

# **COMPARISON OF ODOR DISPERSION AT SWINE FACILITIES AND A WASTE PROCESSING CENTER USING A EULERIAN-LAGRANGIAN MODEL**

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## **ABSTRACT**

The purpose of this report is to compare odor dispersion at swine facilities that use alternative waste technologies (as well as a waste processing center) with odor dispersion at two control farms that use conventional lagoon technology. The goal was to determine if these alternative technologies reduce or substantially eliminate the emission of odor that is detectable beyond the boundaries of the parcel or tract of land on which the facility is located. Odor dispersion from these alternative technologies was compared to odor dispersion from two control farms using conventional lagoon technology in order to determine if the alternative technologies were superior to conventional procedures in reducing odors downwind. Twelve sites were evaluated: 1) Stokes farm (standard lagoon technology), 2) Moore farm (standard lagoon technology), along with ten alternative technologies including 3) Ambient Temperature Anaerobic Digester and Greenhouse for Swine Waste Treatment and Bioresource Recovery at Barham Farm, 4) “ReCip” Solids Separation – Reciprocating Wetland, 5) Constructed Wetlands at Howard Farm, 6) “Ekokan” Biofiltration Technology, 7) “BEST” (solids / liquids separation), Biomass Energy Sustainable Technology Site 1 (FAN® + TFS), 8) “BEST” (solids / liquids separation) Biomass Energy Sustainable Technology Site 2 (Filtramat™ + TFS), 9) “ORBIT” High Solids Anaerobic Digester, 10) BELT (LWRFLsite), 11) “Super Soils” Solids Separation / Nitrification-Denitrification / Soluble Phosphorus Removal / Solids Processing System, and 12) BELT (Grinnells lab, NCSU campus).

The trajectory and spatial distribution of odor and odorants downwind of each of the facilities (the alternative technologies and two controls) under two meteorological conditions (daytime and nighttime) were predicted using a Eulerian-Lagrangian model. The model was validated with experimental data. In general, the odor tended not to extend beyond the property boundaries of any of the farms during the daytime (when no spray irrigation of lagoon effluent was occurring ) when the layer of air above the earth’s surface is usually turbulent. However, odor can extend greater distances in the evenings when deep surface cooling through long-wave radiation to space recreates a stable

(nocturnal) boundary layer. The relative effectiveness of the different technologies differed somewhat by time of the day. The reason for the difference in rankings between day and night is a function of multiple factors including: a) the surface area that emits odorants, b) the geometry of the facility (i.e. the distribution of odor sources), and c) the spatial distribution of the relative concentrations of odor intensity.

Modeling was performed using all odor sources at a facility (including the swine houses) in the computation as well as using all odor sources except the swine housing in the computation. These computations show that the swine housing plays a dominant role in odor downwind. Comparison of the dispersions for alternative technologies with control farms suggests that the Barham farm and Super Soils may have an advantage over conventional lagoon technology with regard to odor emissions. However, when the houses are included and the proposed operational definition of “substantially eliminate” odor given in the Appendix is used, odor emissions from these two technology sites exceed the “very weak” rating of “1” on a 0-8 scale. This illustrates the importance of technologies to focus on the waste stream as well as the house emissions to be consistently effective in substantially eliminating odor downwind.

## **TECHNOLOGIES EVALUATED**

Long distance dispersion of odors is a problem in some communities surrounding large-scale swine operations. The purpose of this research was to determine if alternative waste technologies reduce or substantially eliminate the emission of odor that is detectable beyond the boundaries of the parcel or tract of land on which the swine farm is located. Odor dispersion from these alternative technologies was compared to odor dispersion from two control farms using conventional lagoon technology in order to determine if the alternative technologies were superior to conventional procedures in reducing odors downwind. Twelve sites were evaluated: 1) Stokes farm (standard lagoon technology), 2) Moore farm (standard lagoon technology), along with ten alternative technologies including 3) Ambient Temperature Anaerobic Digester and Greenhouse for Swine Waste Treatment and Bioresource Recovery at Barham Farm, 4) “ReCip” Solids Separation – Reciprocating Wetland, 5) Constructed Wetlands at Howard Farm, 6) “Ekokan” Biofiltration Technology, 7) “BEST” (solids / liquids separation), Biomass Energy Sustainable Technology Site 1 (FAN® + TFS), 8) “BEST” (solids / liquids separation) Biomass Energy Sustainable Technology Site 2 (Filtramat™ + TFS), 9) “ORBIT” High Solids Anaerobic Digester, 10) BELT (LWRFLsite), 11) “Super Soils” Solids Separation / Nitrification-Denitrification / Soluble Phosphorus Removal / Solids Processing System, and 12) BELT (Grinnells lab, NCSU campus).

### ***Odor Sources at Control farms***

The control farms were the Stokes farm (Control Farm 1) near Scuffleton, North Carolina which had naturally ventilated houses and the Moore farm (Control Farm 2) which had fan ventilated houses. Measurements at the Stokes farm included edge of houses

downwind, between the houses, house effluent, house effluent pipe, lagoon, downwind of spray field, and at varying distances downwind from the farm. Measurements at the Moore farm included house exhaust fans, between the houses, house effluent, lagoon, downwind of spray field, and at varying distances downwind from the farm.

Land application at control (and alternative technology) farms was not included in the modeling due to the intermittent nature of the process.

### ***Odor Sources at Farms with Alternative Technologies***

#### Ambient Temperature Anaerobic Digester and Greenhouse for Swine Waste Treatment and Bioresource Recovery at Barham Farm

Odor source measurements at the Barham farm included house exhaust fans, between houses, digester effluent lagoon, digester effluent, house effluent, storage pond, biofilter 1 effluent, biofilter 2 effluent, greenhouse effluent, and at varying distances downwind of farm.

#### “ReCip” Solids Separation – Reciprocating Wetland

Odor source measurements at ReCip included edge of houses downwind side, between houses, house tunnel/pit fan, at ReCip cells, house effluent, lagoon 2 (storage pond), separated liquids, separated solids, day tank, and at varying distances downwind of farm.

#### Constructed Wetlands at Howard Farm

Odor source measurements at Howard included house exhaust fans, between houses, solids separator, storage pond, house effluent, pre-settling basin, post-settling basin, settling basin, inner cell influent, inner cell effluent, outer cell influent, outer cell effluent, separated solids, downwind of spray field, at point source of land application of solids, and at varying distances downwind of farm.

#### Ekokan Biofiltration Technology

Odor source measurements at Ekokan included house exhaust fans, between houses, house effluent, solids separator, separated liquids, separated solids, lagoon section 1 (treated water storage), lagoon section 2 (biosolids reservoir), lagoon section 3 (lagoon), equalization tank, biofilter A1 out, biofilter A2 out, biofilter B1 out, biofilter B2 out, biofilter A1 backwash, biofilter A2 backwash, biofilter B1 backwash, biofilter B2 backwash, and at varying distances downwind of farm.

#### BEST (solids / liquids separation), Biomass Energy Sustainable Technology Site 1 (FAN® + TFS)

Odor source measurements at BEST/ Corbett 1 included edge of houses downwind side, between houses, house tunnel/pit fan, reception pit, solids separator, house effluent, separated liquids, separated solids, stabilization pond, TFS effluent, solids thickening effluent, feed tank, and at varying distances downwind of farm.

#### BEST (solids / liquids separation) Biomass Energy Sustainable Technology Site 2 (Filtramat™ + TFS)

Odor source measurements at BEST/ Corbett 4 included edge of houses downwind side, between houses, filtramat feed tank, solids separator, house effluent, separated liquids, separated solids, primary stabilization pond, secondary stabilization pond, TFS effluent, filtramat feed tank, post screen, solids thickening tank effluent, and at varying distances downwind of farm.

#### ORBIT High Solids Anaerobic Digester

Odor source measurements at ORBIT included the feedstock, port 1 digester, port 2 digester, port 3 digester, port 4 digester, digester area, and at varying distances downwind of facility.

#### BELT (LWRFL site)

Odor source measurements at LWRFL included exhaust fan, solids from belt system, urine from belt system, and at varying distances downwind of exhaust fan.

#### Super Soils Solids Separation / Nitrification-Denitrification / Soluble Phosphorus Removal / Solids Processing System

Odor source measurements at Super Soils included edge of houses downwind side, between houses, house tunnel/pit fan, homogenization tank, house effluent, separated liquids, separated solids, homogenization tank, solids separator, lagoon, storage tank, denitrification tank #1, denitrification tank #2, nitrification tank, settling tank, and at varying distances downwind of farm.

#### BELT (Grinnells lab, NCSU campus)

Odor source measurements at Grinnells included exhaust fan, solids from belt system, urine from belt system, and at varying distances downwind of exhaust fan.

### **MODEL USED TO EVALUATE DISPERSIONS FROM SWINE FACILITIES**

The model used here to predict the trajectory of odorous emissions from multiple sources on a swine operation (e.g. housing units, lagoons) has been used previously to predict the long-distance dispersal of seeds by wind (Hsieh et al. 1997; Nathan et al., 2002; Hsieh et al., 2003). This model allows us to utilize the spatial distribution of odor concentrations at multiple emission sources (in steady-state conditions) to predict the spatial distribution of odor (sensations) and odorants (compounds that induce odor sensations) downwind under a variety of meteorological conditions. For this report, dispersion of odor from each swine operation was simulated under two meteorological conditions: 1) during daytime when the boundary layer is usually turbulent due to ground-level heating from solar short wave radiation, and 2) during the evening when deep surface cooling through long-wave radiation to space recreates a stable (nocturnal) boundary layer.

The model is based on stochastic differential equations for turbulent diffusion that utilize a Eulerian-Lagrangian approach (Katul and Albertson, 1998; Hsieh et al., 2003). The methodology was developed with support from the National Science Foundation (NSF-EAR and NSF-DMS), the Department of Energy through the National Institute for Global

Environmental Change (NIGEC), and Terrestrial Carbon Processes (TCP) programs. This model has multiple advantages over standard Gaussian plume models in that it explicitly considers the velocity variances and covariances among its three components, integral time scale (a measure of eddy coherency), and complex boundary conditions (e.g. complex release points, surface boundary conditions).

Data used to predict the trajectory and spatial distribution of odor and odorants downwind from each facility using the model was collected in the following manner. The geographical area containing the odorant sources for each facility was partitioned into 10 meter<sup>2</sup> grids based on aerial photographs and architectural drawings. The relative odorant concentrations present at each grid point that corresponded to an odor source were determined from on site measurements using a trained odor panel. These data were supplemented and corroborated by samples collected in the field and evaluated in the laboratory by the trained panel. Panelists determined the intensity of the odor at each of the multiple odor sources on each farm using two methods: 1) 9 point rating scale (0 = none at all, 1 = very weak, 2 = weak, 3 = moderately weak, 4 = moderate, 5 = moderately strong, 6 = strong, 7 = very strong, 8 = maximal) and 2) using an olfactometer to determine the odor threshold.

In order to perform the dispersion modeling for odor, it is necessary to determine a mathematical relationship between odor perception and measurable concentration of odorants. The model utilizes hypothetical “odorous air parcels” to predict downwind odor intensity using an equation that was confirmed by experimental downwind odor measurements in the field during daytime measurements using a worst case scenario (without considering spraying). Odorous air parcels are used for modeling rather than sensations themselves because it is the physical odorants rather than sensations that are dispersed. For the examples illustrated in this report, we developed an equation to represent the relationship between perceived odor intensity determined in the field by a trained odor panel and “odorous air parcels” released by the mathematical model at each 10 meter<sup>2</sup> grid point that decay over distance:

$$y = 33.546 e^x$$

where x is the odor intensity on a scale from 0 to 8 (given above) and y is the number of “particles” released. When odor is maximal (e.g. rated 8 on the scale above) at a specific 10 meter<sup>2</sup> grid point, the number of odorous air parcels released will be 100,000. When odor is rated moderate strong (e.g. rated 5), only 4,978 odorous air parcels will be released. When no odor is perceived at a specific 10 meter<sup>2</sup> grid point (e.g. rated 0), no odorous air parcels will be released from the 10 meter<sup>2</sup> grid point. After the dispersion modeling was performed and it was time to convert parcel numbers back into intensity, any number under 34 was considered to be “0” or no odor. This was to avoid difficulties in introducing negative numbers that arise due to logarithmic equations. The model predicts the decay over distance when odorous air parcels (related monotonically to human odor intensity) are released from each of the 10 meter<sup>2</sup> grid points of an odorous facility. The model is then reconfirmed by experimental field measurements.

## RESULTS

The dispersion plots derived from the odor dispersion modeling are shown in Figures 1 to 20 below; they illustrate the predicted odor intensity for each facility shown during the day and at night utilizing human odor intensity measurements. Human threshold data and instrumental measurements provided similar dispersion plots as those for human intensity rating measurements. The plots utilize the logarithmic values of the number of odorous air parcels. That is, the number of odorous air parcels that reach any grid location downwind on dispersion were plotted because odor intensity is exponentially related to odorant concentration.

After modeling, the farms were then compared using the following procedure. First, the mean of the non-zero elements of the grid points at 200 meters from the source of odor closest to the downwind property line was determined for 4 directions (east, north, south, and west). For “North” (i.e. with a wind blowing to the north), the average was calculated at 200 meters from the northernmost odor source. In order to remove directional dependence in rankings, the average in each of the 4 directions was calculated. The farms were then compared with respect to mean odor intensity at 200 meters from the edge of the last odorous source in the direction of the wind for both day and night. The farms were also modeled with the houses removed and ranked under daytime conditions using the same model. This procedure was repeated at 400 meters. The results are shown in Table 1 below. Overall, the predicted odor dispersion was found to be greater at nighttime than during daytime at all farms which is consistent with field reports from individuals living nearby.

The reason for the difference in rankings between day and night is a function of multiple factors: a) the surface area that emits odorants; b) the geometry of the facility (i.e. the distribution of odor sources); and c) the spatial distribution of the relative concentrations of odor intensity. A farm with odor sources that align extensively in the direction of the wind will lead to higher odor intensities downwind at night than during the day because the most distant odor sources will reach further due to reduced mixing. Conversely, this same farm during the day will allow for odor dispersion within its own boundaries. If there are extreme differences in the relative intensities of the odor sources on a farm, the most intense source(s) should not be located near the boundary of the farm in the predominant wind direction. If there is no predominant wind direction, the most potent odor source should be located at the center, surrounded by weaker sources.

Table 1. Environmentally Superior Technology candidate projects demonstrated performance for odor reduction (Phase 1 Technology Determinations). Values shown are approximate average odor intensity ratings at 200 and 400 meters from the odor source during the day and night where : 0=none at all; 1=very weak; 2=weak; 3=moderately weak; 4=moderate; 5=moderately strong; 6=strong; 7=very strong; and 8=maximal. The first value represents whole farm odor emissions / the second value represents partitioned emissions from the technology treatment components targeted in the experiment. NA means not available.

<b>Technology</b>	<b>Day values 200m</b>	<b>Night values 200m</b>	<b>Day values 400m</b>	<b>Night values 400m</b>
Conventional Technology (Stokes)	1.0 / 0.6	4 / NA	0 / 0	3.1 / NA
Conventional Technology (Moore Bros.)	1.3 / 0.7	2.2 / NA	0 / 0	1.4 / NA
Ambient Temperature Anaerobic Digester and Greenhouse for Swine Waste Treatment and Bioresource Recovery at Barham Farm	1.3 / 0.2	2.2 / 0	0.04 / 0	1.4 / 0
“ReCip” Solids Separation – Reciprocating Wetland	0.1 / 0	2.8 / 0	0 / 0	2.0 / 0
Constructed Wetlands at Howard Farm	0.8 / 0.7	3.9 / NA	0 / 0	3.1 / NA
“Ekokan” Biofiltration Technology	2.0 / 1.6	3.0 / 2.7	0.8 / 0.4	2.1 / 1.8
“BEST” (solids / liquids separation) Biomass Energy Sustainable Technology Site 1 (FAN® + TFS)	0.9 / 0.6	1.9 / 1.5	0.05 / 0	1.1 / 0.7
“BEST” (solids / liquids separation) Biomass Energy Sustainable Technology Site 2 (Filtramat™ + TFS)	0.5 / 0.3	1.3 / 1.0	0 / 0	0.6 / 0.3
“ORBIT” High Solids Anaerobic Digester	0	0	0	0
BELT (LWRFLsite)	0	0	0	0
“Super Soils” Solids Separation / Nitrification-Denitrification / Soluble Phosphorus Removal / Solids Processing System	1.1 / 0	2.1 / 0	0.1 / 0	1.3 / 0
BELT (Grinnells lab, NCSU campus)	0	0	0	0

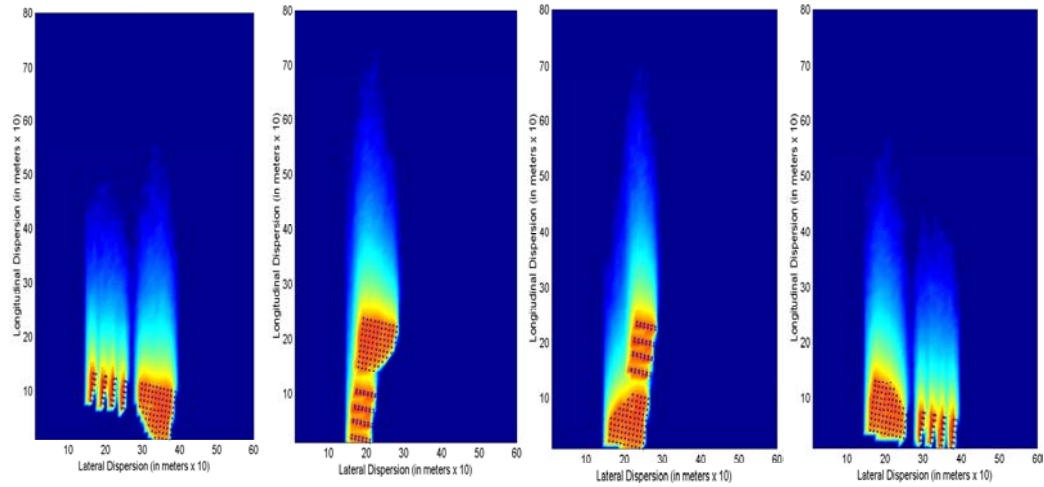


Figure 1a: Conventional Technology (Control Farm 1, Stokes): Daytime dispersion (East, North, South, West). Dots indicate odor release points on the grid.

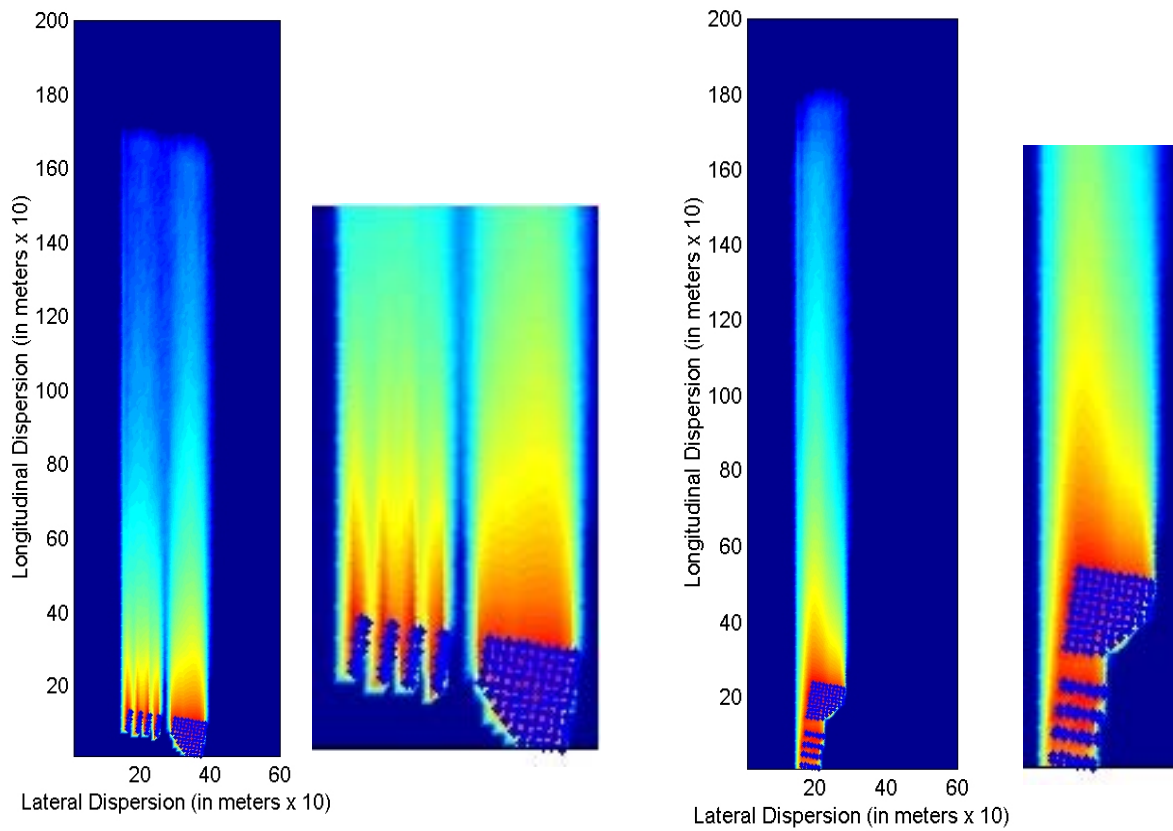


Figure 1b: Conventional Technology (Control Farm 1): Nighttime dispersion (East, North, with magnification). Dots indicate odor release points on the grid.



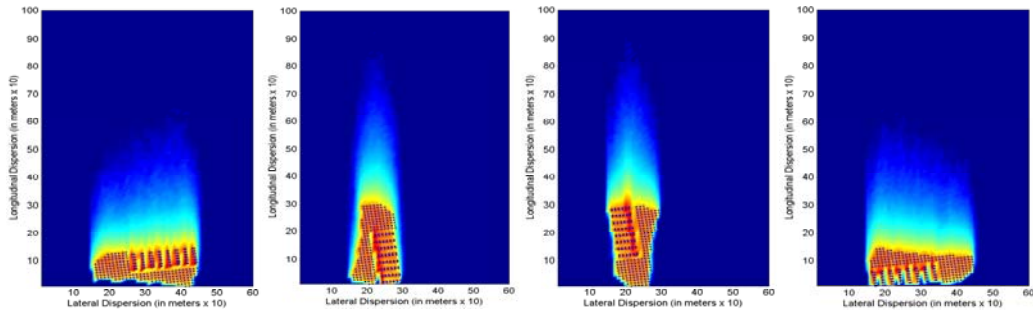


Figure 2a: Conventional Technology (Control Farm 2): Daytime dispersion (East, North, South, West). Dots indicate odor release points on the grid.

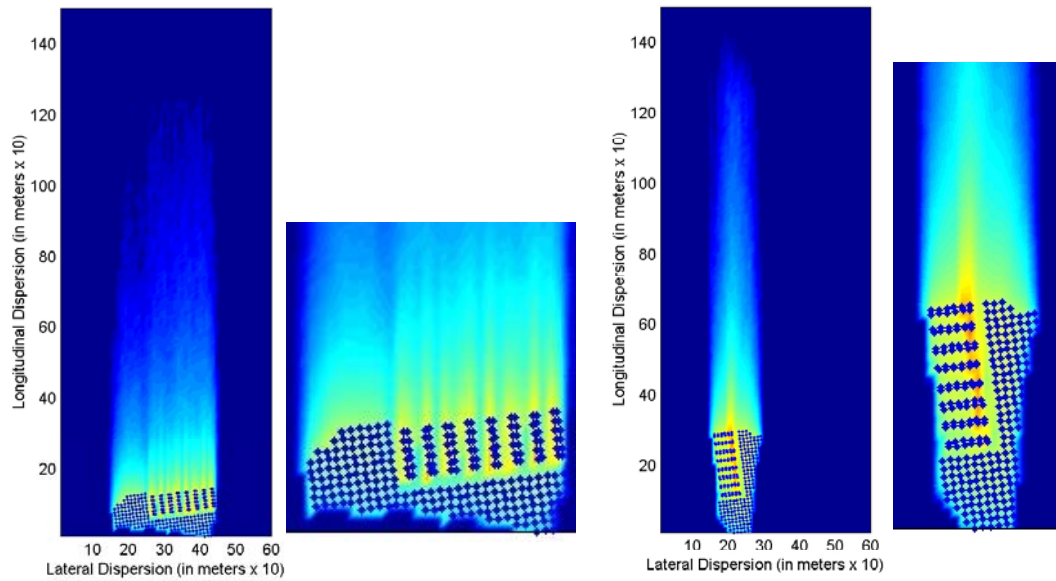


Figure 2b: Conventional Technology (Control Farm 2): Nighttime dispersion (East, North, with magnification). Dots indicate odor release points on the grid.

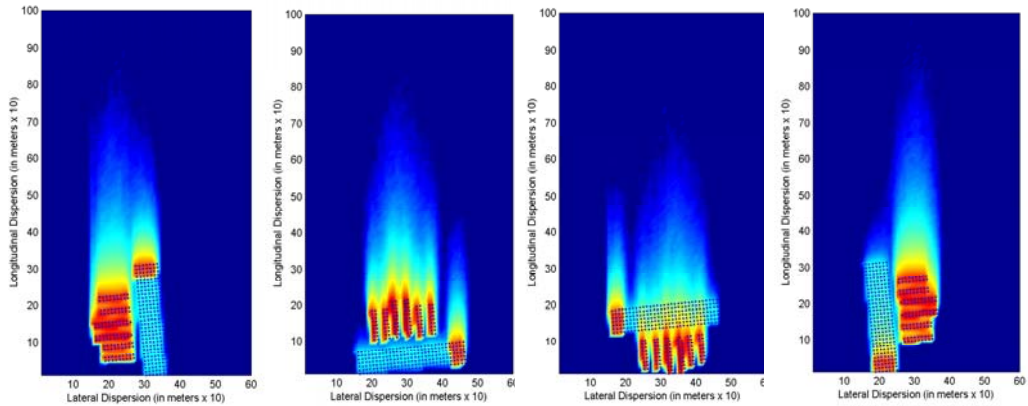


Figure 3a: Ambient temperature anaerobic digester and green house for swine waste treatment and bioresource recovery along with swine houses at Barham Farm. Daytime dispersion (East, North, South, West). Dots indicate odor release points on the grid. See Figure 3c for odor intensity scale.

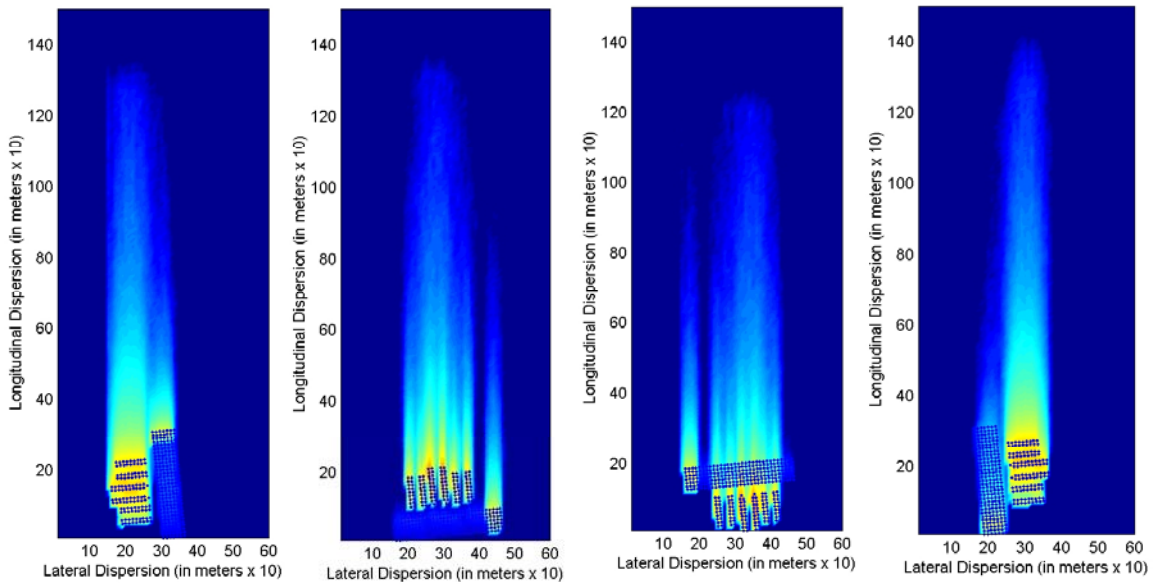


Figure 3b: Ambient temperature anaerobic digester and green house for swine waste treatment and bioresource recovery and swine houses at Barham Farm. Nighttime dispersion (East, North, South, West). Dots indicate odor release points on the grid. See Figure 3c for odor intensity scale.

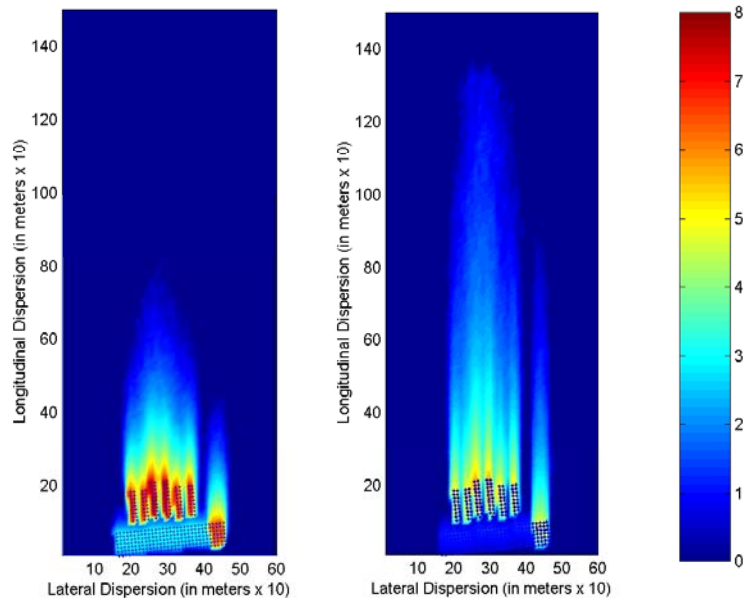


Figure 3c: Ambient temperature anaerobic digester and green house for swine waste treatment and biorecovery and swine houses at Barham Farm. Comparison of Daytime and Nighttime dispersion (North). Dots indicate odor release points on the grid.

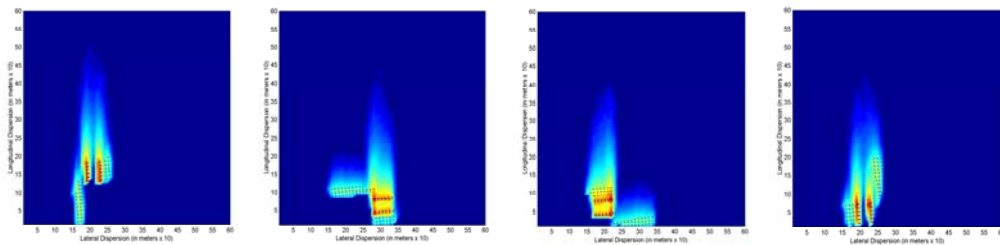


Figure 4a: ReCip solids separation/reciprocating water technology system along with swine houses: Daytime dispersion (East, North, South, West). Dots indicate odor release points on the grid.

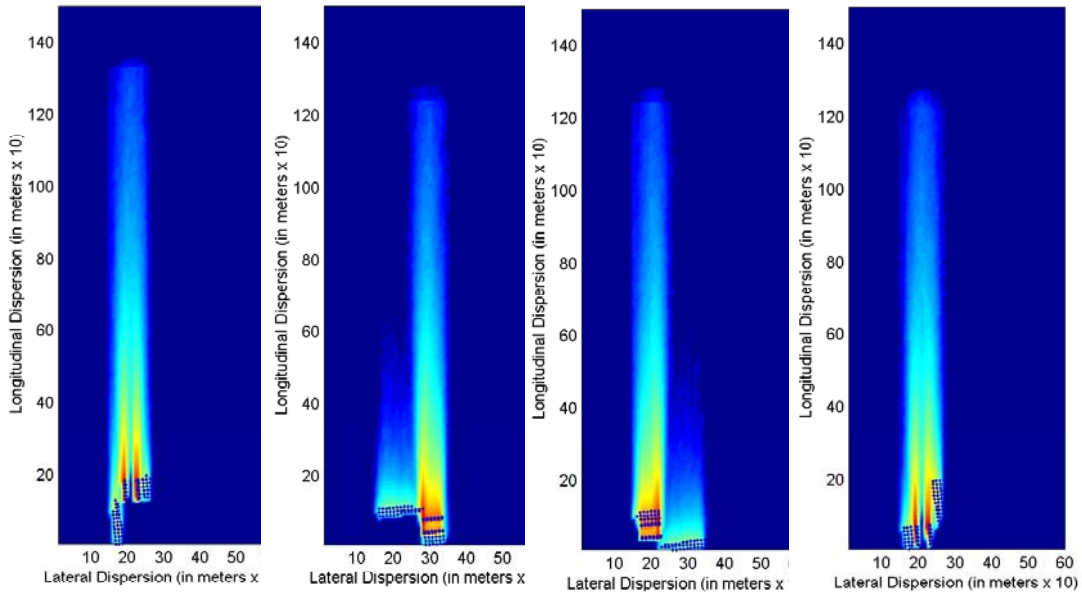


Figure 4b: ReCip solids separation/reciprocating water technology system along with swine houses: Nighttime dispersion (East, North, South, West). Dots indicate odor release points on the grid.

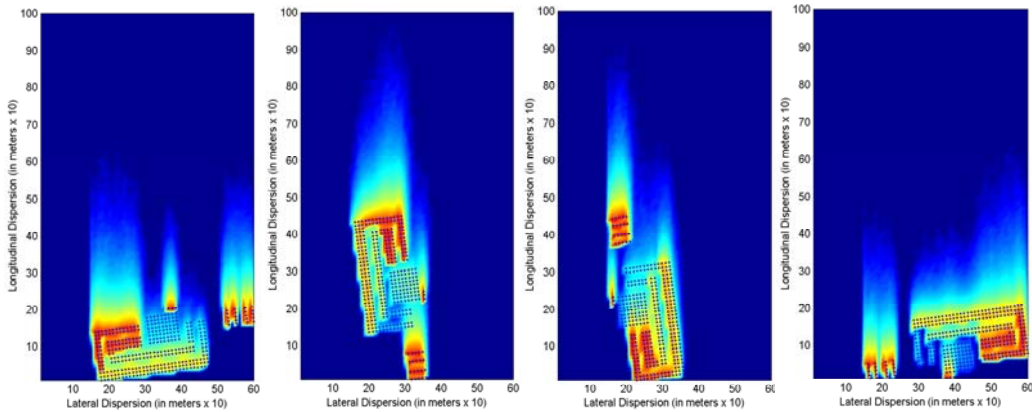


Figure 5a: Howard farm with solids separation/constructed wetlands system: Daytime dispersion (East, North, South, West). Dots indicate odor release points on the grid.

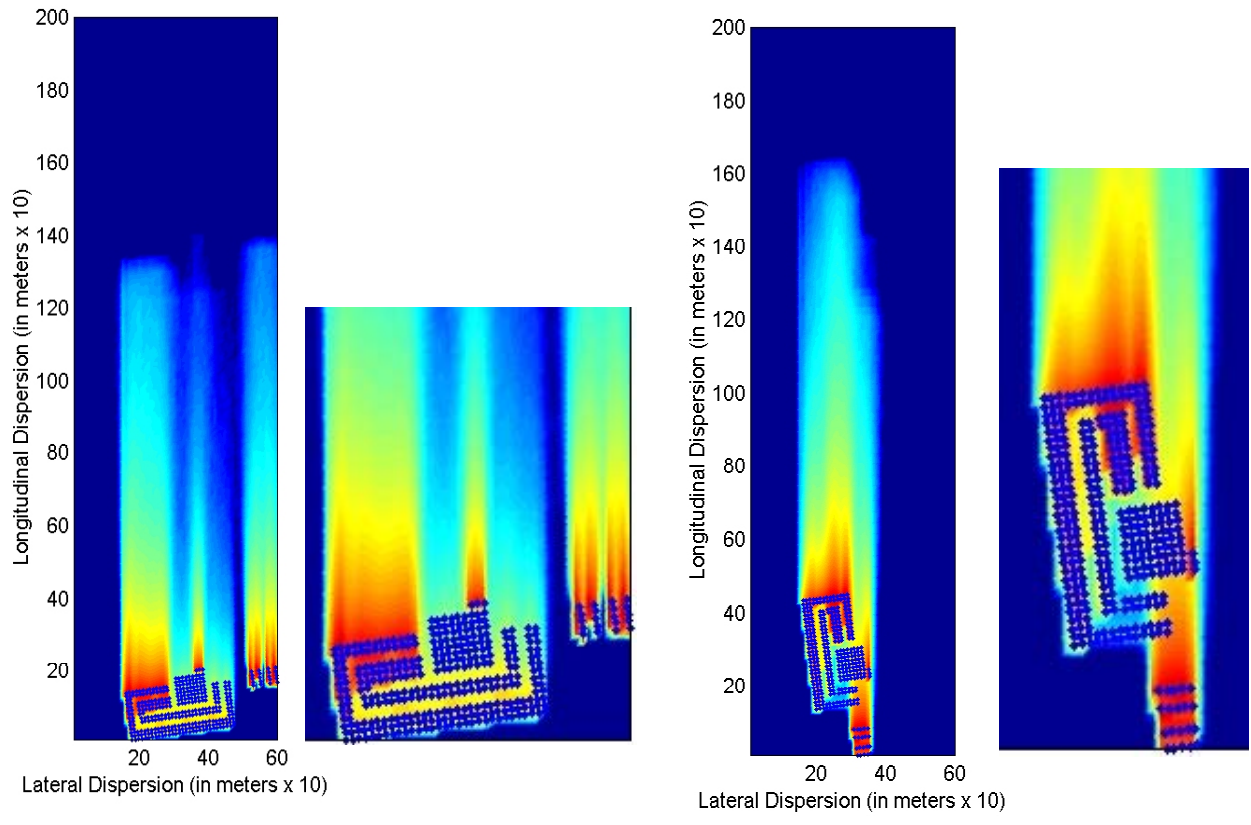


Figure 5b: Howard farm with solids separation/constructed wetlands system: Nighttime dispersion (East, North with magnification). Dots indicate odor release points on the grid.

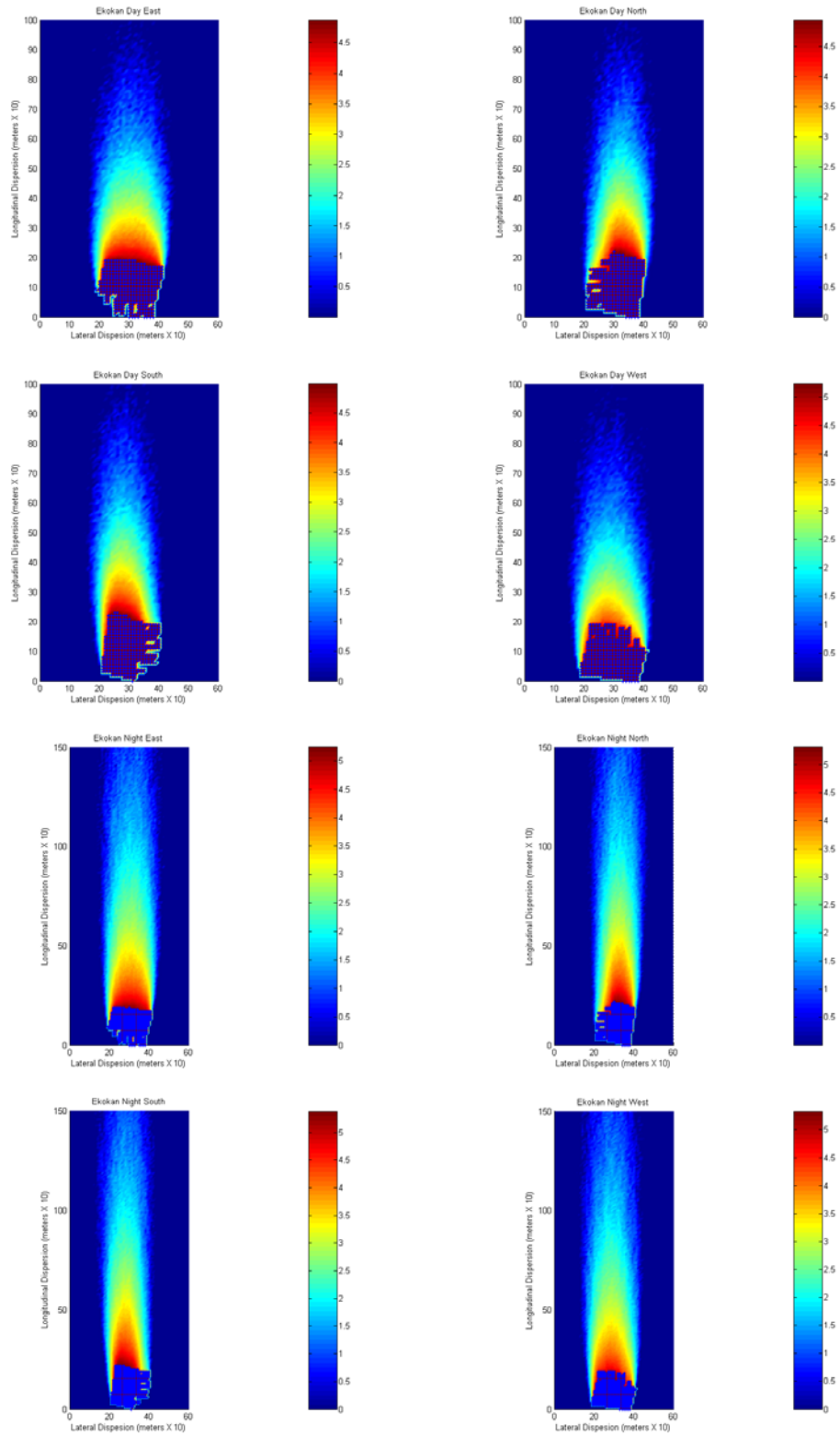


Figure 6: Ekokan: Daytime and nighttime dispersions. Dots indicate odor release points on the grid.

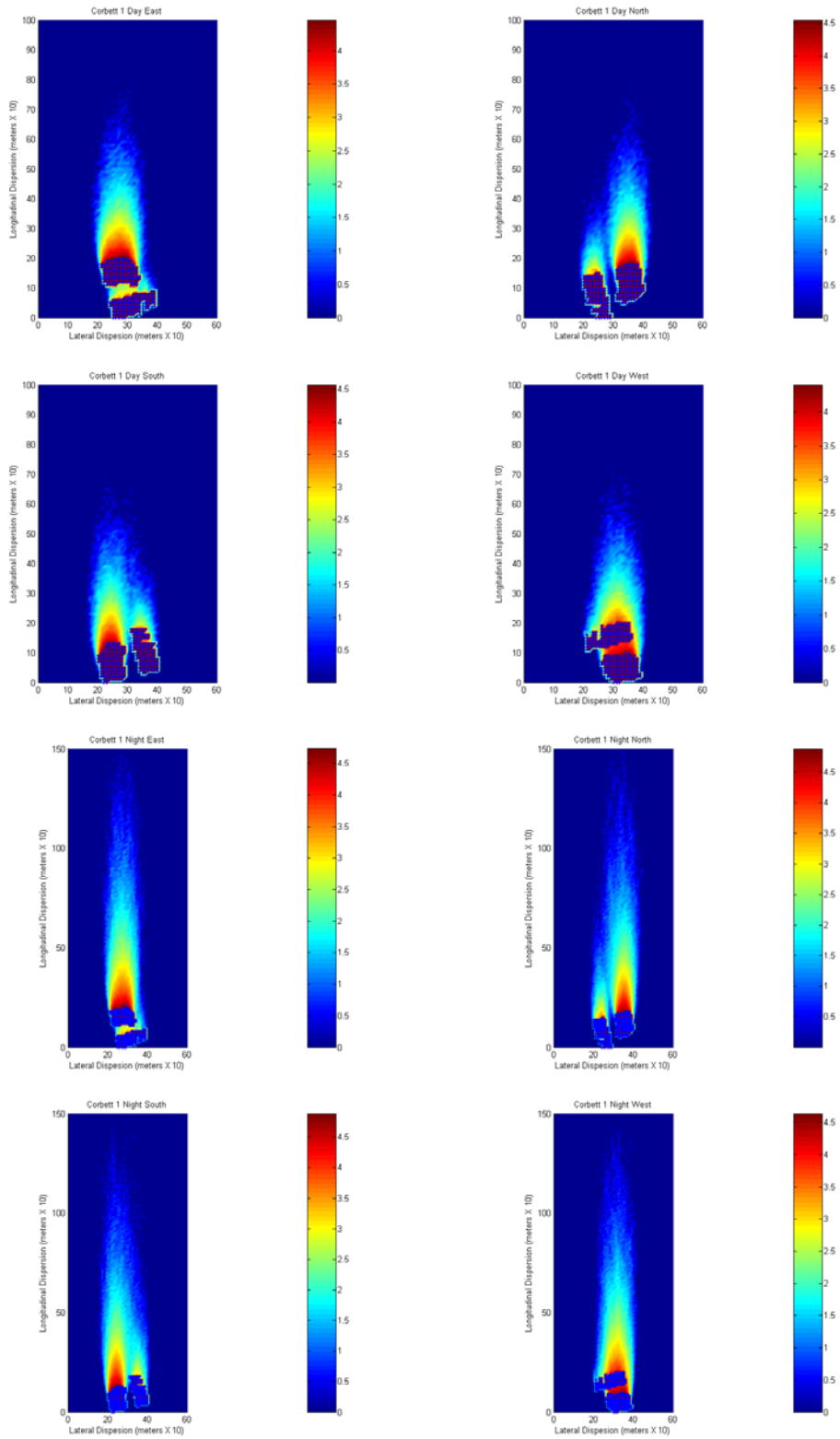


Figure 7: Best Site 1/Corbett 1: Daytime and nighttime dispersions. Dots indicate odor release points on the grid.

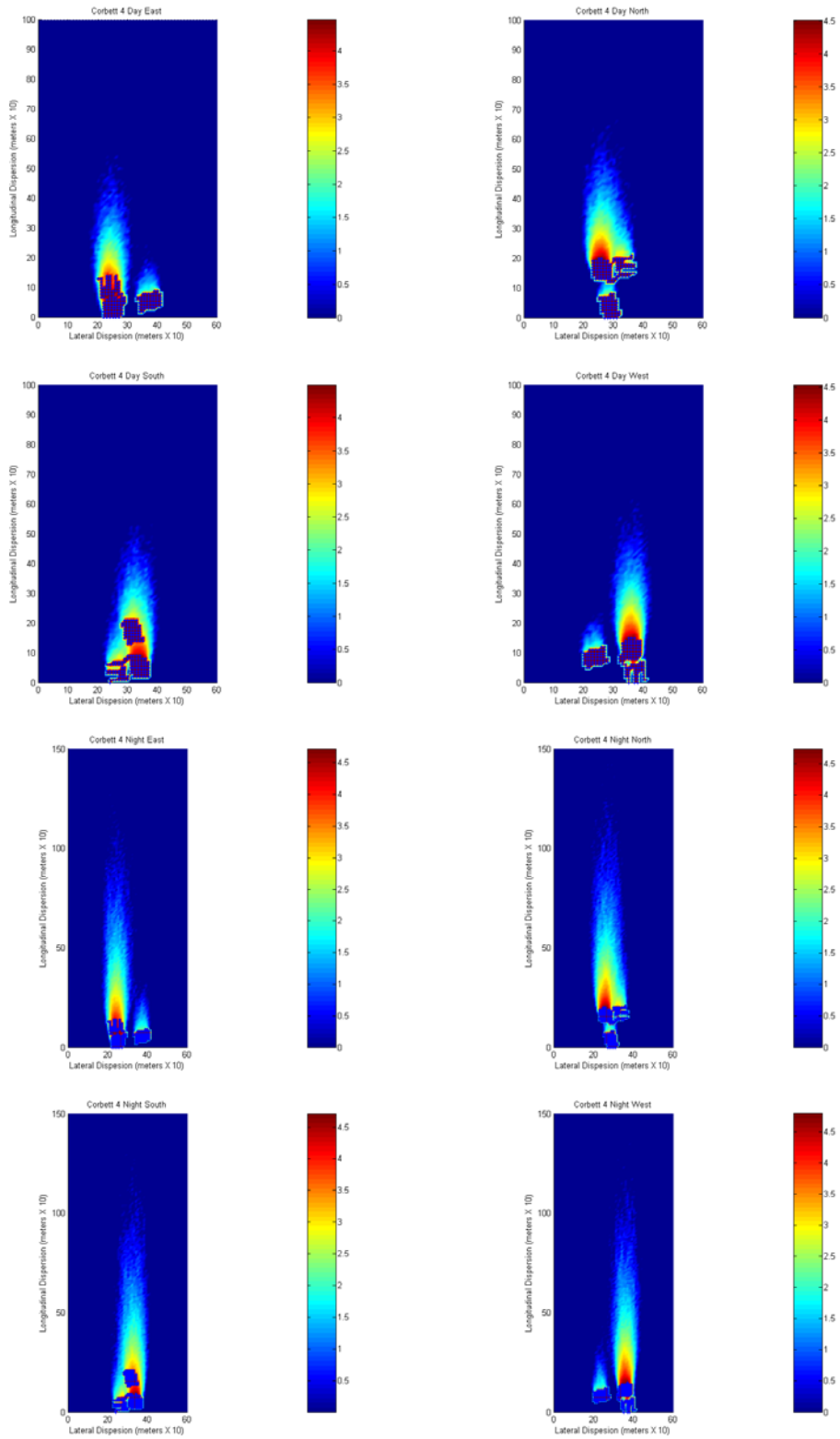


Figure 8: Best Site 2/Corbett 4: Daytime and nighttime dispersions. Dots indicate odor release points on the grid.



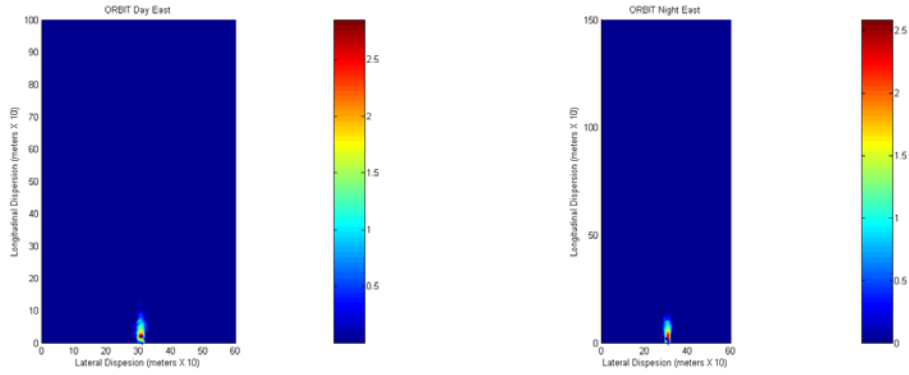


Figure 9: ORBIT high solids anaerobic digester: Daytime and nighttime dispersions. Dots indicate odor release points on the grid.

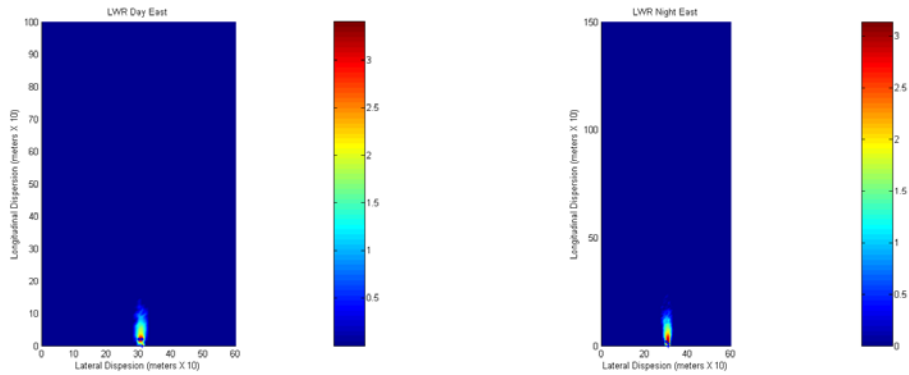


Figure 10: Belt (LWRFL): Daytime and nighttime dispersions. Dots indicate odor release points on the grid.

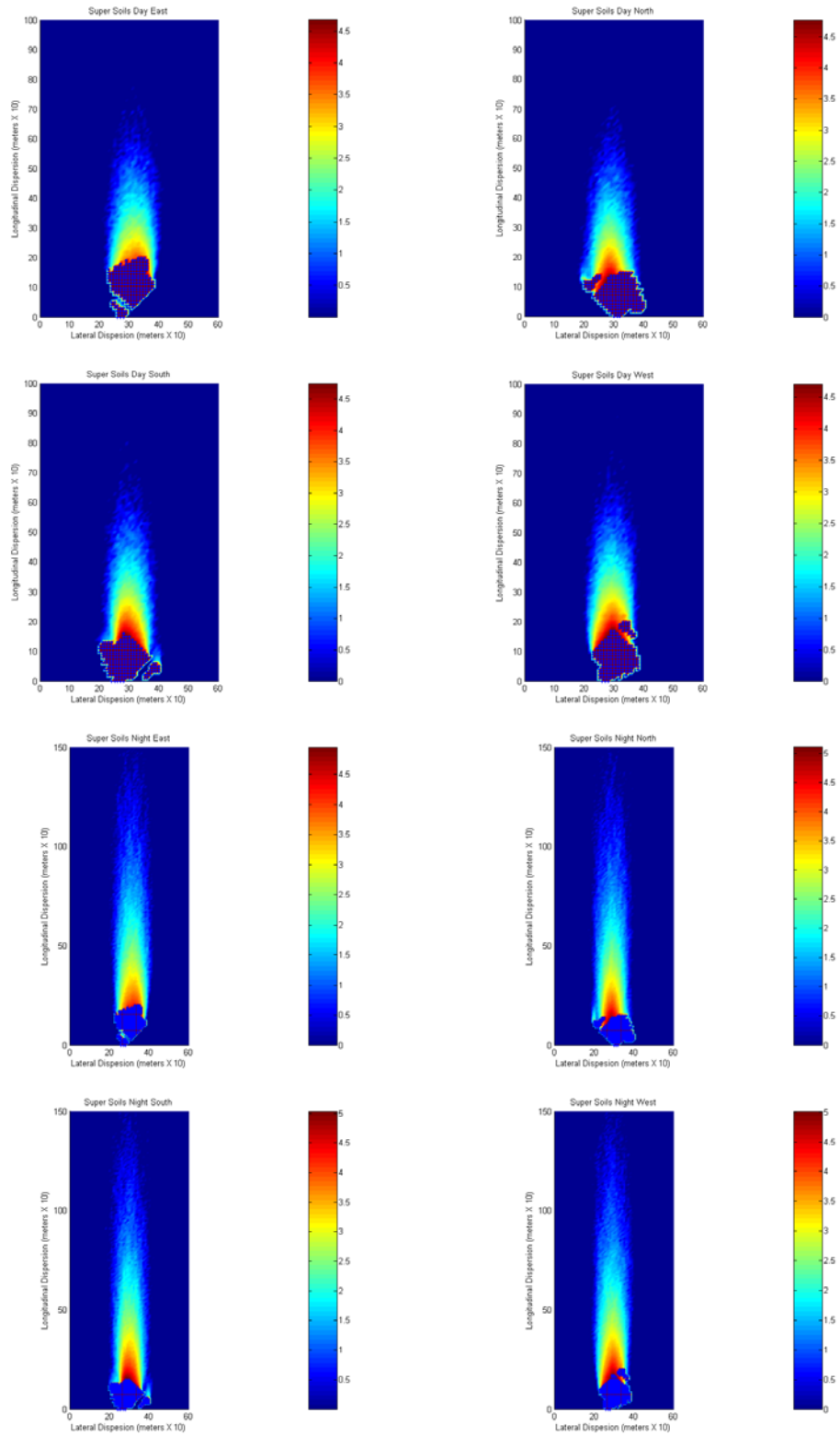


Figure 11: Super Soils: Daytime and nighttime dispersions. Dots indicate odor release points on the grid.

The dispersion from Grinnells, like ORBIT and the Belt system at LWRFL, arises from a point source that does not reach 200 meters.

Odor dispersion modeling was also performed without the houses at certain facilities. These dispersions are shown below.

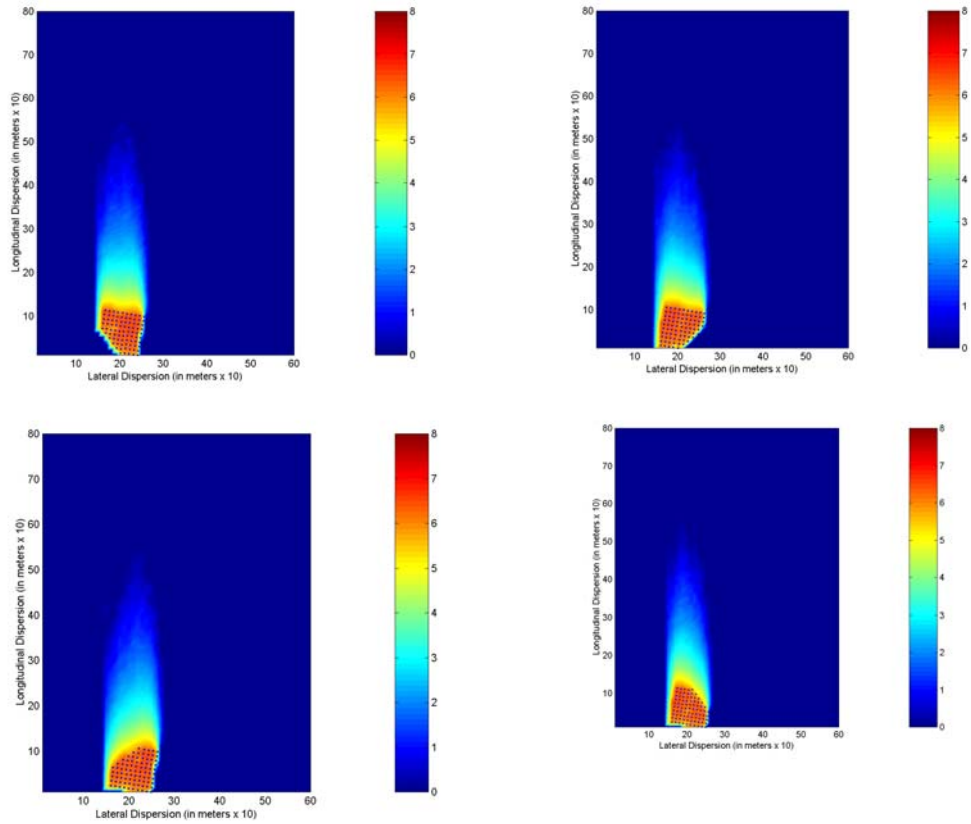


Figure 12: Stokes without houses during daytime. Note that the odor is greatly reduced when the houses are removed from the modeling.

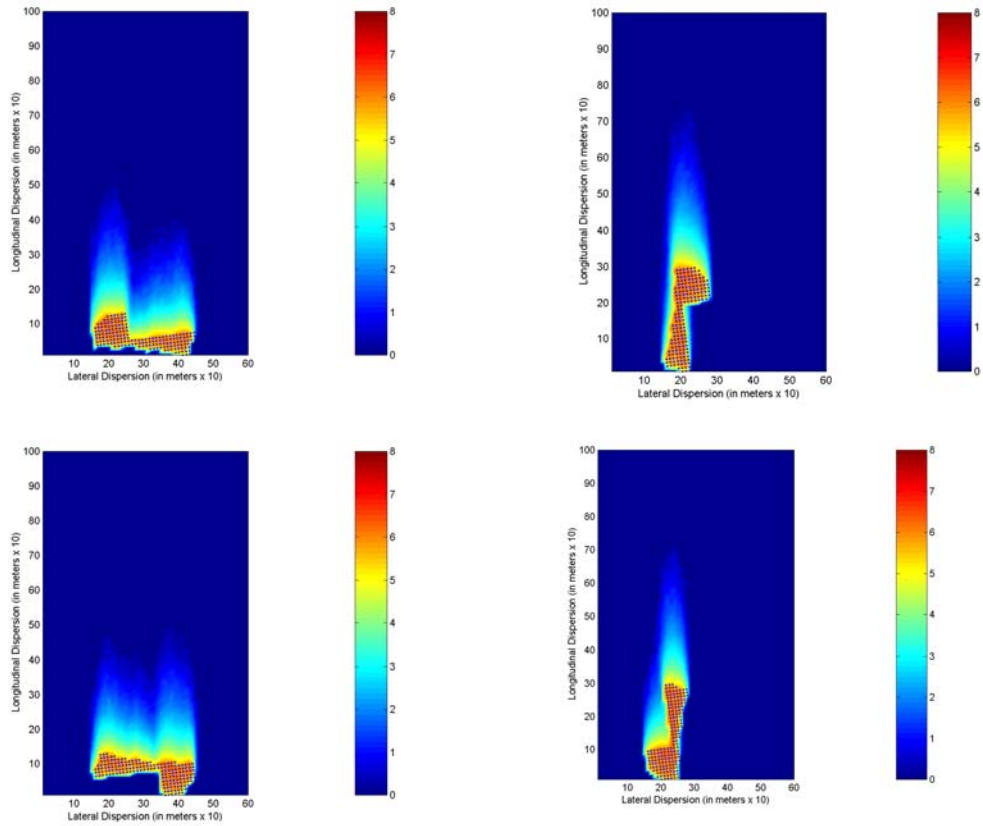


Figure 13: Moore without houses during daytime. Note that the odor is greatly reduced when the houses are removed from the modeling.

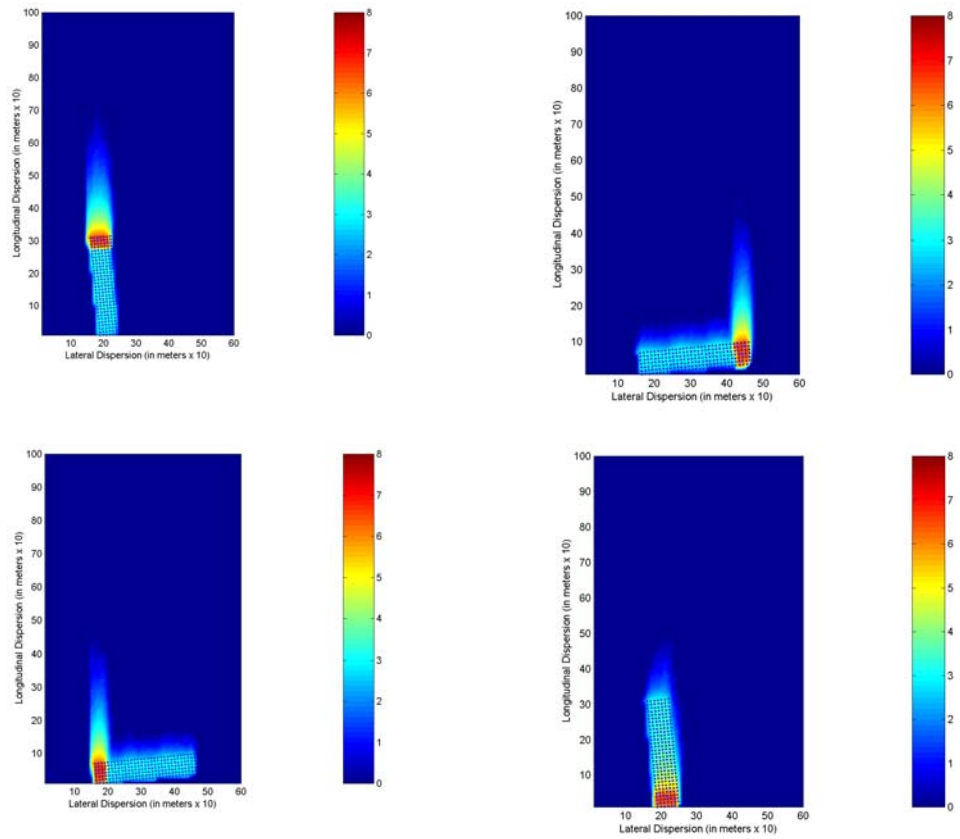


Figure 14: Barham without the houses during daytime. Note that the odor is greatly reduced when the houses are removed from the modeling.

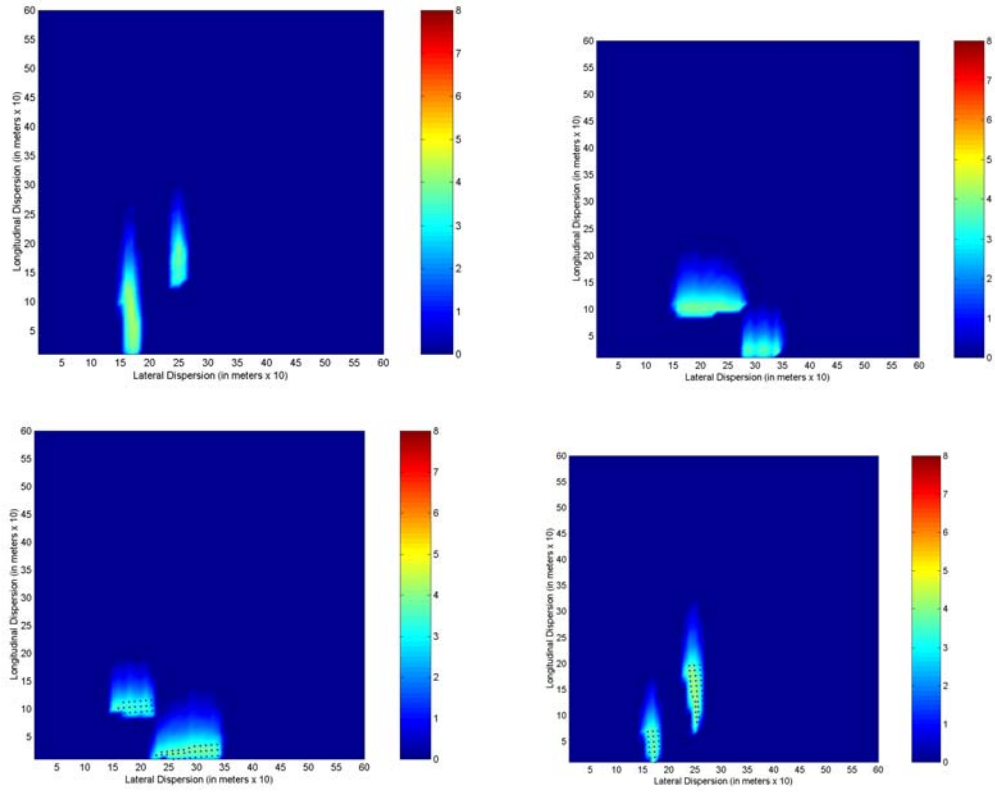


Figure 15: ReCip without houses during daytime. Note that the odor is greatly reduced when the houses are removed from the modeling.

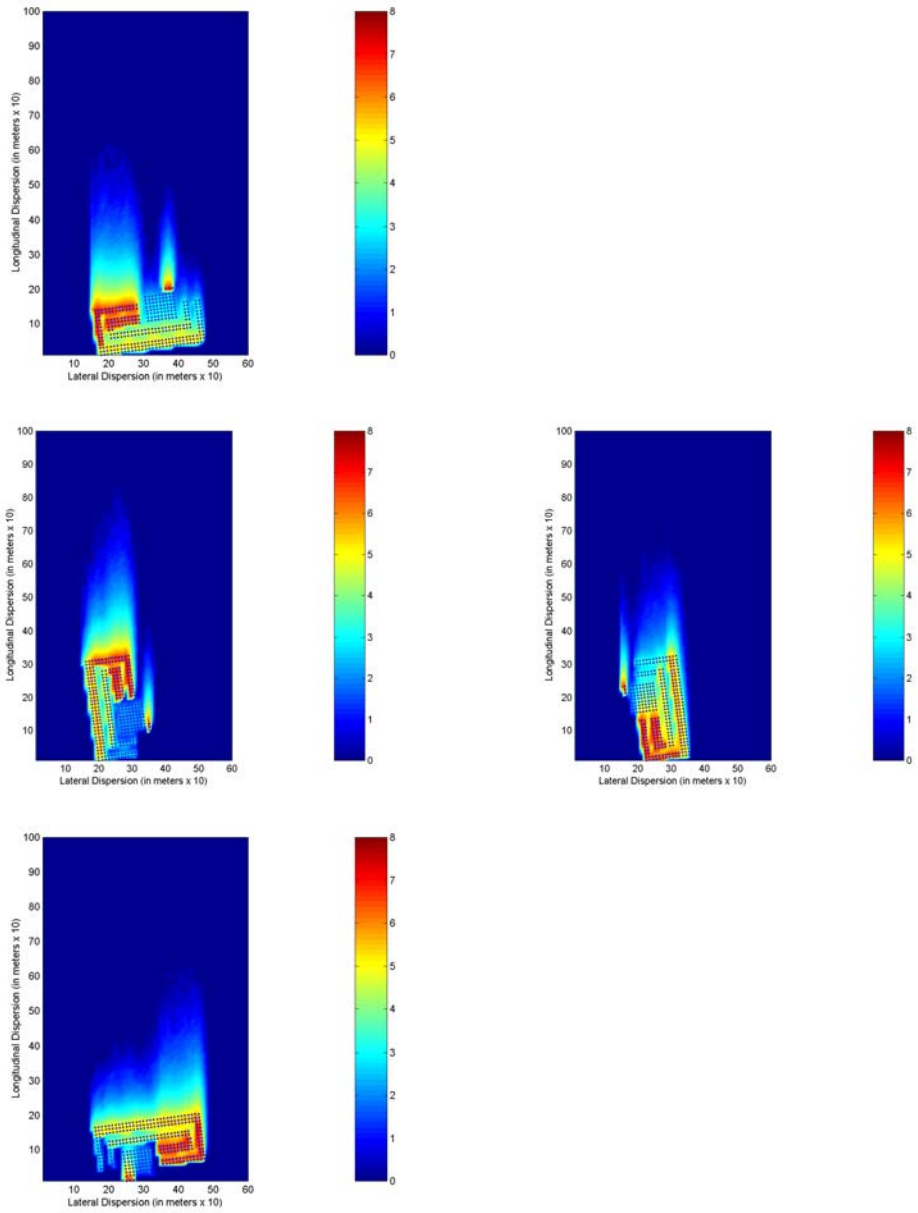


Figure 16: Wetlands without houses during daytime.



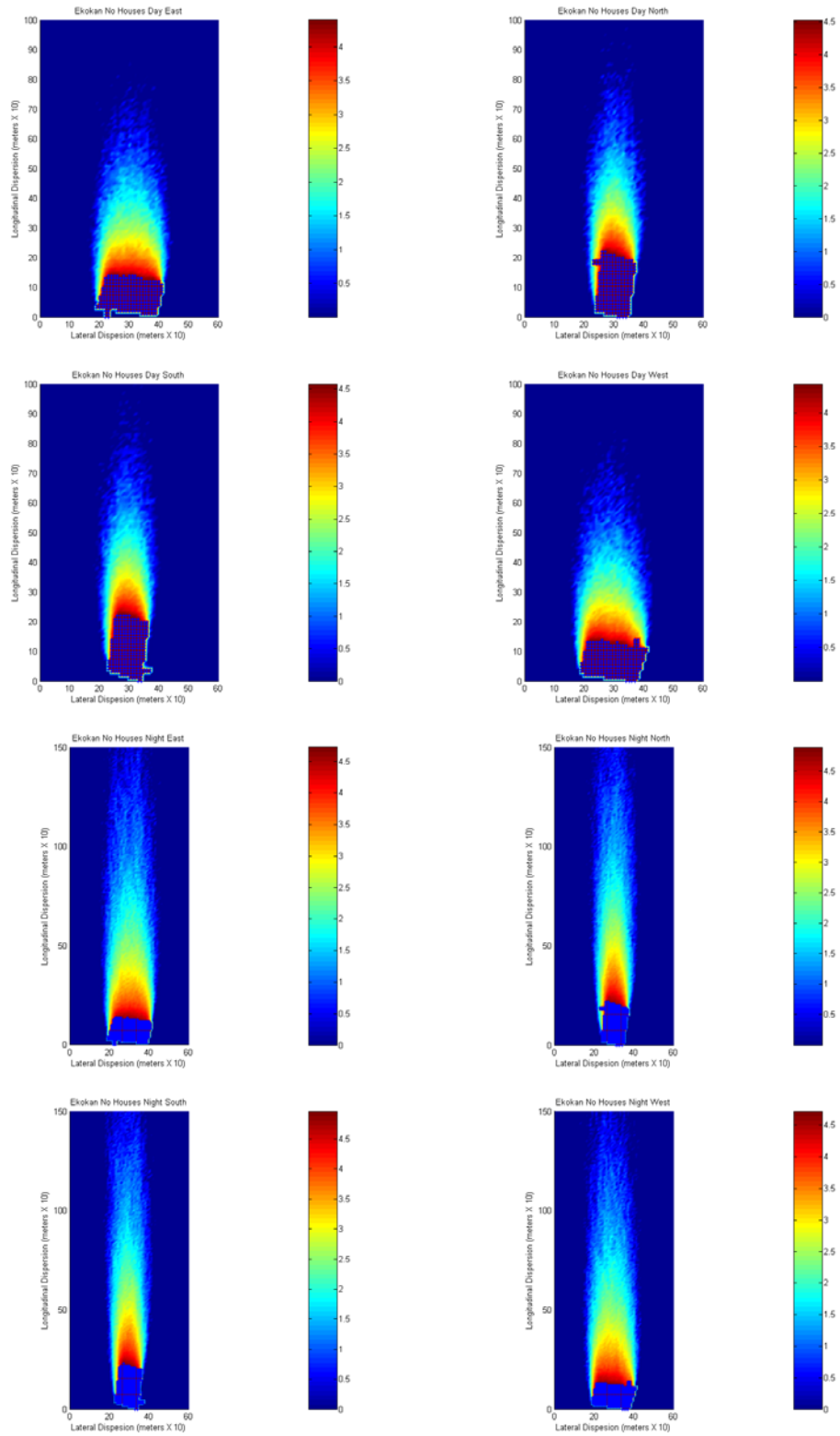


Figure 17: Ekokan without houses: Daytime and nighttime dispersions. Dots indicate odor release points on the grid.

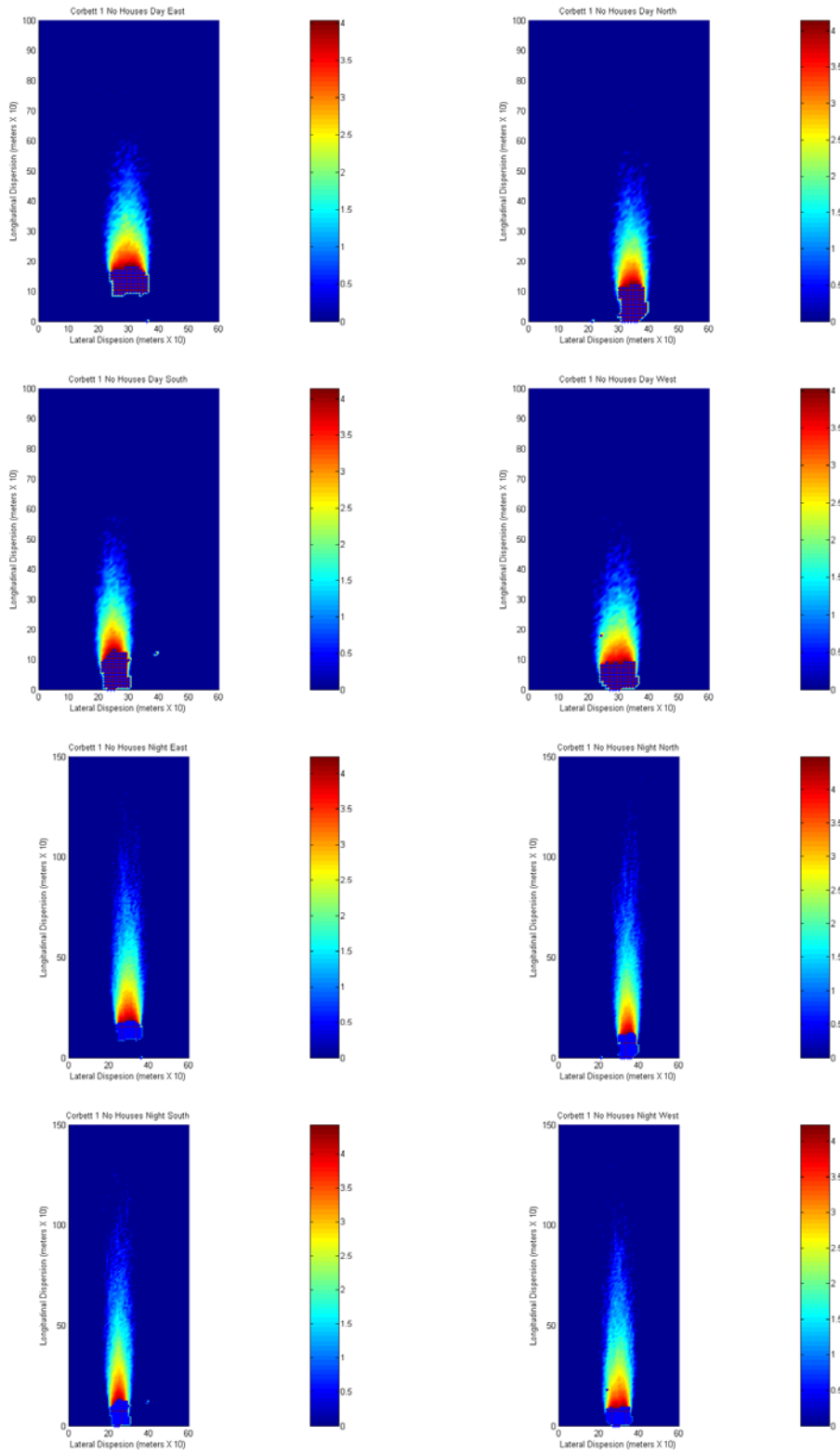


Figure 18: Best Site 1/Corbett 1 without houses: Daytime and nighttime dispersions. Dots indicate odor release points on the grid.

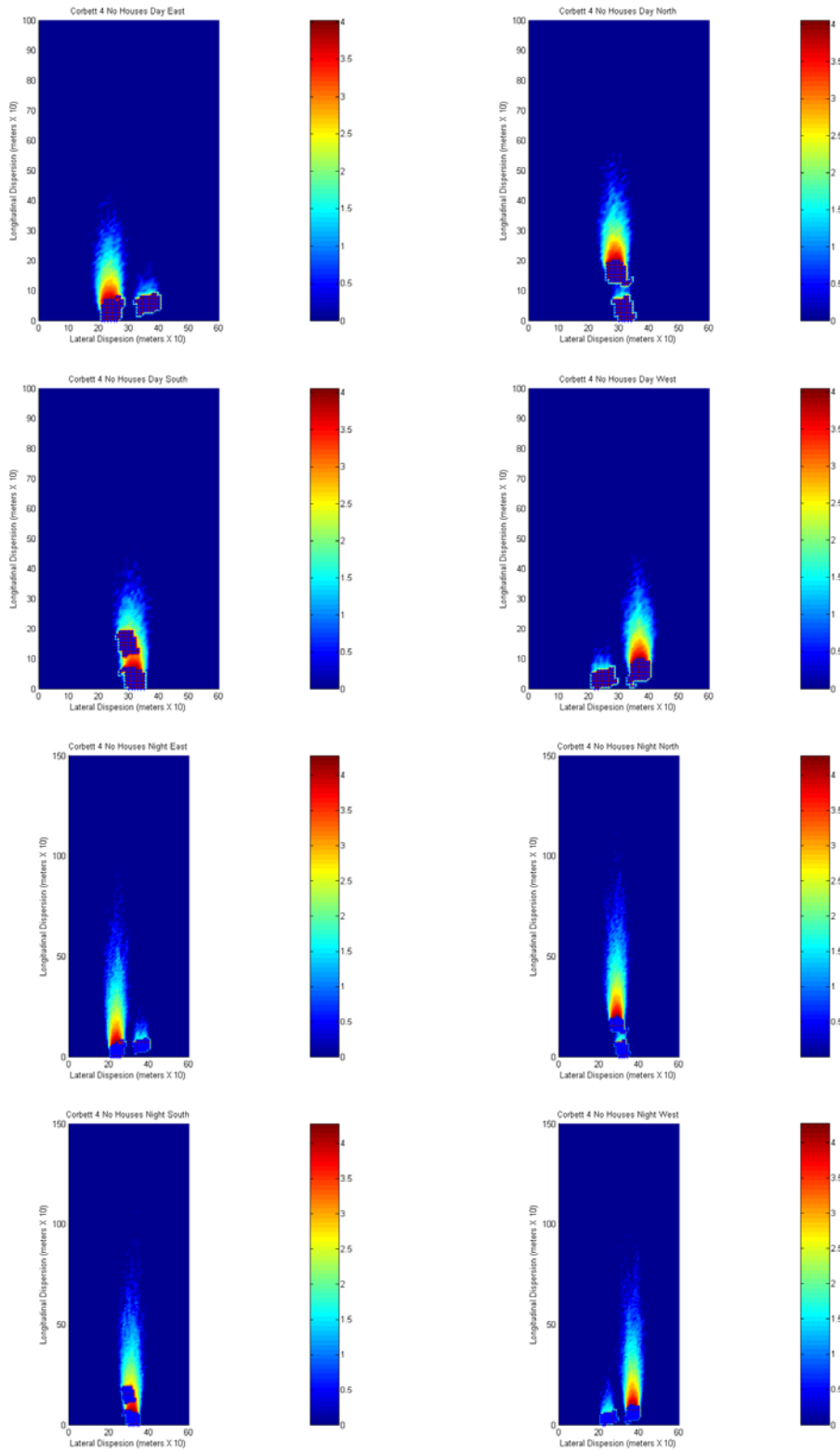


Figure 19: Best Site 2/Corbett 4 without houses: Daytime and nighttime dispersions. Dots indicate odor release points on the grid.

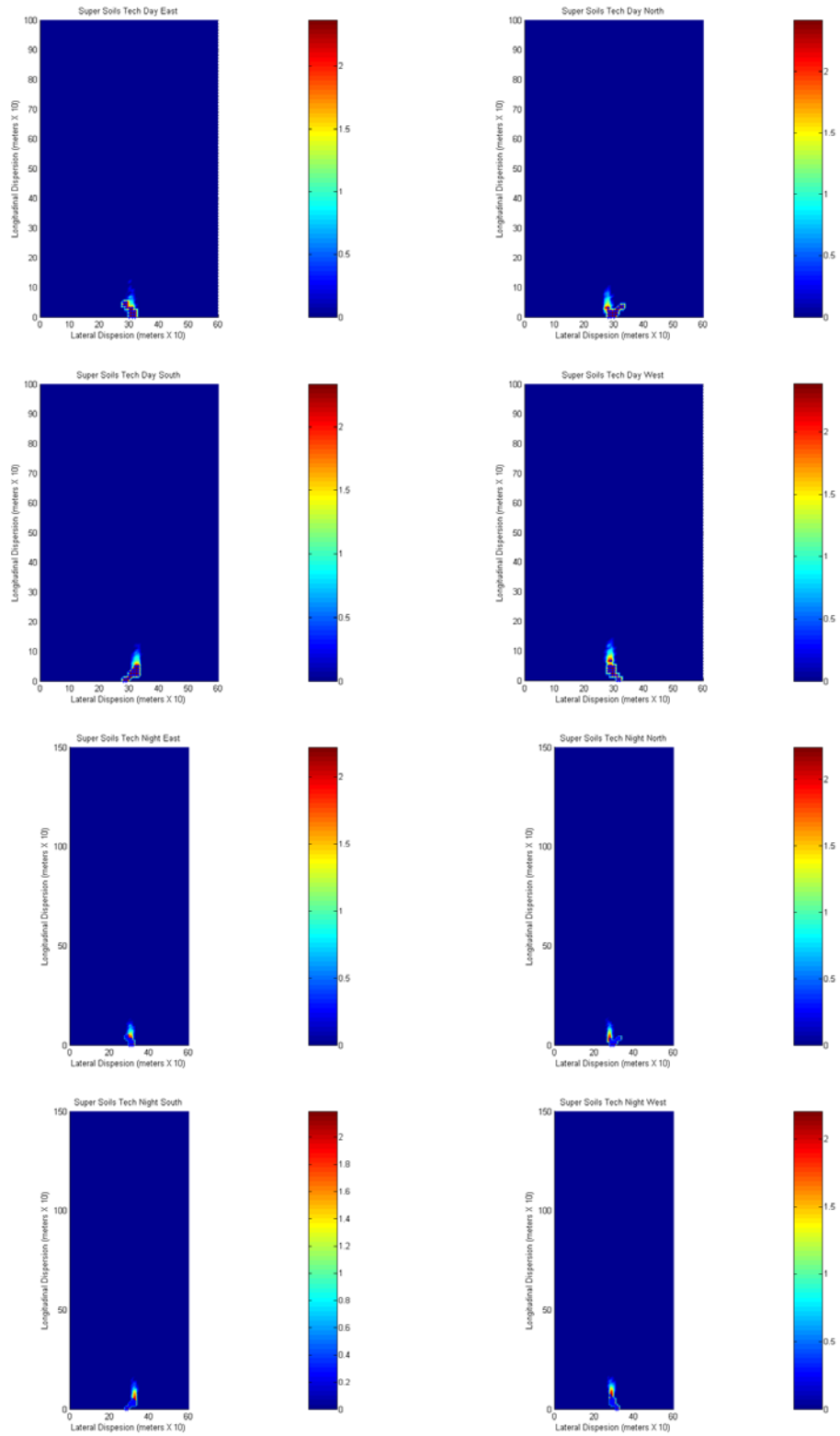


Figure 20: Super Soils without houses: Daytime and nighttime dispersions. Dots indicate odor release points on the grid.

## CONCLUSION

Odor dispersion depends on a variety of factors including the surface area that emits odorants, the geometry of the facility (i.e. the distribution of odor sources), the spatial distribution of the relative concentrations of odor intensity, and the meteorological conditions. In order to determine if a specific waste technology reduces or substantially eliminates the emission of odor that is detectable beyond the boundaries of the parcel or tract of land on which the swine farm is located, each of these factors must be taken into account using a dispersion model.

Modeling was performed using all odor sources at a facility in the computation as well as using all odor sources except the swine housing in the computation. These computations show that, under the conditions measured and modeled, the swine housing plays a dominant role in odor downwind. Comparison of the dispersions for alternative technologies with control farms suggests that the Barham farm and Super Soils may have an advantage over conventional lagoon technology with regard to odor. However, when the houses are included and the proposed operational definition of “substantially eliminate” odor given in the Appendix is used, odor emissions from these two technology sites exceed the “very weak” rating of “1” on a 0-8 scale. This illustrates the importance of technologies to focus on the waste stream as well as the house emissions to be consistently effective in substantially eliminating odor downwind.

### References

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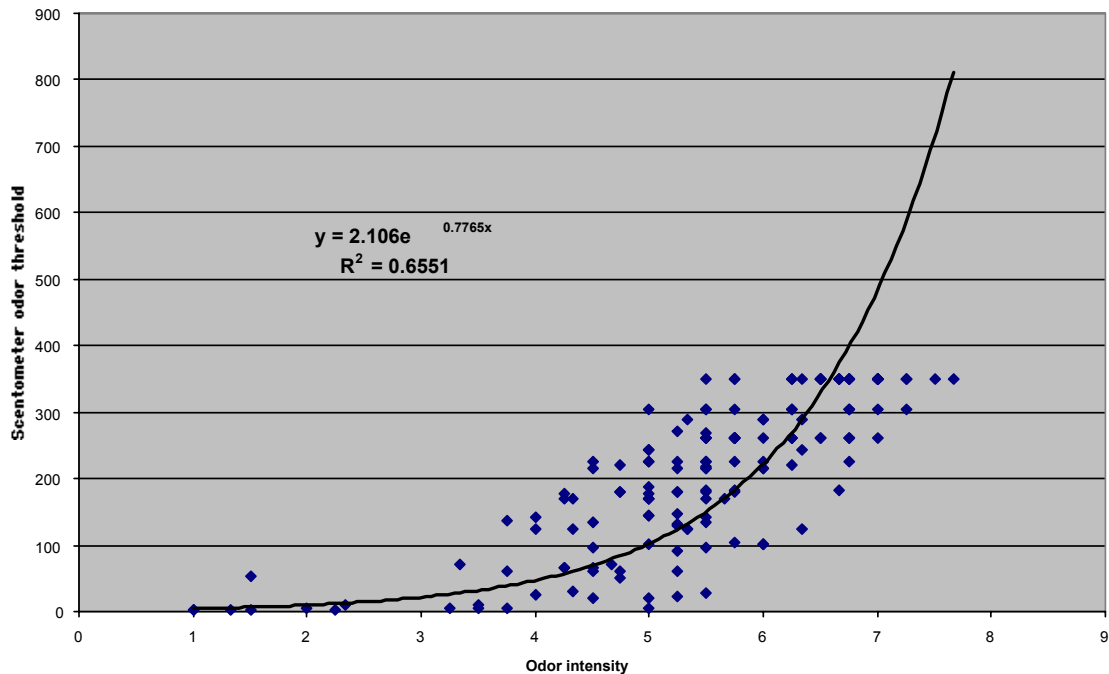
## APPENDIX: OPERATIONAL DEFINITION

An operational definition of “substantially eliminate” odor has been developed by our team based on experimental human data at swine operations. The definition is as follows:

Odor is considered to be substantially eliminated when the odor is rated “very weak” (e.g. “1” on a 0 to 8 scale), when the odor is only slightly above threshold (0 to 4.5 times above threshold), and when the odor has a neutral hedonic tone (neither pleasant nor unpleasant).

This definition is based on the figures below using data collected at farms participating in the OPEN project. Figure 1 shows the relationship between odor intensity ratings (9-point line scales numbered from 0 – 8 where 0=none at all; 1=very weak; 2=weak; 3=moderately weak; 4=moderate; 5=moderately strong; 6=strong; 7=very strong; and 8=maximal) and threshold values on the Scentometer (field olfactometer). When the odor intensity rating is a “1”, the threshold value is a 4.5 based on the best-fitting curve. Figure 2 shows the relationship between odor intensity and unpleasantness of the odor. The descriptors for pleasantness/unpleasantness are: 0=extremely pleasant; 1=very pleasant; 2=moderately pleasant; 3=slightly pleasant; 4=neither pleasant nor unpleasant; 5=slightly unpleasant; 6=moderately unpleasant; 7=very unpleasant; and 8=extremely unpleasant. When the hedonic value is a 4 (neutral), the odor intensity is a 1 on Figure 2.

Odor intensity vs. Scentometer odor threshold



Odor intensity vs. Unpleasantness

