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APPLICATIONS OF USING THE ODOR FOOTPRINT TOOL

R. R. Stowell, L. Koppolu, D. D. Schulte, and R. K. Koelsch[1]

ABSTRACT

The Odor Footprint Tool is a science-based computer resource for use in evaluating the potential odor impact of new and expanded animal production facilities. It was developed to assist livestock producers, their service providers, and county planning and zoning officials in making reasonable decisions while limiting the negative impact of livestock operations on surrounding neighbors and rural communities. The Odor Footprint Tool utilizes an EPA regulatory model (AERMOD), weather databases, new source code, and user input to generate regional *odor roses*, *odor footprints*, and *directional setback distance curves*. Odor roses provide a generic picture of the directionality of odor impact within a region, independent of the type or size of livestock facility involved. Odor roses are well suited for general educational purposes where the directional impacts of odor emissions from an unspecified source are desired. Odor footprints show a plan view of the projected odor impact of an operation, based upon the total odor emission rate of the site. The total emission rate depends on the type of livestock housing and/or manure storage facilities involved, and whether any odor control technologies are implemented. Odor footprints can be developed for specific scenarios, and are most useful for visualizing the projected odor impact of an operation on the surrounding area. Directional setback distance curves facilitate determining minimum recommended setback distances in four 90-degree sectors around a site. The directional setback distance curves are useful when key setback distances are desired, and when a number of preliminary comparisons are to be made. Further development of the Odor Footprint Tool will facilitate generation of site-specific odor footprints.

KEYWORDS. Odor impact, setback distance, setback estimation, siting

INTRODUCTION

As livestock and poultry producers have expanded and intensified their operations, the level of community concern and number of complaints registered about emissions of air pollutants, especially odorants, from animal production facilities have risen dramatically as well. One approach to deal with these concerns involves establishing minimum setback (separation) distances between production facilities and residences or public facilities. Many governing bodies have implemented setback requirements through local zoning and/or state regulatory procedures. Unfortunately, very few of these setback requirements have a scientific basis.

Current siting requirements for new livestock and poultry production systems in the U.S. are based mainly on the number and weight of animals on a site and the distance to the nearest neighbor. This approach does not account for existing odor sources in a community, the influence of localized meteorological or topographic factors on odor dispersion, or the use of improved odor management practices. Odor dispersion is a complex process that depends on characteristics of the source, weather patterns, terrain, and the presence of other odor sources.

Atmospheric dispersion models can account for these factors and could provide rural communities and the livestock industry with the tools needed to incorporate science and objectivity into the odor management decision-making process. Air quality research groups at the University of

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Nebraska and the University of Minnesota developed the Odor Footprint Tool for estimating setback distances. The purpose of this paper is to present examples of output from the Odor Footprint Tool and to discuss opportunities for utilizing this resource.

DEVELOPMENT OF THE ODOR FOOTPRINT TOOL

Koppolu, et al. (2004) presented an overview of odor dispersion models and the details involved in the development of the Odor Footprint Tool. The engine behind the Odor Footprint Tool is a recently released air dispersion model called AERMOD (AMS/EPA Regulatory Model), which was developed in a joint effort by the American Meteorological Society and the U.S. EPA. This model was selected because it has considerable flexibility, and its use is generally accepted by the regulatory community (U.S. EPA). AERMOD can handle a variety of source types, which accommodates its use with very large feedlots, lagoons and other facilities that are not accurately described as point sources. It can also incorporate the effects of topography, which will be desirable in making accurate site-specific assessments.

Source code was written to pre-process meteorological data from sources such as the National Weather Service (NWS) and the Automated Weather Data Network (AWDN). Before weather data can be provided as input to AERMOD, the data must be processed to account for missing data and data representing calm conditions, the latter of which is especially important for accurate modeling of odor transport and detection frequency. The Odor Footprint Tool is equipped to accept and process surface and upper air weather data from common U.S. sources.

A user interface was also developed to collect necessary information and process it in the correct manner for use by AERMOD. Essential information includes the type, size, and location of facilities present on the site, the source of weather data and timeframe (generally a 10-year period, if available) over which to run the model, as well as information on the format for the output, such as what coordinate system and units are preferred. Since the long-range goal is that the Odor Footprint Tool be readily usable in practical settings, further development and refinement of this user interface continues to be performed to make it user-friendly.

The output from AERMOD must be processed for plotting and presentation. Post-processing programs and subroutines have been developed for this purpose and continue to be enhanced.

The Odor Footprint Tool has been calibrated to determine scaling factors, appropriate for use with AERMOD, to accurately predict odor intensities downwind of an odor source. Koppolu et al. (2004) describe this calibration effort and summarize the scaling factors recommended. Validation of the Odor Footprint Tool in a community setting is underway in Nebraska.

DESCRIPTION AND ILLUSTRATION OF CURRENT OUTPUT

Early development work addressed fairly generic situations: the odor source is a point source, surface weather data comes from a primary [e.g. NWS] weather station, no other significant odor sources are in the vicinity surrounding the site, and the site and surrounding area are on fairly flat, level terrain. Although the Odor Footprint Tool is capable now of handling more varied and specific situations, the focus of much of the effort to this point has been on producing output for generic situations within a region surrounding a readily identified primary weather station.

Output has been developed for several regions: seven regions encompassing the state of Nebraska, and a region each within Iowa and Minnesota. In this paper, output is presented for two of these regions: the regions surrounding Norfolk, NE, and Lincoln, NE; also identified as northeast and southeast Nebraska, respectively.

All of the information presented is based upon weather conditions from April 15 through October 15, sometimes referred to as the ‘odor season’ in the Midwest. People are more likely to be exposed to odors during this period since the warm months of the year are generally when odors are most prevalent and people are active outdoors. This time period can be modified to consider other climates or considerations.

The term ‘odor annoyance’ is used throughout the text. Conditions of odor annoyance are indicated with the Odor Footprint Tool as having the intensity of livestock/manure odor at which 50% of an exposed, unbiased population identifies the presence of an annoying odor. The best available scientific knowledge to date, incorporating triangular forced-choice olfactometry, has been used to establish the dilutions-to-threshold value of 75 D/Ts to determine an annoying odor originating from cattle and swine facilities. The Odor Footprint Tool uses this value, which corresponds to an intensity of 2 on a 0 to 5 n-butanol scale according to trained panelists, when determining the presence of annoying odor for a given location and time.

Odor Roses:

An odor rose depicts the comparative likelihood of annoying odors existing in a given direction from a source, irrespective of the source emission rate or distance from the source. The likelihood of annoyance is expressed as the percentage of the total annoyance incidences for all directions, so the sum of the sector bars in all directions equals 100%. Referring to Figure 1, the comparative likelihood of annoying odors existing to the south of an odor source is about 3% in northeast Nebraska versus 13% in southeast Nebraska.

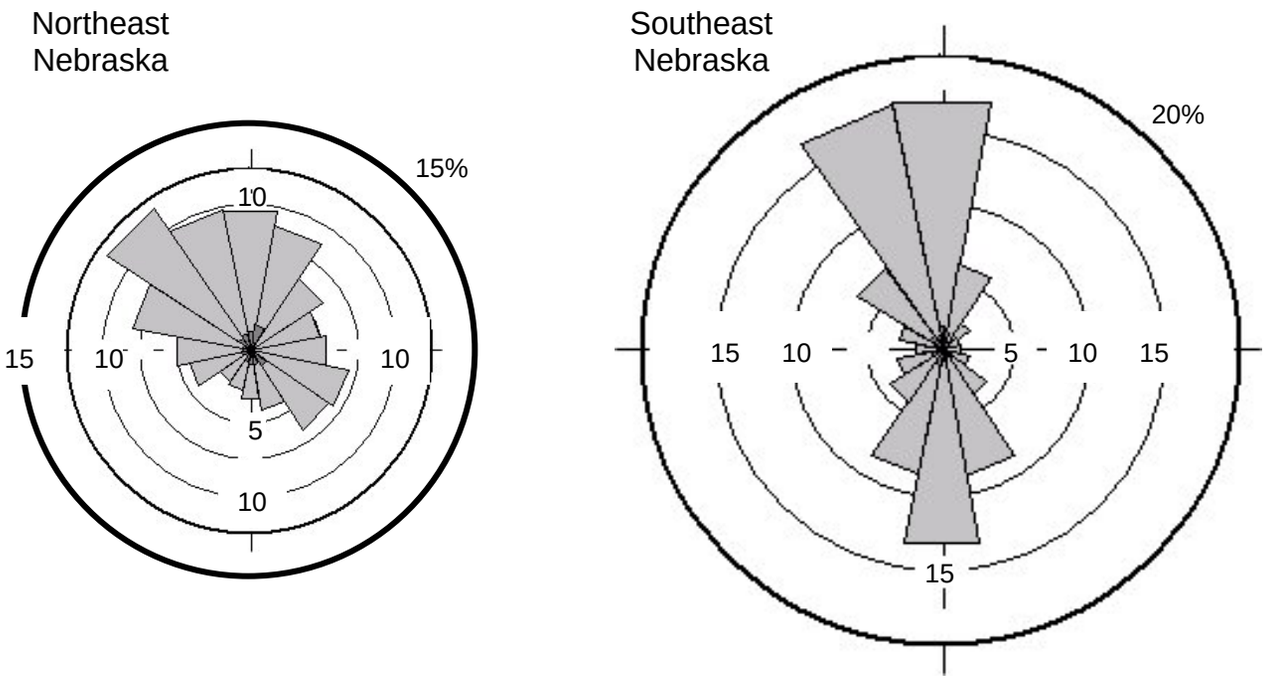


Figure 1. Odor roses for Norfolk, Nebraska (left) and Lincoln, Nebraska (right). The extent of the radial bars represents the proportion of annoying odors expected in that direction.

The likelihood of being exposed to annoying odors is a function of the surface and upper air weather conditions in the region over an extended period of time (typically 10 years). Wind direction plays a key role in the directionality of odor annoyance, as one might expect. The influence of other factors such as humidity, cloud cover, and atmospheric stability also play a role, however, and the regional odor roses that have been developed are not mirror images of the corresponding wind roses for the given locations.

Comparison of odor roses for northeast and southeast Nebraska exemplifies the influence of weather patterns in the two regions and illustrates a basic difference in directional exposure to annoying odors. The influence of the Missouri River Valley and regional weather patterns are fairly clearly illustrated in these graphics. The Missouri River defines Nebraska’s entire eastern border (Figure 2). At the northern boundary of the state, the Missouri River runs almost due east, and then curves toward the south until it is running nearly due south when it is to the east of Lincoln. Many of the warm-season frontal systems, which are characterized by hot, humid conditions, travel northward from the Gulf of Mexico, eventually paralleling the Missouri River Valley. The stable air conditions associated with these systems cause odors to remain concen-

trated near the ground and be transported to downwind neighbors. Frontal systems from the north or west generally bring drier, less stable air. When the two frontal systems meet, the thunderstorms for which this region of the U.S. is famous are likely to develop.

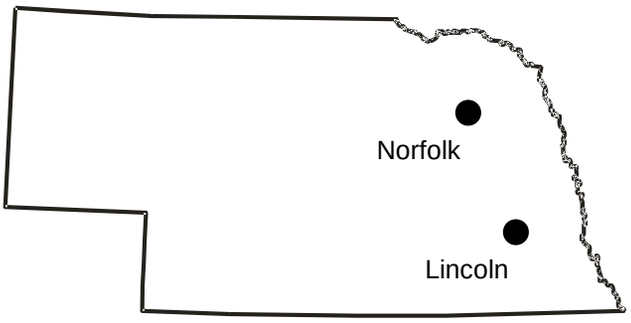


Figure 2. State borders and locations of weather stations for northeast and southeast Nebraska regions.

In northeast Nebraska, odor annoyance is likely to be most prevalent generally to the north of a source, with maximum odor annoyance to the northwest (Figure 1). In contrast, directional odor annoyance in southeast Nebraska is expected to be very polarized with maximum annoyance due north and north-northwest of an odor source followed closely by due south. This has noteworthy implications for planning and assessing sites for livestock facilities in the two regions. For the region surrounding Lincoln (southeast Nebraska), using a constant setback distance in all directions (that is, defining a circle about the source facility) would not be very representative of what would be expected in terms of likelihood of exposure to annoying odors. In such a scenario, the practical outcome of using a constant setback distance would be having an excessively conservative setback requirement to the east and west of a source facility and potentially having insufficient or a non-conservative setback to the north and south of the facility.

As an additional point of interest, each of the directional bars within the odor roses has a darkly shaded interior sector while the outer portion is lightly shaded. The interior sectors represent daytime (08:00 to 18:00) hours and the outer portion represents nighttime and transition hours (18:00 to 08:00). These time periods were selected after some investigation to represent the expected stability conditions of the atmosphere. It is quite apparent from the odor roses shown that the potential for annoying odors is greatest during transition and nighttime hours, when the atmosphere is more likely to be stable. The likelihood of annoying odors irrespective of the direction from the facility for northeast Nebraska is about 86% between 18:00 and 8:00 (a 14-hour period or 58% of a day), while between 8:00 and 18:00 it is only 14%. For southeastern Nebraska these percentages are 88% and 12%, respectively. Therefore, directional trends for the transition and nighttime portions of a day are quite representative of overall trends (and visa versa). When viewing only the sectors for daytime hours, it should be noted that the directional trends for odor annoyance might shift in a differing direction. If one was interested specifically in a certain time period of the day or in differing time periods from that shown, the data needed for making these assessments is produced by the Odor Footprint Tool as an output data file. Odor roses are produced via a separate post-processing procedure.

Odor Footprints:

An odor footprint shows a top [plan] view of the projected odor impact of a livestock operation in terms of the extent of exposure to annoying odor in all directions from the source. Exposure is quantified within the Odor Footprint Tool as the frequency of exposure to annoying odor ($\geq$ 75 D/T or I $\geq$ 2), with the frequency being the percentage of hours of annoyance out of the total hours considered for the April 15 to October 15 timeframe over multiple years (typically a 10-year period). Using the concept of contour lines, isopleths are plotted showing the locations of constant odor-annoyance-free frequency, which is simply 100% minus the frequency of annoyance. The conventional odor footprint produced using the Odor Footprint Tool shows isopleths for 90%, 94%, 96%, 98% and 99% odor-annoyance-free frequencies. The percentage value considered represents the minimum proportion of hours during the spring-through-fall period during which a residence situated on or outside the isopleth should not be exposed to annoying levels of odor coming from the particular livestock site. So, for 96%, odors at a location inside the isopleth would be expected to be at annoying levels more than 4% (100% - 96%) of the time, while odors at a location outside the isopleth would be expected to be at annoying levels less

than 4% of the time. The given percentages were selected as covering the practical range of acceptable odor annoyance, representing from 2 to 18 full days of odor annoyance in a typical year.

Figure 3 contrasts odor footprints for northeast and southeast Nebraska, respectively, at a total odor emission rate (OER) of 500 x 10^4 OU/s. Odor footprints are specific to both a location and an odor emission rate, which is a function of the number, types and sizes of facilities on a site, and whether any odor control technologies are implemented. For illustrative purposes, 500 x 10^4 OU/s represents the scaled emission rate from a 3,300-head swine finishing building with deep pits and no special odor control practice in place. Note that the OER scaling factors used with AERMOD are different than those used with other modeling tools (such as OFFSET) and that the same total odor emission rate can be achieved for numerous combinations of facility types and sizes.

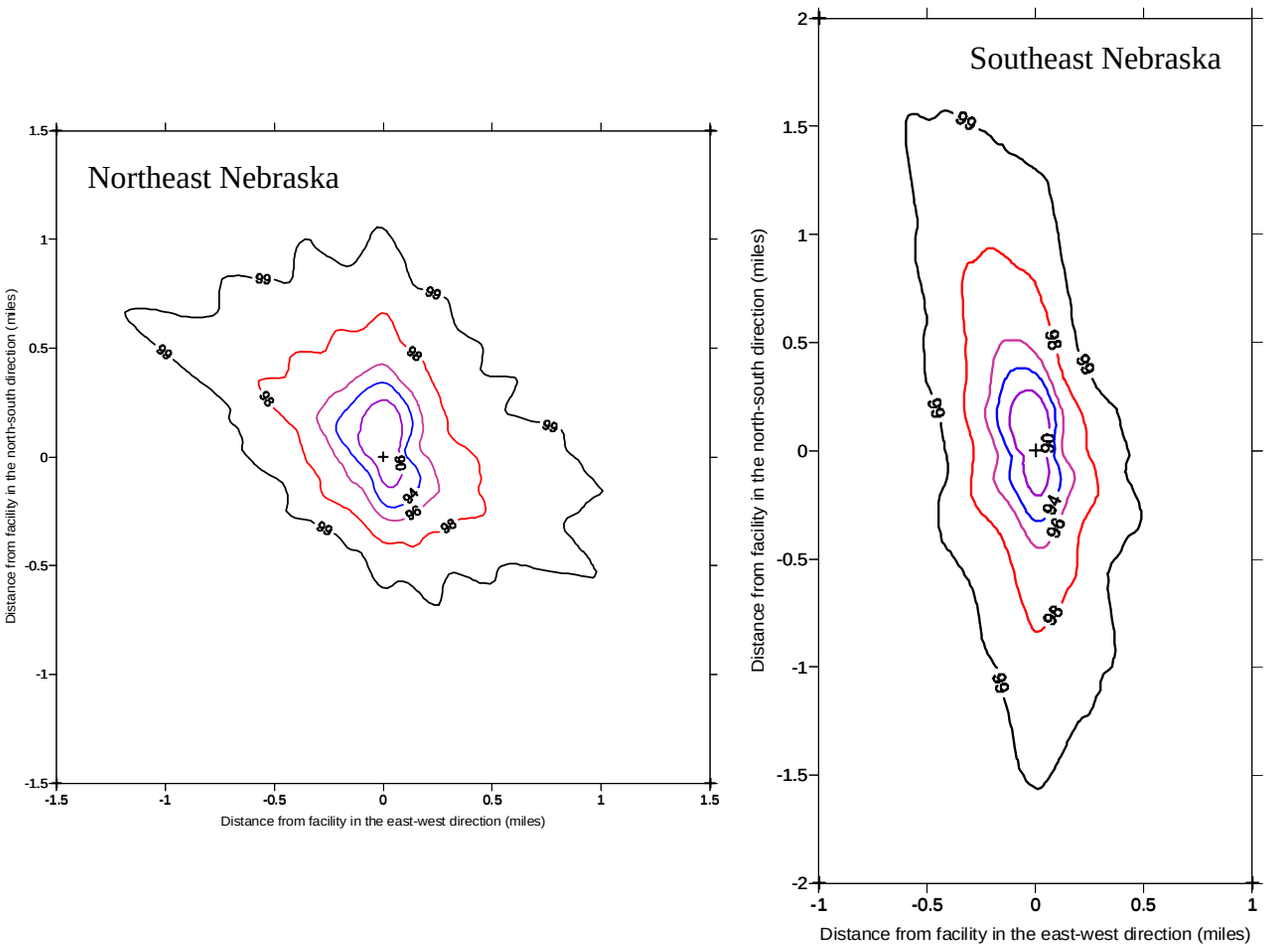


Figure 3. Regional odor footprints for Norfolk, Nebraska (left) and Lincoln, Nebraska (right) at total odor emission rates of 500 x 10^4 OU/s [1 mile ~ 1,600 m].

The odor footprint curves shown for northeast and southeast Nebraska were developed using hourly meteorological data for 1981-1990 and 1984-1992, respectively. An immediate observation that can be made is that the shapes of the isopleths differ for the two regions, with each corresponding to the basic shape of the odor rose for that region. A primary axis for isopleths can usually be identified with odor footprints. In this case, the primary axis runs diagonally from the northwest toward the southeast for the Norfolk footprint and north - south for Lincoln. The orientation of footprints will be brought up again in the discussion of directional setback curves.

Looking at the detail of each footprint in Figure 3, both have five isopleths plotted representing locations having odor-annoyance-free frequencies of 90 to 99%. As the distance from the source increases, less odor annoyance should occur as indicated by greater odor-annoyance-free frequencies. The separation distance required to achieve a greater odor-annoyance-free percentage

increases significantly with each isopleth. For example, the distance between the 98% and 99% odor-annoyance-free isopleths is at least twice that needed to move from 90% to 94%. Therefore, lower tolerance for risk of exposure to annoying odors is directly reflected by noticeably larger required separation between the source and receptor. Note that it is not possible to plot an isopleth for 100% odor-annoyance-free conditions.

Both the extent of projected odor impact and the directions of maximum and minimum impacts differ noticeably for the two regions (Figure 3 and Table 1). These differences, along with the fact that neither footprint shows a circular odor pattern about the source, highlight the deficiencies of employing a constant setback scheme or bulls-eye approach to account for odor.

Table 1. Example separation distances for northeast and southeast Nebraska on regional odor footprints at total source emission rates of 500 x 10^4 OU/s.

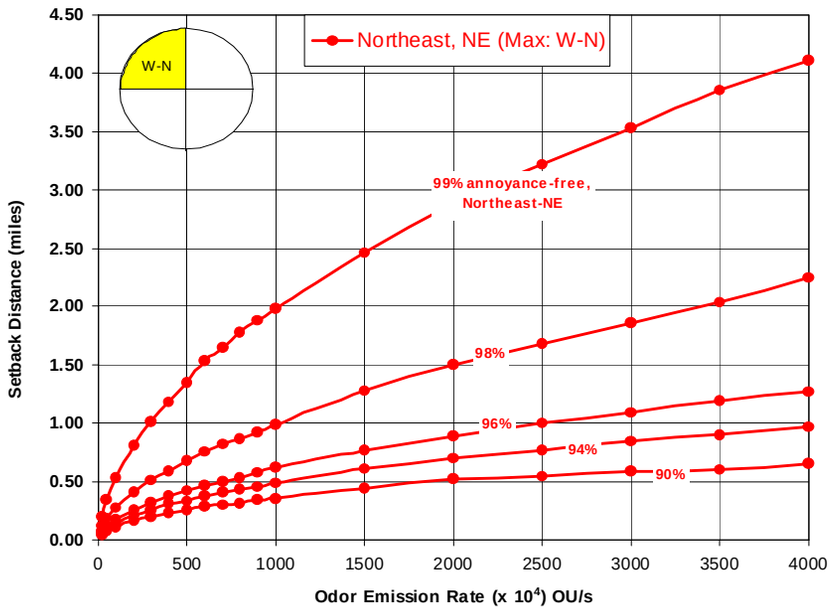
Odor-annoyance-free frequency	Northeast Nebraska (Norfolk)				Southeast Nebraska (Lincoln)			
	Minimum separation distance		Maximum separation distance		Minimum separation distance		Maximum separation distance	
	Direction = SW		Direction = NW*		Direction = East		Direction = NNW	
90%	300 ft.	90 m	1,200 ft.	380 m	300 ft.	90 m	1,200 ft.	380 m
98%	1,600 ft.	470 m	3,400 ft.	1,040 m	1,200 ft.	380 m	4,700 ft.	1,520 m
99%	2,200 ft.	660 m	7,100 ft.	2,180 m	2,200 ft.	660 m	8,700 ft.	2,650 m

* For 90%, the maximum separation distance is to the north of the source.

A regional odor footprint can be utilized to formulate a rough approximation of the impact of an odor source within a particular region. Regional odor footprints can serve as a good educational tool and can be very helpful in the early planning stages for siting a proposed new livestock facility. The use of regional odor footprints should be restricted to illustrative purposes, however, since the regional footprints do not consider the effects of local terrain, nor are these footprints necessarily based upon surface climatic data that is applicable for all locations within a given region. Current and future enhancements to the Odor Footprint Tool will facilitate the development of site-specific odor footprints that can be used by individual producers (or their consultants / technical service providers) for in-depth planning purposes. A principal long-range goal in the development of the Odor Footprint Tool is that local communities / governing bodies will choose to utilize it for making decisions regarding the siting of livestock facilities and/or the requirements that might be placed on some livestock operations for controlling odor.

Directional Setback Distance Curves:

Another useful application of using the Nebraska Odor Footprint Tool is estimating the minimum setback distances desired for various directions downwind from an existing or proposed livestock facility. Directional setback distance curves were developed based upon the concepts presented with OFFSET, a groundbreaking setback-estimation tool developed at the University of Minnesota (Jacobson, et al., 2002). Using a worksheet and graphs that apply for the geographic region in which the facilities are [proposed to be] located, four directional setback distances can be determined for a specified odor-annoyance-free frequency. Each of the four distances represents the minimum setback desired for a corresponding 90-degree sector extending to either the north, south, east, or west of the site; or, alternatively, to the northeast, southeast, southwest or northwest. The alignment of the directions for a given region matches the direction of maximum expected odor impact with one of the 90-degree sectors. For example, a review of the odor roses (Figure 1) or odor footprints (Figure 3 and Table 1) shows that the maximum impact of a generic odor source in northeast Nebraska would be expected to the northwest, while for southeast Nebraska, the maximum projected impact would be more due north of the facility.



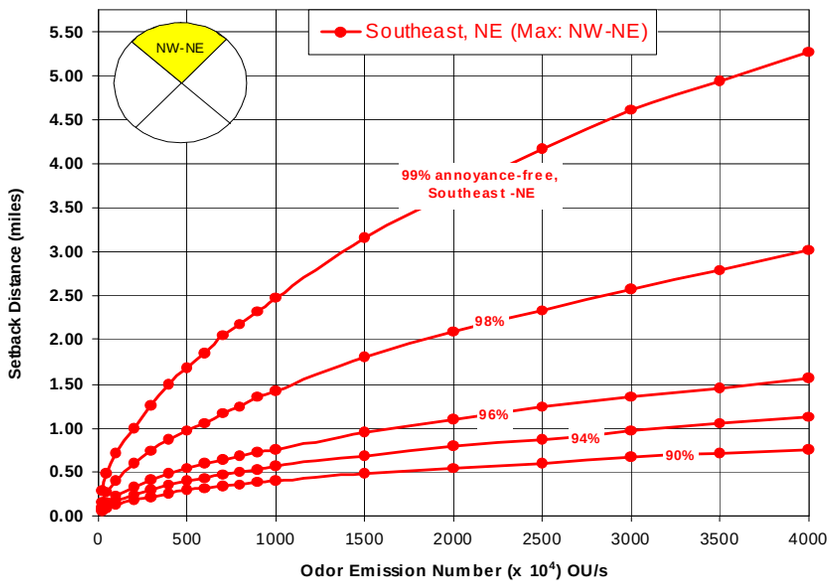


Figure 4. Directional setback distance curves for regions surrounding Norfolk (top) and Lincoln (bottom), NE. Curves are shown for the direction of maximum projected odor impact. Companion curves are available for the other 3 primary directions. [1 mile ~ 1600 m].

Two pieces of information about the facilities on a site are required to estimate directional setback distances: the types of [proposed] facilities on the site and each facility's floor or surface area. Most general types of facilities considered will have an odor emission number associated with them. The odor emission number represents the relative amount of odor one could expect to be released by the source facility into the surrounding air per unit of floor or surface area. These values are based upon currently available emissions data and are scaled for use with AERMOD. As more data becomes available, these values may be updated.

An odor control factor may also be applied to assess the impact of utilizing odor control technologies. The more odor reduction provided, the lower the odor control factor (value between 0 and 1). Several odor control technologies have been evaluated to determine their effectiveness in reducing odor emissions and assign appropriate odor control factors.

The setback distance is determined based upon the total scaled odor emission rate from all noteworthy odor sources on the site. Scaled odor emission rates for an individual facility are found using the following formula:

OER = Odor emission number x Plan area x Odor control factor

Using the appropriate set of directional setback distance curves, a calculated total OER, and a selected odor-annoyance-free frequency, one can read off the distance of projected odor impact (or minimum setback) for each of the four primary directions around the site of the odor source(s). The setback distances described by these curves take into consideration historical weather conditions that influence odor transport and dispersion in the selected region.

To illustrate the use of these curves, consider a 5-building, swine finishing complex, with each building housing 2,000 hogs and having slatted flooring over a deep pit. Assuming rough building dimensions of 45 ft. x 400 ft. (14 m x 120 m) and given that the odor emission number assigned this type of facility is 165 OU s^{-1} ft^{-2} (1,775 OU s^{-1} m^{-2}), the OER for each building is about 3,000,000 OU/s and the total for the complex is about 15,000,000 or 1,500 x 10^4 OU/s. Using Figure 4, the setback distance in the direction of maximum projected impact should be at least 1.3 miles (2,100 m) for northeast Nebraska and 1.8 miles (2,900 m) for southeast Nebraska at 98% odor-annoyance-free frequency. These distances would jump to nearly 2.5 miles (4,000 m) and 3.2 miles (5,200 m), respectively, at 99%. By employing additional odor control, one could reduce the odor impact of the complex and the setback needed. For example, oil sprinkling has been demonstrated to reduce odor emissions by about 50%, so the total OER of this complex could drop to about 750 x 10^4 OU/s with use of oil sprinkling, and the setback distance at 98% would now be about 0.8 miles (1,300 m) and 1.25 miles (2,000 m), respectively.

SUMMARY & CONCLUSIONS

The Odor Footprint Tool, which utilizes the AERMOD dispersion-modeling package, was used to develop regional resources for assessing odor impact from livestock and poultry operations. Three resources – odor roses, odor footprints, and directional setback distance curves – were described, along with their respective practical applications.

The odor rose offers basic insights into a region's directional risk for odor impact, independent of the nature of a source and receptor distance from the source. Although limited in terms of depth of information offered, an odor rose may provide significant educational value in understanding how regional weather patterns influence odor transport and dispersion. Odor footprints can be developed for specific sets of facilities and odor control scenarios. Odor footprints are effective resources for visualizing the potential impact of a livestock odor source on the surrounding area. An odor footprint's practical utility is somewhat limited, however, because it is tied to a specific odor emission rate. Therefore, minor changes to input generally require that the user run the Odor Footprint Tool through all of its major processing steps to generate a new footprint. So, until the Odor Footprint Tool is capable of quickly producing odor footprints on a laptop computer in the field, there is application for other forms of output that can be used in the field to assess different scenarios or options. Directional setback distance curves can be used to help meet this need. Long-term, development of site-specific odor footprints is a major project goal.

ACKNOWLEDGEMENT

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