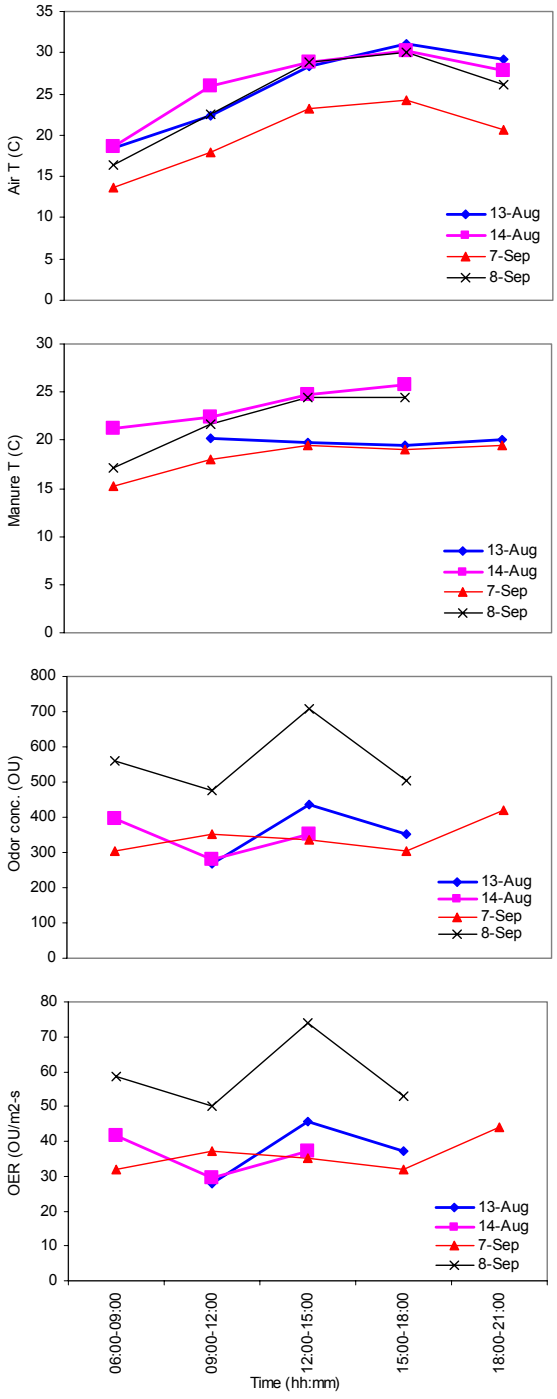


Figure 7-7. Finishing cell 2 diurnal air and manure temperatures and odour emissions

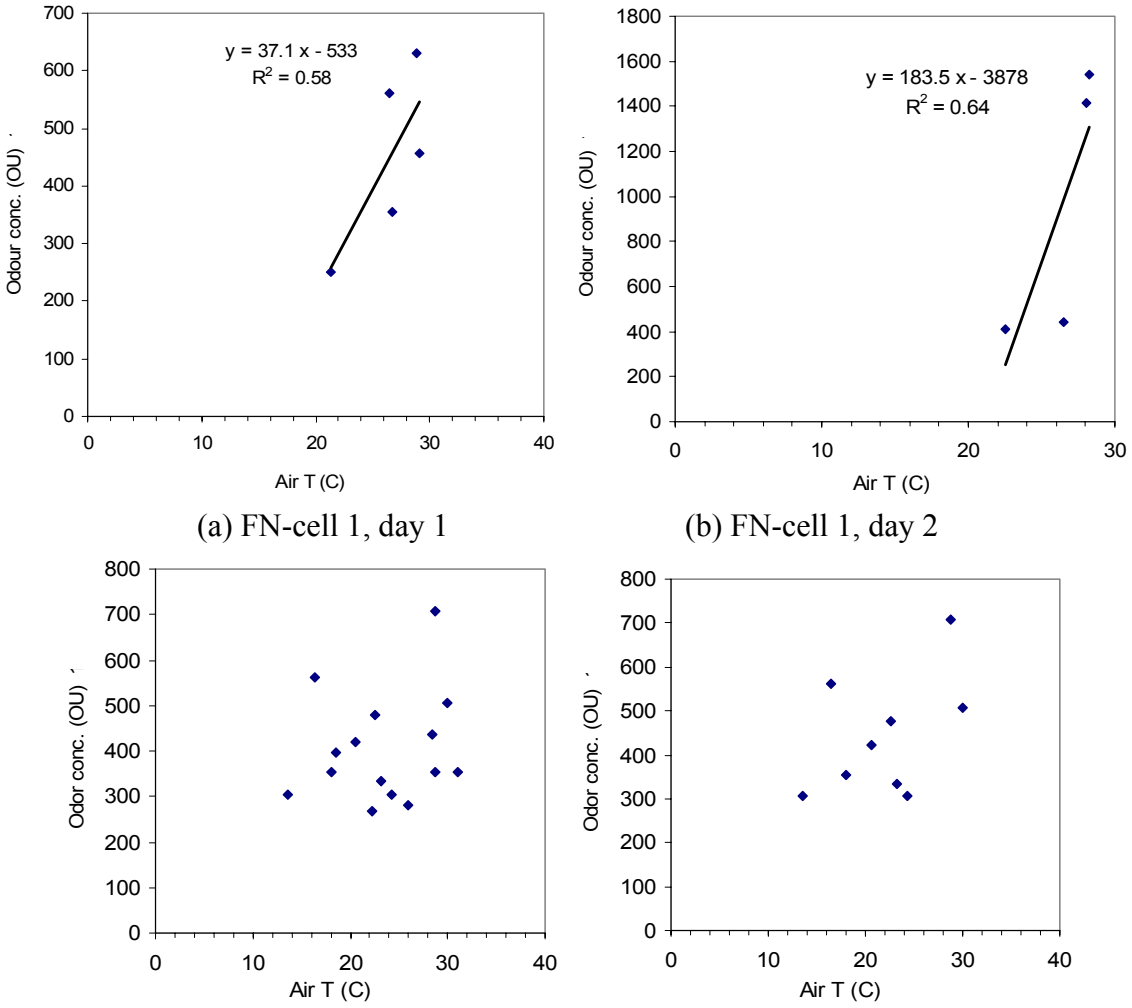
Table 7-7. Summary of diurnal manure storage measurement results

Manure Storage	Time (m/dd)		Air T (C)	Manure T (C)	Odour conc. (OU)†	OER (OU/m^2-s)†
FN-cell 1	07/23	Geomean*	26.5	29.0	428a	40.3a
		S.D.**	3.1	3.4	153	18.6
		Min.	21.3	25.3	250	16.8
		Max.	29.1	32.0	630	65.9
	07/24	Geomean*	26.3	23.6	793a	83.0a
		S.D.**	2.7	3.3	610	63.9
		Min.	22.5	19.5	410	43.0
		Max.	28.3	26.5	1542	161.5
	07/23 & 07/24	Geomean*	26.4	25.9	563	55.6
		S.D.**	2.8	4.2	470	50.5
		Min.	21.3	19.5	250	16.8
		Max.	29.1	32.0	1542	161.5
FN-cell 2	08/13	Geomean*	25.9	19.9	346b	36.2b
		S.D.**	5.3	0.3	84	8.8
		Min.	18.4	19.5	268	28.1
		Max.	31.1	20.3	436	45.6
	08/14	Geomean*	26.3	23.5	341b	35.7b
		S.D.**	4.6	2.1	59	6.1
		Min.	18.6	21.3	281	29.4
		Max.	30.2	25.8	397	41.6
	08/13 & 08/14	Geomean*	26.1	21.7	343	35.9
		S.D.**	4.7	2.4	65	6.8
		Min.	18.4	19.5	268	28.1
		Max.	31.1	25.8	436	45.6
	09/07	Geomean*	19.9	18.3	341b	35.7b
		S.D.**	4.3	1.8	48	5.0
		Min.	13.6	15.3	305	31.9
		Max.	24.3	19.5	421	44.1
	09/08	Geomean*	24.8	21.9	556a	58.3a
		S.D.**	5.5	3.5	102	10.7
		Min.	16.4	17.1	478	50.0
		Max.	30.0	24.5	707	74.0
	09/07 & 09/08	Geomean*	22.4	19.9	424	44.4
		S.D.**	5.3	3.1	136	14.2
		Min.	13.6	15.3	305	31.9
		Max.	30.0	24.5	707	74.0

*geometric mean.
**standard deviation.
†Means with the same letter in the same column for each cell are not significantly different (P>0.05).

ODOUR CONCENTRATION AS AFFECTED BY AIR AND MANURE TEMPERATURE

Correlation analysis using SAS indicated that there was no significant effect of air and manure temperature on the odour concentration and emission rates of the two cells ($P>0.05$). Figure 7-8 describes the air temperature and odour concentrations from the manure storage facilities. For cell 1, temperature seemed to have a linear relationship with odour emission with r^2 values of 0.58 and 0.64 for day 1 and day 2, respectively. However, if two days data were pooled, the r^2 would be reduced to 0.25. For cell 2, there was little correlation between odour concentration and air temperature (r^2= 0.03 for all four days' data and 0.22 for September data). Because the data set sizes were very small, more work is needed to verify this result.



(a) FN-cell 1, day 1 (b) FN-cell 1, day 2

(c) FN-cell 2, all 4 days' data (d) FN-cell 2, September 7th and 8th data

Figure 7-8. Odour concentration vs. ambient air temperature for EMS cells

CONCLUSIONS

For odour emissions from earthen manure storage facilities over the warm season from May to October, the following conclusions can be drawn:

a) No clear seasonal patterns were found regarding odour concentration or emission rate. Due to the large seasonal variations, geometric means of odour concentration and emission rates are recommended for estimating odour emissions from similar manure storage facilities. Relying on one or two measurements may either underestimate or overestimate odour emission values.
b) Using the wind tunnel method to measure the odour emission rate for individual cells, finishing cell 2 had the highest odour concentration and emission rates, followed by farrowing cell 2, nursery cells 1 and 2, and finishing cell 1, while farrowing cell 1 had the lowest values. The geometric mean of odour concentration was higher for cell-2s than cell-1s (1111 vs. 878 OU) as was the odour emission rate (geometric mean of 79 OU m^{-2} s^{-1} for cell-2s and 67 OU m^{-2} s^{-1} for cell-1s).
c) Ambient and manure temperature had little effect on the odour concentration and emissions from manure storage facilities ($P>0.05$).
d) The finishing EMS had the highest odour emissions, followed by the nursery EMS, while the farrowing EMS had the lowest emissions.
e) The method of surface sampling needs to be standardized and the odour emission rate calculated by this method needs to be further investigated.

For diurnal emissions from the earthen manure storage facilities, the following conclusions can be drawn:

f) No consistent diurnal patterns were observed regarding odour concentration or emission rate.
g) The diurnal variations of odour concentration and emission were relatively small for finishing cell 2 as the result of two 2-day measurements (the geometric mean of odour emission rate was 35.9 (S.D. 6.8) OU m^{-2} s^{-1} for August 13th and 14th and 44.4 (S.D. 14.2) OU m^{-2} s^{-1} for September 7th and 8th). However, finishing cell 1 showed higher diurnal variations with a geometric mean odour emission rate of 55.6 (SD 50.5) OU m^{-2} s^{-1}. The results from cell 2 indicate that a snap-shot measurement would likely give a representative odour emission data; however, the result from cell 1 implies that multiple measurements are needed to get the representative odour emission data. Hence, multiple measurements at different times of a day are recommended and the geometric means should be used as odour emissions from similar manure storage facilities.
h) Correlation analysis indicated that air and manure temperature did not have a significant effect on the odour concentration and emission rates of the two cells ($P>0.05$). However, the odour emission rate was found to have a linear relationship with ambient air temperature for cell 1($r^2 = 0.58$ and 0.64 for days 1 and 2, respectively); however, this relationship was not found for cell 2. Because the data set sizes were very small, more work is needed to verify this result.

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