The Canadian Society for Bioengineering
The Canadian society for engineering in agricultural, food, environmental, and biological systems.

La Société Canadienne de Génie Agroalimentaire et de Bioingénierie
La société canadienne de génie agroalimentaire, de la bioingénierie et de l'environnement

CSBE | SCGAB

Paper No. 08-107

Setting Acceptable Odor Criteria Using Steady-state and Variable Weather Data

Z. Yu

Division of Environmental Engineering, University of Saskatchewan, Saskatoon, SK

H. Guo

Department of Agricultural and Bioresource Engineering, University of Saskatchewan, Saskatoon, SK

C. Laguë

Faculty of Engineering, University of Ottawa, Ottawa, ON

Written for presentation at the
CSBE/SCGAB 2008 Annual Conference
North Vancouver, British Columbia
July 13 - 16, 2008

Abstract

Odor travel distances predicted by air dispersion models, at which odor dilutes to a certain odor concentration, e.g. the chosen acceptable odor concentration, are different using steady-state and variable weather conditions, therefore, the acceptable odor concentration criteria should be different using these two types of weather data. The objective of this study was to determine the odor criteria that result in the same setback distance under these two types of weather conditions. Using CALPUFF model, the odor dispersion from a typical swine farm in Saskatchewan, Canada was modeled using both steady-state and annual hourly variable weather conditions. The model predicted concentrations under steady-state conditions and the annual occurrence frequencies of these weather conditions, and the model predicted concentrations and the exceeding frequencies under variable (hourly) weather conditions are compared and the equivalent combination of odor concentrations and frequencies under these two types of weather conditions are identified in order to achieve the same odor travel distances. These equivalent odor concentrations and frequencies under these two types of weather conditions may be used as acceptable odor criteria to determine setback distances from livestock farms.

Introduction

With the expansion of livestock industry, the increasing odor nuisance complaints against animal operations have become one of the main barriers for its further development. Determining setback distances between neighboring residents and farms is an effective way for both the livestock industry and regulating agencies. The current guidelines of setback distances are mostly determined by simple parameterization of the odor source, the dilution of the emission and the assessment of the protection level depending on the land use category (Piringer and Schauberger, 1999). The application of such setback distances needs to be validated due to the lack of sufficient scientific bases.

By applying air dispersion model to predict odor dispersion, the separation distance can be determined according to certain acceptable odor criteria. By far, the widely used odor criteria is defined by using a threshold of the odor concentration and its exceeding probability. Schauberger and Piringer (2001) summarized the odor criteria used in different countries. Although the odor criteria are different both in the odor threshold and exceeding probability, the odor concentrations are in the range of 1 to 10 OU and 1 OU is the most commonly used one while the exceeding probabilities vary from 0.01% to 10% (Schauberger and Piringer, 2001). In Ireland, a 1-h odor concentration of 6 OU (for existing facilities) and its exceeding probability of 2% is implemented for intensive agricultural facilities, mushroom compost facilities and the tanning industry in order to limit complaints (Sheridan et al., 2004)). Schauberger (2005) used odor concentration 1 OU and 3% annual occurrence frequency and used 2 year 0.5-hour data for a 1000 head swine finishing barn to obtain setback distance. Minnesota OFFSET (Jacobson et al., 2005 and Guo et al., 2005) used 75 OU as the acceptable odor concentration. Six different weather conditions from neutral to stable were chosen to calculate the setback distances required (where odor concentration reduced to 75 OU) assuming the weather conditions are steady during the dispersion modeling periods. Then the occurrence frequency of each weather condition (which includes the specific weather condition and all weather more stable than that) was used as the odor occurrence frequency. Various setback distances are generated to meet different odor-annoyance-free requirements of the neighbors. Eight years of hourly historical data was used to determine the frequencies of 75 OU with 1% annual occurrence frequency (99% odor-annoyance-free frequency), 2%, up to 9% (as low as 91% odor-annoyance-free frequency).

Acceptable odor concentrations are much different ranging from 1 OU to 75 OU due to various reasons: a) different odor intensity/strength perceptions for odor concentrations, b) the 1 OU or 75 OU were calculated using different weather data: steady-state or variable weather data, c) different odor occurrence frequencies were used. Xing et al (2007) found that using steady and variable weather data can result in much different odor travel distances using the same odor concentration criterion. They calculated odor travel distances where odor was diluted to 10 OU using 7 different steady weather conditions ranging from neutral to stable for an 11,550 head swine finishing farm. The odor travel distance predicted by CALPUFF model was as high as 21.8 km under stable atmospheric condition with wind speed of 1 m/s (F1) while that was 0.5 km under slightly unstable atmospheric condition with wind speed of 5 m/s (C5). Using hourly annual weather data, the same model predicted the maximum odor travel distance of only 0.7 km in all directions around the farm for annual average odor concentration to achieve 10 OU; even for odor to dilute to 1 OU the maximum distance in all directions was 2.3 km, which is similar to the odor travel distance to achieve 10 OU under steady state weather condition slightly stable atmospheric condition with wind speed of 5 m/s (E5). The results indicate that a) different odor concentration criteria may be used when using steady state or variable weather data for odor setback distance determinations, i.e. acceptable odor concentration may be set much higher when using steady-state weather condition than using variable weather conditions, such as hourly weather data; and b) odor occurrence probability should be considered together with odor concentration as acceptable odor occurrence criteria.

Objectives

The objective of this study is to explore the odor dispersion under steady-state and variable (hourly historical) weather conditions by CALPUFF model and to identify the equivalent odor criteria (odor concentration and occurrence frequency) for determination of setback distance using these two weather conditions.

Materials and Methods

The Swine Farm

A typical swine farm in Saskatchewan, Canada was selected to achieve the objectives of this study.
The swine farm had one barn with 10 rooms for 11,550 feeder pigs and an uncovered two-cell earthen manure storage basin (Fig. 1). The barn was mechanically ventilated with wall-mounted fans. There were shallow manure pits underneath the fully slatted floor that were gravity-drained once every 2 to 4 weeks. The odor emission rates measured by Guo et al. (2005) were used by this study (Table 1). The study area was a rural crop field with flat terrain and no obstacles.

Air Dispersion Model

CALPUFF model (Earth Tech, Inc. Concord, MA) is a recommended model by the US EPA (US EPA, 1998 a) and was selected to simulate the odor dispersion. It is a Lagrangian puff model with the ability to account for the effects of temporally and spatially varying meteorological conditions on pollutant transport. It consists of three sub-systems: CALMET, CALPUFF, and CALPOST. CALMET is a meteorological model that combines meteorological data and geophysical data to generate a wind field. CALPUFF model uses the provided meteorological data, source and receptor information to predict concentration, at each receptor for a specified average time (at least 1 hour). CALPOST is a post-processor for the model.

CALPUFF can predict dispersion from point, volume, and area source emissions. Up to 50×50 grid receptors and discrete receptors can be handled in one run time. Both the three dimensional meteorological fields developed by the CALMET model and the meteorological files used by the ISCST3 model can be accommodated by CAPUFF model. Five schemes of dispersion coefficients were provided. CALPUFF contains algorithms for near-source effects such as building downwash, transitional plume rise, partial plume penetration, sub-grid scale terrain interactions as well as long range effects such as pollutant removal, chemical transformation, vertical wind shear, over water transport, and coastal interaction effects.

Xing et al. (2008) compared the predictions of CALPUFF with three other models (ISCST3, AUSPLUME, and INPUFF2) using steady-state and variable meteorological weather conditions. Under steady-state weather conditions, the four models' predictions for odor concentrations varied greatly within 1 km from the source; beyond that, ISCST3 and CALPUFF gave similar results (within 24.8%) while AUSPLUME and INPUFF2's predictions were much lower than that of ISCST3 by up to 45.3%. Using one year hourly meteorological data to calculate the annual mean odor concentration in the nearby area of a swine farm, all predictions were different and CALPUFF predicted the greatest distances for odor concentrations from 1 to 10 OU while INPUFF2 predicted the shortest distances. For example, to allow odor dilute to 1 OU, the maximum odor travel distance ranged from 1.6 km (INPUFF2) to 2.3 km (CALPUFF).

Weather conditions

Steady-state meteorological conditions For steady-state meteorological conditions, the same seven weather conditions as used by Xing et al. (2008), from stable weather F1 to unstable weather C5, that favor odor travel and result in high odor concentrations at the ground level downwind of the odor sources were chosen for this study, i.e.,:

- F1: atmospheric stability F (moderately stable) with wind speed 1 m/s,
- F3: atmospheric stability F (moderately stable) with wind speed 3 m/s,
- E3: atmospheric stability E (slightly stable) with wind speed 3 m/s,
- E5: atmospheric stability E (slightly stable) with wind speed 5 m/s,
- D5: atmospheric stability D (neutral) with wind speed 5 m/s,
- D8: atmospheric stability D (neutral) with wind speed 8 m/s, and
- C5: atmospheric stability C (slightly unstable) with wind speed 5 m/s.

Under the other weather conditions that are less stable than C5, strong vertical mixing will result in great air dispersion and normally will not allow odor to travel for long distances.

The prevailing winds were from the West-North-West (WNW). This direction was used for simulating odor dispersion from the farm under steady-state meteorological conditions.

Variable meteorological conditions The variable meteorological data was chosen as the annual hourly meteorological data recorded in this study area, Yorkton, Saskatchewan, Canada in the year 2003. When using annual hourly meteorological data to study the actual occurrence and duration of the steady-state weather conditions indicated before, the steady-state weather condition marked as stability with wind speed (F1, F3, etc.) represented the weather condition with certain stability class and the wind speed equal or less than certain value and any other conditions that are more stable than the indicated condition. This is because that the odor can travel more easily to a specified location under more stable conditions as mentioned in the study of Jacobson et al. (2005).

Computation Assumptions and model setup

Some assumptions were applied to odor dispersion simulation using CALPUFF model under the steady-state meteorological conditions:

1. The barn was treated as point sources and the two manure storage cells were considered as area sources. A total of 32 point sources were used in order to best represent the shape of the barn.
2. Constant emission rates from both the barn and manure storage cells were used as given in Table 1. The odor emitting height was 1.5 m for the barn and the manure storage cells located on ground level.
3. Due to the fact that the point sources were attributed to the barn area instead of individual fans, the odor exit velocity was considered to be 0.05 m/s. The exhaust air temperature from the barn was 22^{o}C.
4. An ambient temperature of 20^{o}C and mixing height of 1500 m were utilized in the model. The wind direction was constant from WNW.
5. The model simulation time period was set up long enough to allow the odor to travel to the farthest distance before the centerline odor concentration was reduced to 10 OU.
6. During all the simulations, deposition or chemical transformation were not considered.
7. Receptors were arranged in grid format of 100 m from each other within 5 km from the farm. The receptor's detection height was considered to be 1.5 m above the ground.

When simulating odor dispersion using hourly annual meteorological data, the same assumptions and model setup were applied except 4 and 5.

Data analysis method

In this study, the odor dispersion under steady-state meteorological conditions (F1 to C5) was explored by CALPUFF model. The critical detection distances and the odor concentrations within 5 km were simulated. The annual occurrence frequency and duration of each meteorological condition was studied using 2003 annual meteorological data. Meanwhile, model predicted annual mean odor concentrations were used to determine setback distances and compare with those from steady-state meteorological conditions. With annual meteorological data, the annual occurrences of certain odor concentrations (such as 1OU, 10 OU and 75 OU, etc.) at different distances were obtained by CALPUFF model. Finally, the equivalent odor criteria (odor concentration and frequency) was identified using steady-state weather condition and variable (hourly historical) weather condition

Results and Discussion

Odor dispersion under steady-state meteorological conditions

Critical detection distance The critical detection distance (CDD) is defined as the maximum odor travel distance from the source where the odor plume centerline concentration is reduced to 10 OU. With an ambient temperature of 20^{o}C and mixing height of 1500 m, the CDDs under different steady-state meteorological conditions (F1 to C5) were obtained and shown in Fig. 2. The odor traveled 21.8

km under stable condition (F1) but decreased exponentially to 0.5 km as the atmospheric stability changed to unstable (C5). The result clearly indicates that atmospheric stability had a significant effect on odor dispersion. It is important to point out that the great odor travel distances obtained with F1 and F3 were under the assumption that such weather condition would remain for a long enough time to allow odor to travel to such distances, i.e., 5 to 6 h with F1 or 2 h with F3. In reality, it is extremely rare that such weather conditions would occur without any wind direction shift, as examined using 2003 annual meteorological data in the following study (Table 3).

Odor concentration within 5 km Modeled odor plume centerline concentrations within 5 km downwind are given in Table 2. Under each steady-state condition, the odor concentrations reduced with the increased distance due to the vertical and horizontal dispersions. At certain distance, the odor concentrations decreased with stability changes from F1 to C5. Under F1, although the predicted odor concentrations up to 5 km were relatively high (52 to 269 OU), this weather condition seldom occurs. For F3, at 3 km, i.e., the maximum setback distance required by the setback guidelines of the Canadian Prairie Provinces, the odor concentration was 29 OU. Under E3 to C5, odor concentration at 3 km was 1 to 15 OU. The odor plume centerline concentration at 3 km reduced from 84 OU to 1 OU when weather changed from F1 to C5.

Annual occurrence frequency and duration of steady-state weather condition

The annual occurrence frequencies for the seven weather conditions calculated from 2003 hourly meteorological data are shown in Figure 3. The frequency was the accumulative frequency of each specific weather condition or more stable than that. The maximum occurrence frequencies for weather conditions F1 and F3 appeared in WNW direction, while E3 and E5 in W direction and D5, D8 and C5 in SSE direction. The annual occurrence frequencies for F1 to C5 in WNW directions were 0.71%, 1.39%, 1.72%, 2.89%, 4.83%, 8.24% and 10.25%, respectively. The occurrence frequency increased with the decrease of stability.

When modeling the odor dispersion under steady state weather conditions, it is assumed that each weather condition lasts long enough for the odor to travel to CDD distance (where the centerline odor concentration reduces to 10 OU). However this rarely happened in the reality. Figure 4 shows the occurrence and duration of each steady-state condition (F1 to C5) in WNW direction. The duration of each weather condition was investigated in relation to the hour of the day and the day of the year. It was the consecutive hours of that weather condition or more stable than that. It is expressed by the size of the circles in the graph, the larger circle indicated the longer duration of the weather condition. The lines, marking the time of sunset and sunrise, separate daytime from night-time. The stable conditions (F1 and F3) and slightly stable (E3 and E5) conditions seldom occurred at daytime. Neutral conditions (D5 and D8) occurred mostly at nigh and slightly unstable condition (C5) occurred more often at night time than daytime, and the long duration occurrences are mainly in winter season.

Table 3 lists the numbers of consecutive hours of occurrence for each weather condition in WNW direction. It shows that long durations of the same weather conditions (or close to steady-state weather condition) were very rare. For F1 to E5, the largest duration was 5 hours and occurred no more than 4 times in a year. The largest duration is 11 hours for C5 which occurs twice in the year of 2003. It is also important to point out that weather conditions changed over an hour period, such as wind direction change ranging between ±11.25 degrees of due WNW. Therefore, each consecutive occurrence period might not be qualified for strict steady-state condition.

Odor dispersion using annual hourly meteorological data

Mean annual odor concentration in the study area A set of variable meteorological data, i.e., 2003 hourly meteorological data from Yorkton, Saskatchewan, Canada, was used to obtain the annual average odor concentration in the nearby area of this swine farm. The results of the annual average odor concentrations are shown in Figure 5. The maximum distances occur for various odor concentrations leeward of the prevailing winds in the NW and SE areas. Schauberger et al. (2002) calculated direction-dependent separation distance by AODM model and found that for the area leeward of the prevailing winds the odor occurrence frequency is higher than for the areas leeward of less frequent wind directions. Guo et al. (2005b) studied odor occurrence in the same area of this study and found the locations with high odor events were mostly downwind of the prevailing winds from the source.

The maximum downwind distances for 1, 2, 5, and 10 OU are presented in Table 4. If annual average odor concentrations of 1 to 10 OU are used as setback criteria, the maximum setback distance will be in the range of 0.8 to 2.5 km, which falls within the recommended setback distances used by some states in the U.S.A. and the Canadian Prairie Provinces.

Comparing the annual average odor concentrations with the results obtained previously using steady-state weather conditions, odor can travel much farther under steady state weather conditions if using the same odor concentration criterion. For example, odor can travel over 20 km under F1 and up to 8 km under F3 before it is diluted to 10 OU/m^3. These results suggest that we may use different odor concentration criteria for steady state weather conditions, such as F1 to C5, than we use for variable weather conditions, such as annual, seasonal, or monthly hourly weather data. If steady state weather data are used, the acceptable odor concentrations allowed should be set high, for example 75 OU/m^3 as suggested by Guo et al. (2005) using the OFFSET model. If variable weather data are used, the average odor concentration allowed over a year or a month should be much lower. From the results of this study, odor concentrations of 1 to 10 OU/m^3 may be used. Or we may use combination of odour concentration and occurrence frequency and find equivalent steady state weather condition, as we are going to explore below.

Annual occurrence frequencies for various odor concentrations By using the 2003 hourly meteorological data, the hourly odor concentrations were simulated by CALPUFF model and the annual occurrence frequency (percentage of hourly odor concentration exceed a specific odor concentration at each distance) in WNW direction were summarized in Table 5.

For 75 OU, i.e. the acceptable odor concentration in OFFSET, occurrence frequencies are 5.7%, 1.5% and 0.1% in distances 0.5, 1 and 1.5, respectively., If 1 OU was used as acceptable odor concentration, the odor occurrence frequencies range from 7.8% (5 km) to 31.4% (0.5 km). If using the odor acceptance criteria suggested by Schauberger et al. (2005), i.e. allowing annual exceedance of 1 OU by

3%, the separation distance required would be greater than 5 km. Similarly, for 10 OU, odor occurrence frequencies range from 1.2% (3.5 km) to 24.6% (0.5 km); beyond 3.5 km, it is lower than 1%. Hence, different odor acceptable criteria would result in much different setback distances. In order to set the setback distance of 3 km, the odor criteria of 1 OU with occurrence frequency of 12% and 10 OU with 2% should be used.

Comparison of odor criteria under two weather conditions

An odor concentration level and the annual occurrence frequency should be used as the criteria for setback distance determination under either steady-state weather condition or variable weather. In order to compare the odor criteria under these two weather conditions, the occurrence frequency of the weather conditions can be considered as odor occurrence frequency of the selected odor concentration. The odor concentration and the odor occurrence frequency with the WNW wind at 0.5, 1, 2, 3, 4, and 5 km distances under variable weather conditions and steady state conditions are shown in Figure 6 and Figure 7. The patterns between odor concentration level and its occurrence frequency in different distances are similar. The same odor concentration occurs more frequently in near distance than far distance, and vice versa. In the same distance, higher odor concentration level has lower occurrence frequency.

The best fit curves (R^2>0.9, P< 0.01) for the relationship between odor occurrence frequency and odor concentration can be described as:

$$\ln\left(\frac{y}{1-y}\right) = ax + b$$ for variable weather condition,

$$\ln\left(\frac{y}{1-y}\right) = a\ln x + b$$ for steady state weather condition

In which, y (%) is odor occurrence frequency with odor concentration of x (OU), a and b are parameters varied from different distances.

Based on the above equations that best fit the relationship between odor occurrence frequency and odor concentration, the odor criteria for setback distance under different weather conditions can be shown as Figure 8.

When determining the odor criteria for setback distance, the odor concentration is considered to be in the range of 1 to 75 OU. In near distance (less than1 km), the odor occurrence frequency of the same odor concentration level is larger under variable condition than under steady state condition when the odor concentration is greater than 4 OU. In 2 km distance, the odor occurrence frequency of the same odor concentration under variable weather condition is greater than that under steady state condition when the odor concentration is between 4 and 16 OU. In the farther distance (3, 4 and 5 km), the odor occurrence frequencies of same odor concentration are larger under steady state condition than under variable condition.

In other words, under variable weather condition, if odor concentration of 10 OU is used as the criteria, the occurrence frequency of 22.5%, 12.4%, 5%, 2.2%, 1% and 0.5% will result in the setback distances of 0.5, 1, 2, 3, 4 and 5 km, respectively. However when under steady state weather condition, 10 OU concentration with odor occurrence frequency of 10.2%, 6.8%, 4%, 3%, 2.2% and 2% will result in the same setback distances, respectively. When the odor occurrence frequency is selected such as 4%, the odor concentrations of 75, 43, 12, 6, 2, and 1 OU can result in 0.5, 1, 2, 3, 4 and 5 km setback distance, respectively, under variable weather condition. In order to achieve the same setback distances with an odor occurrence frequency of 4%, the odor concentration should be 30, 19, 10, 7, 4 and 3 OU, respectively, under steady state weather condition.

Conclusion

CALPUFF model was selected to simulate the odor dispersion around a typical swine farm using steady-state meteorological data and variable (annual hourly) meteorological data. Some conclusions can be drawn regarding the acceptable odor criteria in order to determine the setback distance:

Under steady-state weather conditions, the odor travels much farther under stable weather condition and the travel distance decreases significantly with decrease of atmospheric stability.

Using the annual hourly meteorological data and considering annual average odor concentrations of 1 to 10 OU as acceptable odor concentration, the maximum setback distance will be in the range of 0.8 to 2.5 km, which falls within the recommended setback distances used by some states in the U.S.A. and the Canadian Prairie Provinces. These distances are much lower than that from using same odor concentration under stable steady-state weather conditions. Different odor criteria should be used to determine setback distances under different weather conditions.

If an odor concentration level and the annual occurrence frequency were treated as the criteria for setback distance determination, the annual odor occurrence frequency with certain odor concentration can be obtained by CALPUFF model in different distance and model predicted odor concentration in different distance and the annual occurrence frequency of each steady state weather condition were obtained. In order to compare the odor criteria between these two weather conditions, the occurrence frequency of the weather conditions can be considered as odor occurrence frequency of the predicted odor concentration. The relationships between odor concentration and its occurrence frequency are different between these two weather conditions. The odor criteria used to determine different setback distance were identified. In near distance (less than1 km), the odor occurrence frequency of the same odor concentration level is larger under variable condition than under steady state condition when the odor concentration is greater than 4 OU. In 2 km distance, the odor occurrence frequency of the same odor concentration under variable weather condition is greater than that under steady state condition when the odor concentration is between 4 and 16 OU. In the farther distance (3, 4 and 5 km), the odor occurrence frequencies of same odor concentration are larger under steady state condition than under variable condition. Hence, suitable odor criteria that can be used to achieve acceptable setback distance under either steady-state and variable conditions can be easily explored.

Reference

Sheridan B. A., E. T. Hayes, T. P. Curran, and V. A. Dodd. 2004. A dispersion modelling approach to determining the odour impact of intensive pig production units in Ireland. Bioresource Technology. 91(2):145-152

Fritz, B. K., B. W. Shaw, and C. B. Parnell, Jr. 2005. Influence of meteorological time frame and variation on horizontal dispersion coefficients in Gaussian dispersion models. Trans. ASAE .48(3): 1185 - 1196.

Guo, H., L.D. Jacobson, D.R. Schmidt, R.E. Nicolai, J. Zhu, K.A. Janni. 2005a. Development of the OFFSET model for determination of odor-annoyance-free setback distances from animal production sites: Part II. Model development and evaluations. Transactions of the ASAE, 48(6).

Guo, H., W. Dehod, J. Feddes, C. Lague, and I. Edeogu. 2005b. Monitoring odor occurrence in the vicinity of swine farms by resident observers: Part I. Odor occurrence profiles. Canada Biosystems Eng. 47: 6.57-6.65.

Li, Y., H. Guo. 2008. Evaluating the effect of computational time steps on livestock odor dispersion using a computation fluid dynamics model. Transactions of the ASABE. Vol. 50(6): 2199-2204

Jacobson, L.D., H. Guo, D.R. Schmidt, R.E. Nicolai, J. Zhu, K.A. Janni. 2005. Development of the OFFSET model for determination of odor-annoyance-free setback distances from animal production sites: Part I. Review and experiment. Transactions of the ASAE, 48(6)

Piringer, M., Schauberger, G 1999. Comparison of a Gaussian diffusion model with guidelines for calculating the separation distance between livestock farming and residential areas to avoid odor annoyance. Atmos. Env. 33, 2219–2228

Schauberger,G., M. Piringer, E. Petz. 2002. Calculating Direction- dependent Separation Distance by a Dispersion Model to avoid Livestock Odor Annoyance.Biosystems Engineering 82 (1), 25–37

Schauberger,G., M. Piringer, E. Petz. 2001. Separation distance to avoid odor nuisance due to livestock calculated by the Austrian odor dispersion model (AODM) Agriculture,Ecosystems & Environment .87(1), 13-28

Schauberger,G., M. Piringer, E. Petz. 2005. Sensitivity analyses of dispersion models to assess odor nuisance: a qualitative comparison with complaint statistics. 17th International Congress of Biometeorology. Sept 5 - 9, Garmisch-Partenkirchen

U.S. EPA. 1995. A user's guide for the CALPUFF dispersion model. EPA-454/B-95-006. Washington, D.C.: U.S. Environmental Protection Agency.

Xing Y., H. Guo, J. Feddes, Z. Yu, S. Shewchuck, B. Predicala.2007. SENSITIVITIES OF FOUR AIR DISPERSION MODELS TO CLIMATIC PARAMETERS FOR SWINE ODOR DISPERSION. Transactions of the ASABE. Vol. 50(3): 1007−1017

Xing Y., H. Guo, J. Feddes and S. Shewchuck. 2006. Evaluation of Air Dispersion Models Using Swine Odor Plume Measurement Data. CSBE paper No. 06-172.

Zwicke, G. W. 1998. The dispersion modeling of particulate for point and multiple point sources in agriculture. MS thesis. College Station, Tex.: Texas A&M University, Department of Biological and Agricultural Engineering.

Table 1 Odor emission rates from the barn and manure storages

Source	Total emission rate (OU/s)	Area emission rate (OU m^{-2} s^{-1})
Barn	437,928	44.9
Cell 1	270,537	48.1
Cell 2	325,944	33.3

Table 2 Downwind maximum odor concentration under weather conditions F1 to C5

Distance (km)	0.5	1.0	2.0	3.0	4.0	5.0
F1	269	161	111	84	65	52
F3	90	54	38	29	22	18
E3	56	36	23	15	11	8
E5	34	22	14	9	6	5
D5	23	15	8	5	3	2
D8	14	9	5	3	2	2
C5	14	7	3	1	1	1

Table 3 Numbers of occurrence of consecutive hours of specific weather conditions or more stable with WNW wind direction in 2003 in Yorkton, Saskatchewan

Consecutive Hours	1	2	3	4	5	6	7	8	9	10	11	12
F1	26	7	3	2	1	0	0	0	0	0	0	0
F3	63	12	7	2	1	0	0	0	0	0	0	0
E3	78	16	3	4	3	0	0	0	0	0	0	0
E5	105	40	7	5	4	0	0	0	0	0	0	0
D5	169	65	18	7	6	1	0	0	0	0	0	0
D8	225	92	43	18	9	4	4	0	0	1	0	0
C5	245	105	42	27	13	6	5	2	1	2	2	0

Table 4 Maximum distances for various odor concentration levels predicted by CALPUFF

Odor concentration (OU/m^3)	Distance (km)
1	2.47
2	1.52
5	1.08
10	0.80

Table 5 Occurrence frequency (%) in the WNW direction at different distances from the swine farm for odor concentration exceeding indicated levels

Distance (km)	1 OU	2 OU	3 OU	5 OU	7 OU	10 OU	75 OU
0.5	31.4	29.4	28.5	27.0	26.1	24.6	5.7
1.0	23.5	20.9	18.9	16.1	14.4	11.6	1.5
1.5	17.6	14.5	13.0	10.2	7.8	5.3	0.1
2.0	15.4	12.0	10.1	7.2	4.9	3.6	0.0
2.5	13.5	10.2	8.1	5.0	3.6	2.7	0.0
3.0	12.0	8.7	6.2	3.8	2.8	2.0	0.0
3.5	10.8	7.3	5.1	2.9	1.9	1.2	0.0
4.0	9.7	6.0	3.9	1.9	1.3	0.7	0.0
4.5	8.8	4.7	2.7	1.5	1.0	0.3	0.0
5.0	7.8	3.4	2.2	1.2	0.7	0.2	0.0

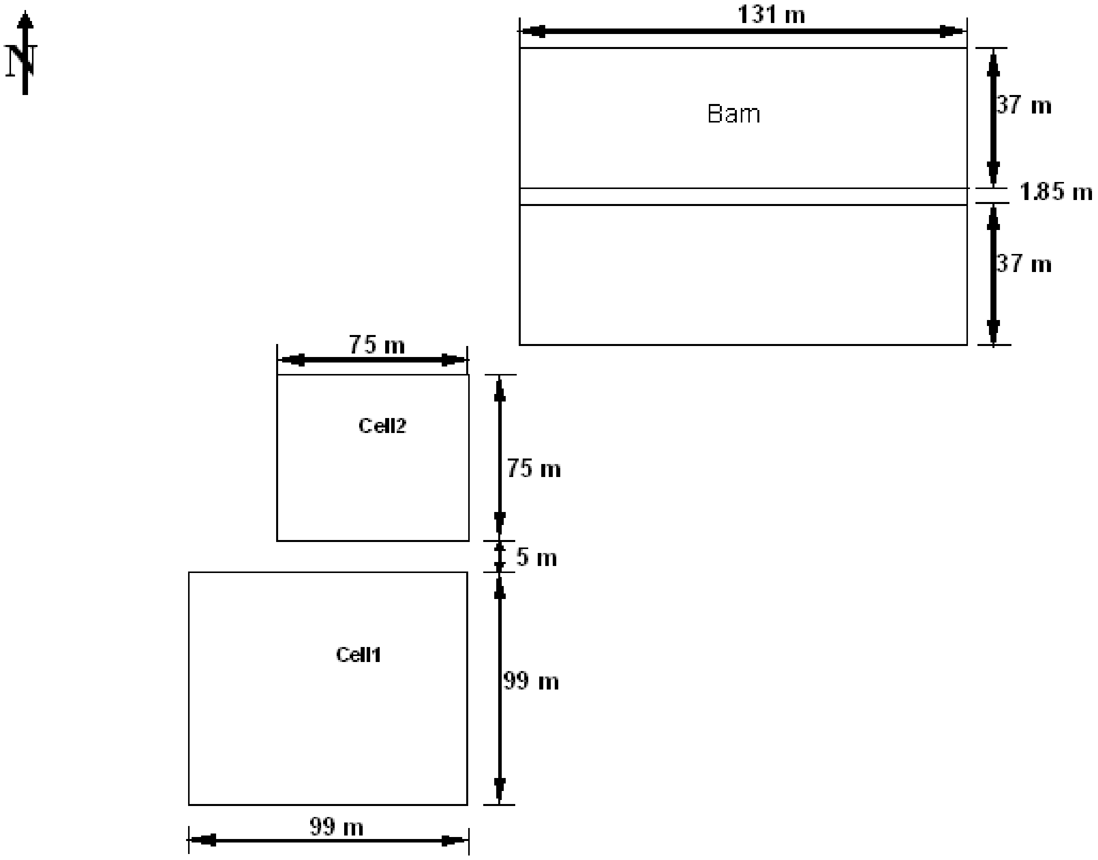


Figure 1. Layout of the swine farm (Xing and Guo, 2006)

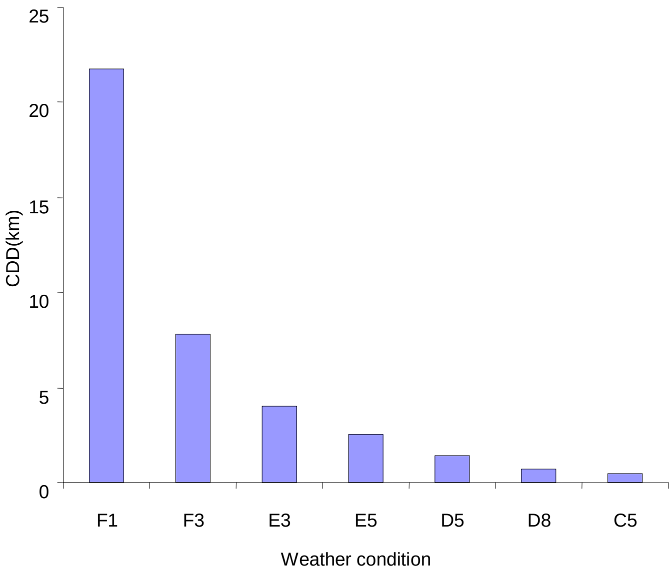


Figure 2. Effect of atmospheric stability on odor travel distances (CDD)

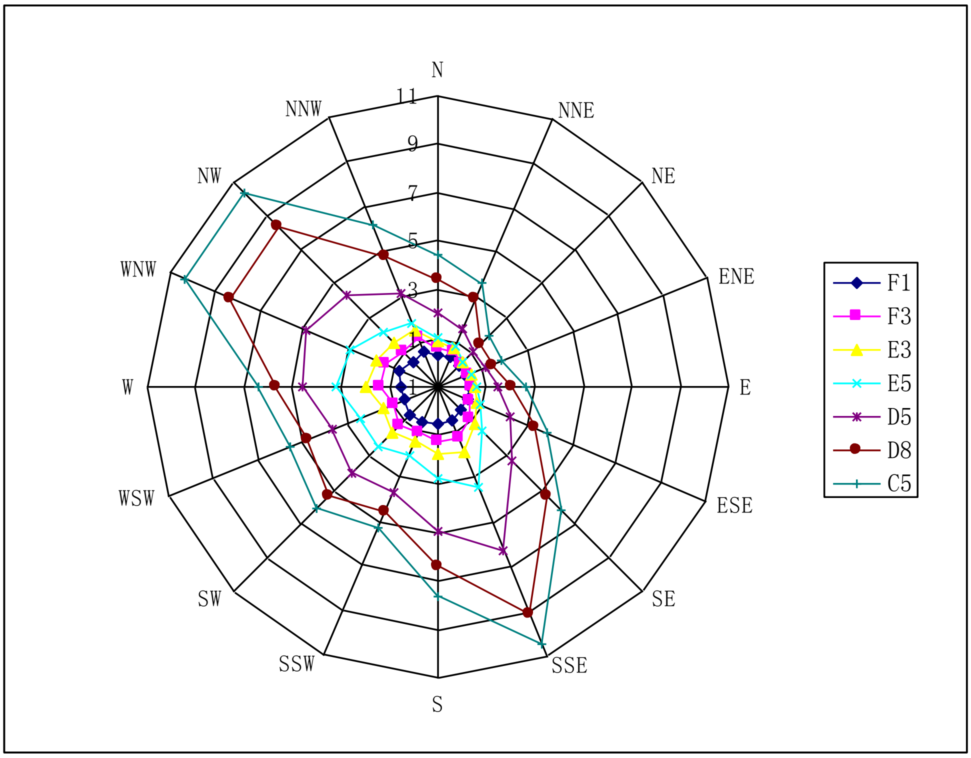
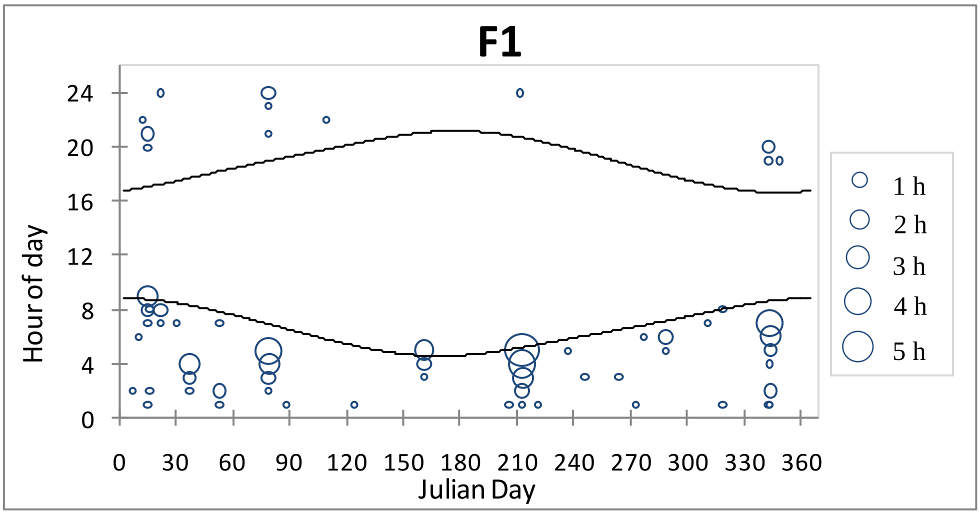
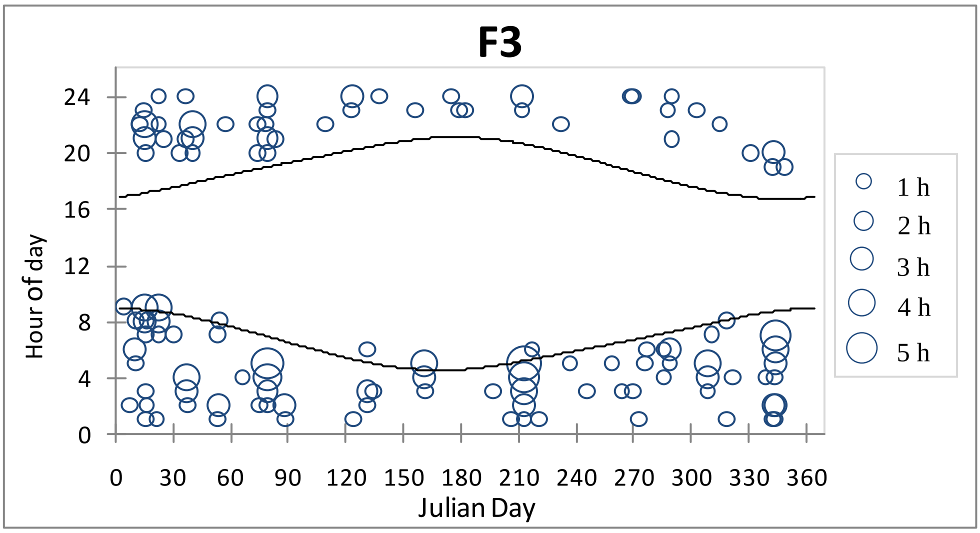
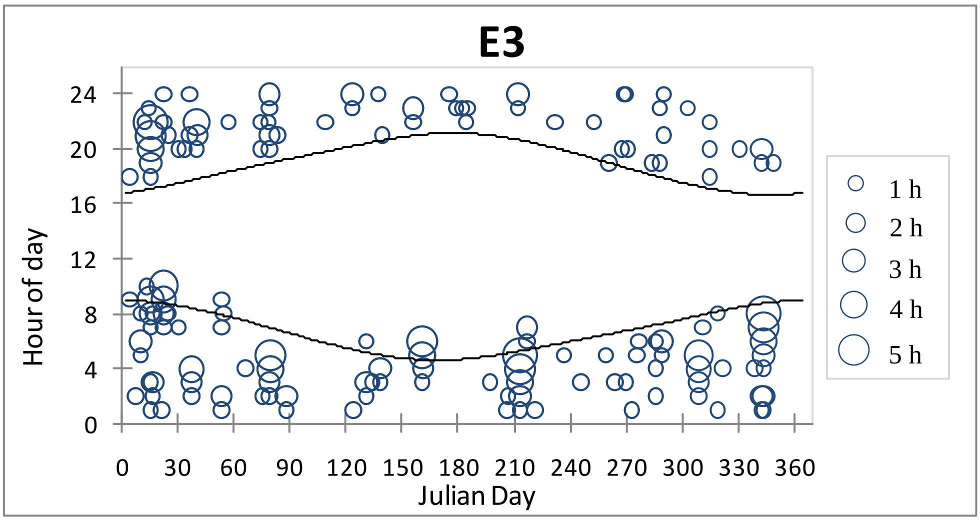
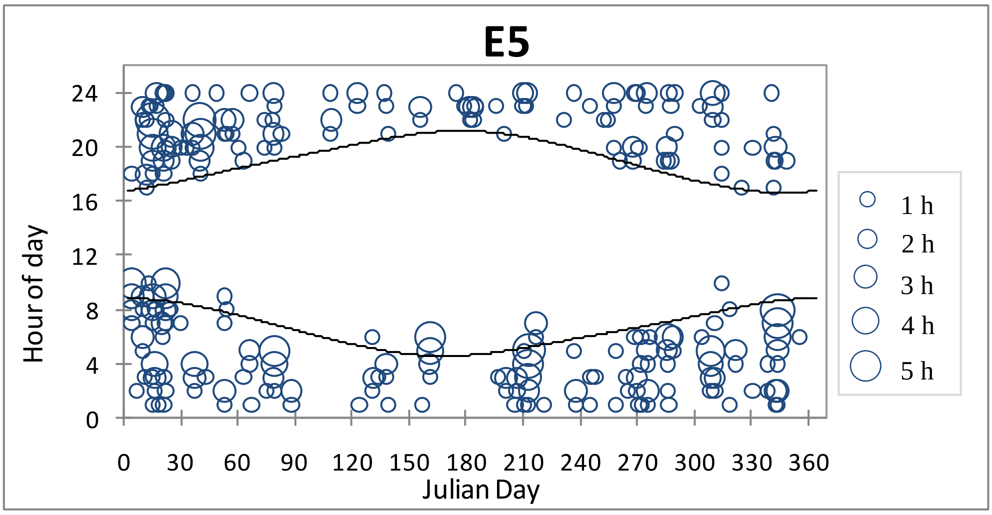


Figure 3 The annual occurrence frequencies for various atmospheric conditions from 2003 meteorological data




F3
Hour of day
24
20
16
12
8
4
0
0 30 60 90 120 150 180 210 240 270 300 330 360
Julian Day
1 h
2 h
3 h
4 h
5 h


E3
Hour of day
24
20
16
12
8
4
0
0 30 60 90 120 150 180 210 240 270 300 330 360
Julian Day
1 h
2 h
3 h
4 h
5 h


E5
Hour of day
24
20
16
12
8
4
0
0 30 60 90 120 150 180 210 240 270 300 330 360
Julian Day
1 h
2 h
3 h
4 h
5 h

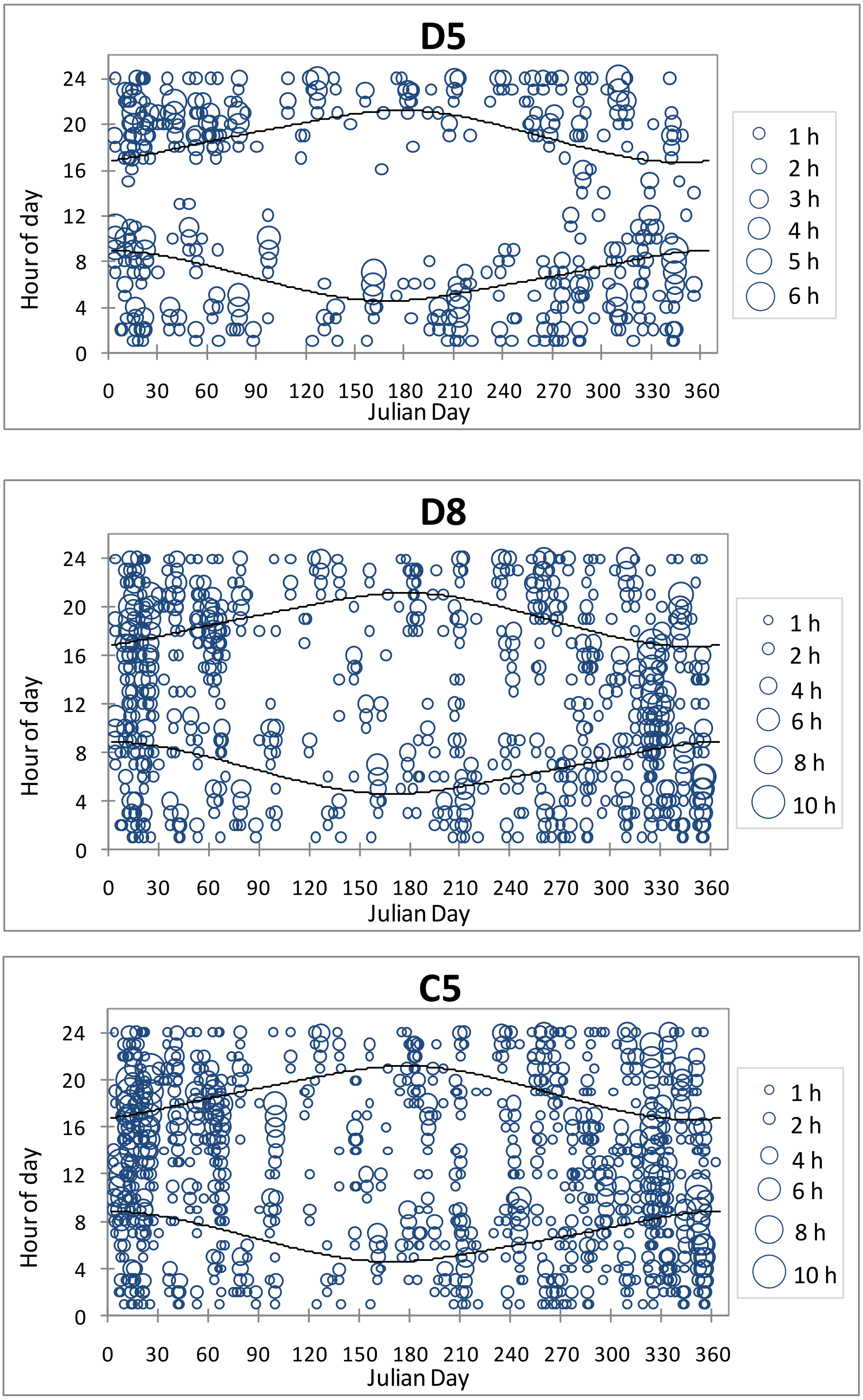


Figure 4 The annual occurrence and duration for various atmospheric conditions in WNW wind direction from 2003 meteorological data. The lines mark the sunrise and sunset of Yorkton (51.22°N, 102.47°W)

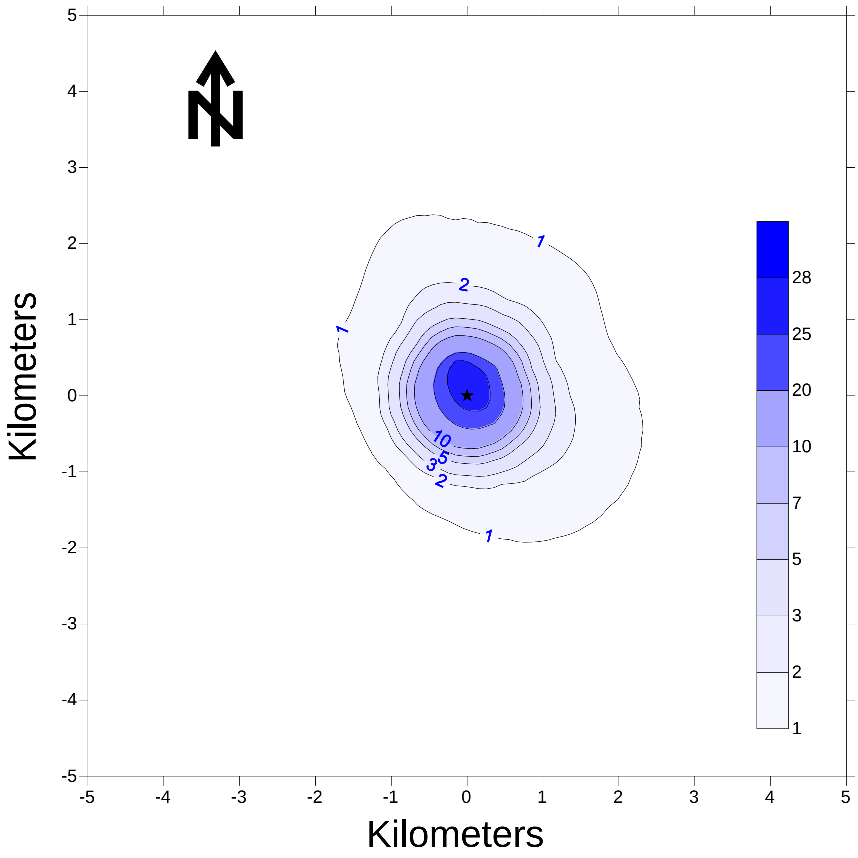


Figure 5. Predicted annual average odor concentration (OU/m^3) in the study area

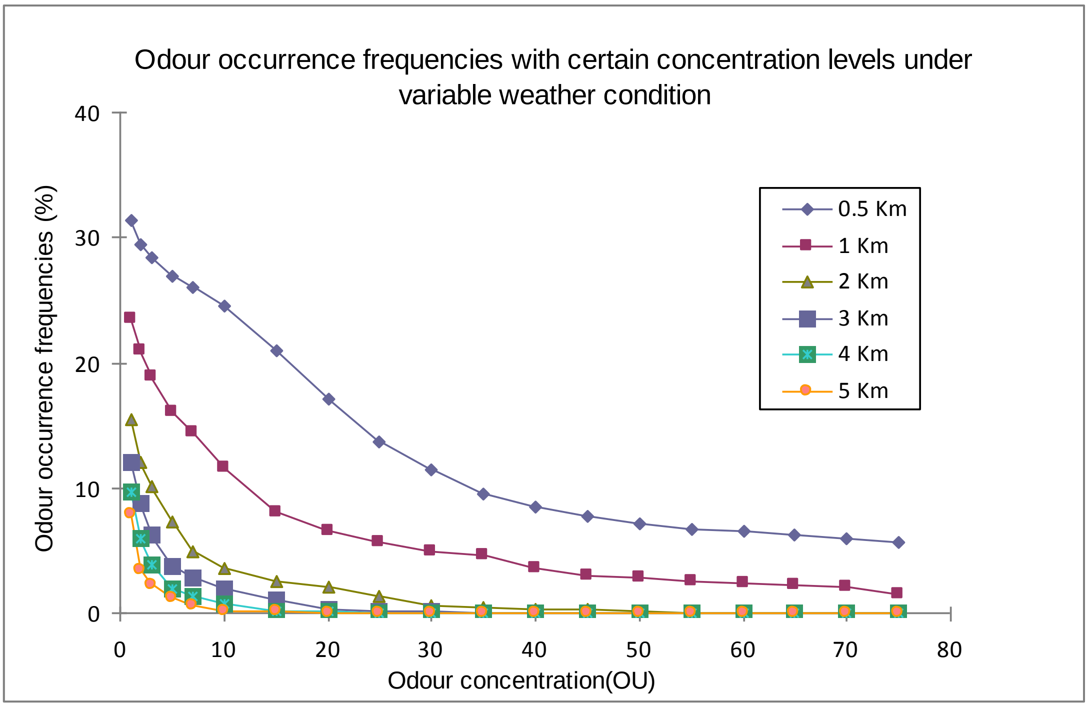


Figure 6 Plot of odor occurrence frequency vs. odor concentration under variable weather conditions

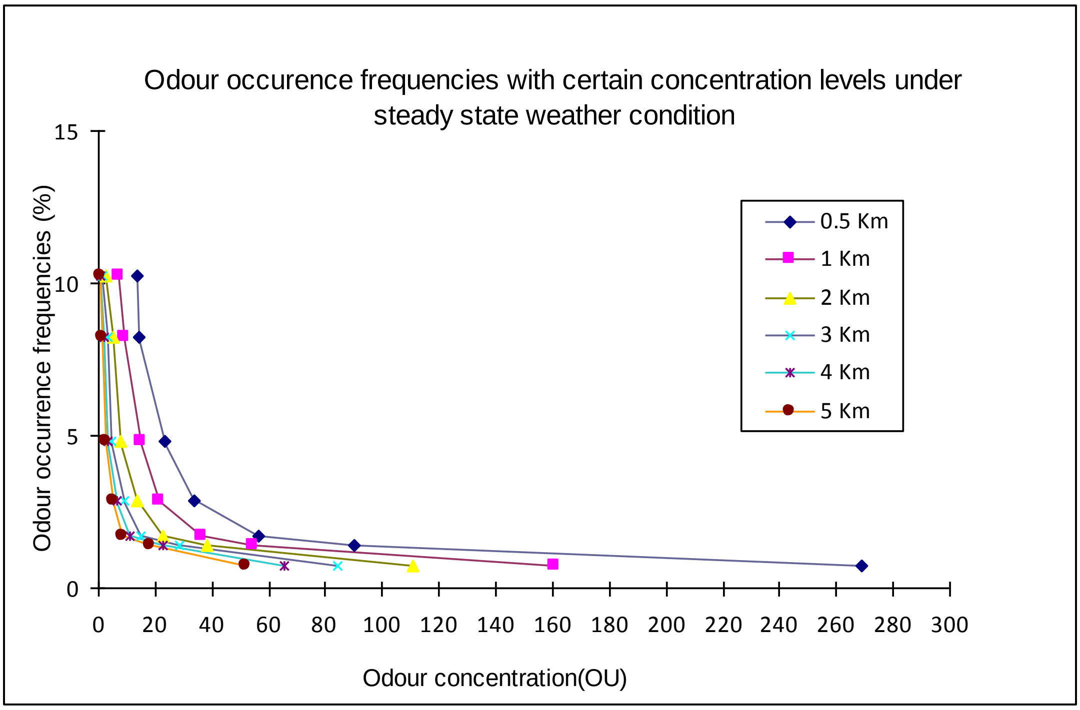


Figure 7 Plot of odor occurrence frequency vs. odor concentration under steady state weather conditions

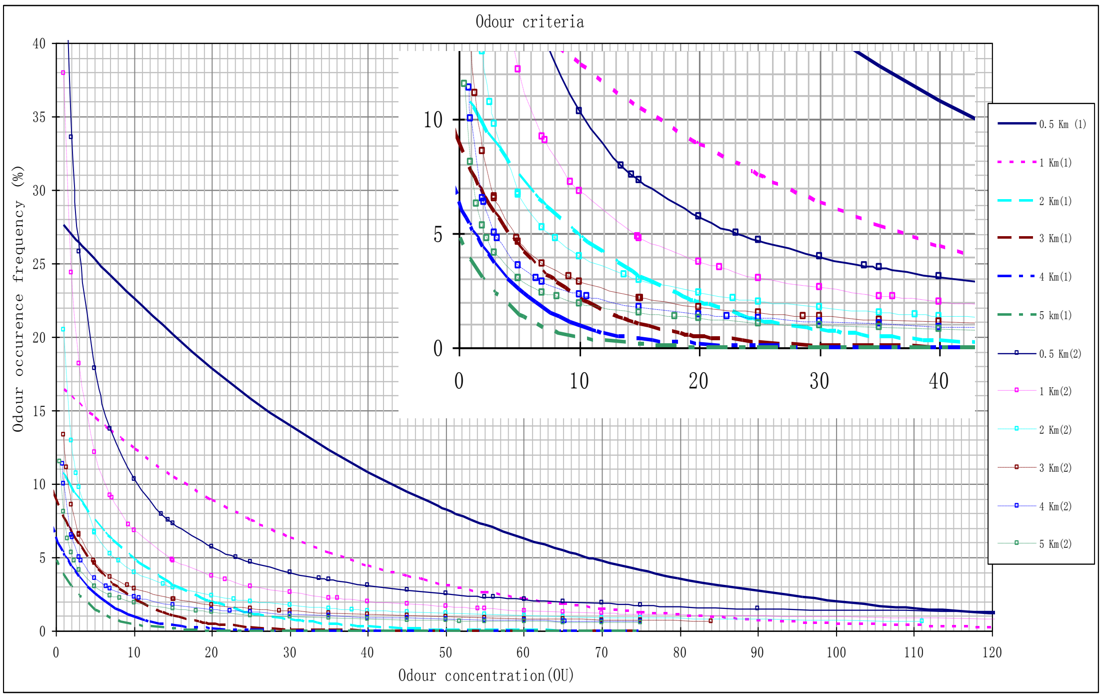


Figure 8 Different odor criteria and setback distances (1: under variable weather condition; 2: under steady-state weather condition)