

# **MI OFFSET 2018 User's Guide: Fundamental Principles, Development History, and User Manual**

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# 1. Introduction

As the title of this document suggests, it has been prepared with three goals in mind:

- (1) Describe the basic principles underpinning the Odor from Feedlots – Setback Estimation Tool (OFFSET) model [Fundamental Principles].
- (2) Trace the evolution from the original OFFSET developed for use in Minnesota, hereafter MN OFFSET, to MI OFFSET 2000, the first version of OFFSET developed for use in Michigan, and finally, to the revised MI OFFSET 2018 [Development History].
- (3) Provide instructions that explain to any user familiar with MI OFFSET 2000 how to run MI OFFSET 2018 [User Manual].

This document is organized in chronological order: MN OFFSET is discussed in section 2, MI OFFSET 2000 is discussed in section 3, and MI OFFSET 2018 is discussed in section 4.

Gray boxes are used in this document to denote supplemental information that, while not essential to an understanding of MI OFFSET 2018, may be of interest to some readers.

## 2. MN OFFSET

### 2.1. Background

In 1997, the Livestock Odor Task Force (LOTF) of Minnesota recommended development of a tool for prediction of offsite odor movement from livestock operations. The MN OFFSET model was developed based on this recommendation. For complete documentation of MN OFFSET, see Jacobson et al. (2005) and Guo et al. (2005).

### 2.2. Livestock odor field measurements

Odor measurements from four separate field campaigns were used in the development of MN OFFSET.

The first field study was performed to establish reference odor emission rates for various types of livestock housing and manure storage facilities (Jacobson et al. 2000). Air samples and ventilation rate measurements were collected in animal production buildings and manure storage units at 85 farms in Minnesota. Within 24 hours of air sample collection, the odor detection threshold of each air sample was determined in a laboratory using an instrument known as an olfactometer (McGinley et al. 2000; Jacobson et al. 2005).

The terms “odor detection threshold”, “odor concentration”, and “odor dilution threshold” are used interchangeably in the literature (e.g., McGinley et al. 2000; Zhu et al. 2000; Jacobson et al. 2005; Guo et al. 2005). In this document, the term “odor detection threshold” is used, as it is the term that is used most often in the MN OFFSET documentation (Jacobson et al. 2005; Guo et al. 2005). In reviewing the history of MN OFFSET, it is helpful to keep in mind that the higher the

odor detection threshold, the greater the odor concentration of the original air sample.

*Supplemental: Odor Testing Primer*

The following information is drawn primarily from McGinley et al. (2000) [“Odor basics: Understanding and using odor testing”].

It is critical to note that measuring odor concentration directly is made impractical by the weak relationship between the detectability of an odor and the mass concentration of the odorous molecules causing it. Thus, odor concentration is measured indirectly by progressively mixing greater and greater quantities of clean air with the original air sample until the odor is undetectable by half of the members of a panel of human observers. The number of dilutions required to render the odor effectively undetectable is used as a measure of the odor concentration of the original air sample. An important term to understand is the “dilution ratio”, which is the ratio of the volume of the diluted air sample to the volume of the original air sample. For example, if the volume of the original air sample is 10 cm<sup>3</sup>, and the sample has to be mixed with 1000 cm<sup>3</sup> of clean air before the odor is undetectable to half of the members of an odor panel, then the dilution ratio is 1010 / 10 = 101.

A panel of six to ten trained assessors are presented with diluted air samples, and using a method known as “ascending concentration series”, progressively less diluted air samples are provided to each panelist until they are able to detect, but not necessarily identify, an odor (comparing the diluted air sample to two samples of clean air). For each panelist, their individual “estimated detection threshold” is determined by geometrically averaging the dilution ratio of the air sample in which they first detected the odor, and the dilution ratio of the preceding (more diluted) air sample. For example, if the odor was first detectable at a dilution ratio of 500, then their estimated detection threshold is 707, which is the geometric average of 500 and 1000  $\left[\sqrt{500 * 1000} = 707\right]$ . Finally, the “odor detection threshold” for the original sample is determined by computing the geometric mean of the individual estimated detection thresholds for the entire panel, and is interpreted as the number of dilutions needed to make the odor sample undetectable by 50% of the human population.

Although the dilution ratio itself is dimensionless, the odor detection threshold is given “pseudo-dimensions” of odor units [OU] or odor units per cubic meter [OU m<sup>-3</sup>], the latter units being analogous to mass concentration units of kg m<sup>-3</sup>.

Subsequently, emission rates for each source category (e.g., dairy, free stall housing) were computed as the product of odor detection threshold and ventilation rate, normalized by the area of the source, and were geometrically averaged over all data samples from that category. The result of this process was a pair of lookup tables giving odor emission references rates for various animal housing and manure storage types. In addition, various odor control technologies were researched and a lookup table of odor control factors was developed (Fig. 1).

(a)

Species	Animal Type	Housing Type	Odor Emission Number, OEN/m <sup>2</sup> -s (Rate, OU/m <sup>2</sup> -s)
Cattle	Beef	Dirt or concrete lot	44 (4.42)
		Free stall, deep pit or scrape; loose housing, flush	70 (2.00)
	Dairy	Tie stall	25 (0.70)
		Open concrete or dirt lot	40 (4.00)
Poultry	Layer	Deep pit; annual cleanout	105 (3.00)
		Deep pit; weekly cleanout	35 (1.00)
	Broiler	Litter	16 (0.45)
		Turkey	Litter
Swine	Gestation	Deep pit or pull plug; natural or mechanical vented	441 (12.60)
	Farrowing	Pull plug, scrape, or flush; mechanically vented	168 (4.80)
	Nursery	Deep pit or pull plug; natural or mechanical vented	303 (8.66)
	Finishing	Deep pit, pull plug, flush, or scrape; natural or mechanical vented	240 (6.86)

(b)

Species	Storage Type	Odor Emission Number, OEN/m <sup>2</sup> -s (Rate, OU/m <sup>2</sup> -s)
Beef cattle	Concrete tank	72 (7.32)
Dairy cattle	Concrete tank	322 (32.20)
	Earthen basin, single cell	269 (26.90)
	Earthen basin, 1st cell	63 (6.33)
	Earthen basin, 2nd cell	51 (5.07)
Swine	Concrete tank	498 (49.80)
	Earthen basin, single cell	141 (14.10)
	Earthen basin, 1st cell	155 (15.50)
	Earthen basin, 2nd cell	113 (11.27)
	Anaerobic lagoon, 1st cell	40 (4.00)
	Anaerobic lagoon, 2nd cell	12 (1.20)
	Settling tank	530 (53.00)
	Crusted stockpile or manure stack	25 (2.46)

(c)

Odor Control Technology	Odor Control Factor	
Biofilter on 100% of building exhaust fans	0.1	
Geotextile cover ( $\geq 2.4$ mm)	0.5	
Straw or natural crust cover on manure:	2 in. thick	0.5
	4 in. thick	0.4
	6 in. thick	0.3
	8 in. thick	0.2
Impermeable cover	0.1	
Oil sprinkling	0.5	

Figure 1: Odor emission reference rates for animal housing (a) and manure storage (b), and odor control factors for selected technologies (c), as developed for MN OFFSET (reproduced from Jacobson et al. (2005)). Numbers outside parentheses are observed values, numbers inside parentheses represent scaled odor emission rates (see section 2.3.1). Note that the scaled odor emission rates, and odor control factors, are similar and in some instances identical to those used in MI OFFSET 2000 and MI OFFSET 2018.

### Supplemental: Additional Field Studies

The second field study was performed in order to develop a relationship between odor detection threshold, determined using olfactometers in the laboratory, and odor intensity, measured by trained nasal field assessors using number and word categories to describe the odor (Guo et al. 2001). Air samples taken in the odor plume downwind of the source are generally below the sensitivity threshold of olfactometers, requiring the use of field observers and a subjective odor intensity scale. Observers judged odor intensity by comparing air samples from the odor plume to a reference n-butanol scale; intensity was assigned by choosing the n-butanol intensity level of the same or similar strength to the odor sample. The relationship between odor detection threshold and odor intensity was developed based on 124 paired odor intensity and odor detection threshold measurements (from 60 swine buildings, 66 swine manure storage facilities, and 55 dairy and beef farms, in MN). The relationship between the two metrics is represented as an exponential function  $Z = ae^{b \cdot I}$ , where  $Z$  is odor detection threshold [OU m<sup>-3</sup>],  $I$  is odor intensity (on a 0-5 scale), and  $a$  and  $b$  are coefficients specific to swine and cattle odor sources. Note that each odor intensity level covers a range of odor detection thresholds, for example odor intensity level 1 for swine odor corresponds to 5-42 OU m<sup>-3</sup>, and odor intensity level 3 for cattle odor corresponds to 142-420 OU m<sup>-3</sup>.

The third study was conducted in order to produce a dataset with which to validate the dispersion model used in the development of OFFSET, INPUFF-2, over distances up to 500 m from the odor source. Short-distance odor plume measurements were made using trained nasal field assessors positioned downwind of odor sources at 28 Minnesota farms (Jacobson et al. 1998). Data collected during this study consisted of odor samples used to estimate odor emission rates, odor intensity measurements taken by nasal field assessors in the odor plume downwind of the odor sources, and on-site weather information, including wind speed and direction, solar radiation, temperature, and relative humidity, required by the INPUFF-2 model. A total of 368 short-distance odor intensity measurements were made using a 0-5 odor intensity scale.

The fourth and final study was performed in order to obtain long-distance odor measurements, up to 3.2 kilometers downwind of the source, for the validation of long-distance smoke predictions in INPUFF-2. A different approach than that used for short-distance measurements was required because it is difficult to predict the location and timing of the odor plume at such distances, making the positioning of field assessors difficult if not impossible. Thus, a total of 296 long-distance odor measurements were made using a simpler 0-3 odor intensity scale, inside a 4.8 km x 4.8 km grid of farmland by trained local resident odor observers (Guo et al. 2001). Like the previous study, data collected during this study consisted of odor samples, odor intensity measurements, and on-site weather information required by the INPUFF-2 model.

### 2.3. Dispersion model evaluation

#### 2.3.1) INPUFF-2 INTRODUCTION

INPUFF-2 is a Gaussian puff model developed by the U.S. Environmental Protection agency for use in predicting mass concentration over short time periods downwind of one or more sources (Petersen and Lavdas 1986). INPUFF-2 was utilized in the development of MN OFFSET in order to explore the relationship between odor emission rate, atmospheric conditions (wind speed and stability), and odor detection threshold (i.e., concentration) at various distances from the source. The impracticality of examining this relationship from observations alone, due to the multiple degrees of freedom involved, necessitated the use of a dispersion model.

#### *Supplemental: Gaussian dispersion models*

As transport and dispersion models vary widely in complexity, and a full review of models is beyond the scope of this document, this brief summary focuses on Gaussian plume and puff models. For a review of dispersion models in the context of odor transport and dispersion, see Guo et al. (2006). Gaussian plume models predict the dispersion of a point source of pollutants, whether elevated or ground level, assuming a steady-state source and steady-state atmospheric conditions. “Gaussian” refers to the assumption of a Gaussian probability distribution of the pollutant downwind of the source, an assumption that implicitly accounts for turbulent diffusion of pollutants in three-dimensions. The concentration of pollutants is greatest at the center of the plume, and decays exponentially with distance from the plume center. One can imagine the plume in a Gaussian plume model as a cone aligned with the mean wind, anchored at the source, that grows in diameter with downwind distance from the source. Gaussian puff models, like INPUFF-2, are similar to Gaussian plume models, except that (i) the pollutant source is not assumed steady-state, and (ii) the atmospheric conditions are allowed to vary in time and space. The pollutant is released in discrete “puffs”, that expand in size with distance downstream of the source. The distribution of the pollutant across the puff is assumed Gaussian, as in the Gaussian plume model. The plume in a Gaussian puff model can be visualized as a cone, like the Gaussian plume model, but with the pollutants contained within puffs or clouds that grow in size as they move away from the source.

A preliminary assessment of INPUFF-2 odor plume predictions revealed the need to apply “scaling factors” to the observed odor emission rates (Fig. 1) before ingesting them into INPUFF-2, in order to obtain odor detection threshold output from INPUFF-2 that, to quote Zhu et al. (2000), “fell into the same numerical range as the field data”. Zhu et al. (2000) argued the the use of scaling factors was justified because INPUFF-2 is a Gaussian model developed for use in predicting mass concentrations (such as for particulate matter), and the mass of odor molecules is unknown. Thus, scaling factors allow Gaussian models, developed specifically for mass dispersion applications, to be applied to the problem of odor dispersion, provided the scaling factors are verified by extensive field tests.

### 2.3.2) SHORT DISTANCE EVALUATION: UP TO 500 M FROM SOURCE

At points spanning the odor plume, odor detection threshold observed by field assessors [converted from odor intensity via an empirical relationship discussed earlier in section 2.2, *Supplemental: Additional Field Studies*], were compared to odor detection threshold values output by INPUFF-2; this process was repeated at distances of 100, 200, 300, 400, and 500 m from the odor source. A total of approximately 30 single and multiple source events were simulated, and as the odor measurements were made on different days at different times of day, a variety of atmospheric conditions were considered. The Wilcoxon Signed Rank Test was used to compare field measurements and INPUFF-2 predictions, revealing 80-95% confidence in using INPUFF-2 at distances of 100-300 m from the odor source, with poor model performance noted at distances of 400-500 m from the source (possibly attributable to human measurement errors at low odor levels).

### 2.3.3) LONG-DISTANCE EVALUATION: UP TO 3.2 KM FROM SOURCE

A total of 170 long-distance odor dispersion events were simulated by INPUFF-2, most of which occurred during the early morning, evening, and night. All odor events occurred within a 4.8 km x 4.8 km odor monitoring grid in rural Minnesota inside which trained resident odor observers reported odor intensity on a 0-3 scale, along with time of measurement, and relevant weather conditions (temperature, relative humidity, wind speed and direction, and solar radiation). Only odor events for which the odor source was located inside the 4.8 km x 4.8 km monitoring grid were considered in the model validation exercise. An INPUFF-2 prediction was considered correct if the predicted odor detection threshold fell within the range of odor detection thresholds corresponding to the odor intensity measurement [see section 2.2, *Supplemental: Additional Field Studies*]. Given the broad range in odor detection thresholds corresponding to each odor intensity level, the evaluation methodology is arguably generous. For example, if the measured odor intensity downwind of a swine farm was 2 [124-1070 OU m<sup>-3</sup>], and INPUFF-2 predicted an odor detection threshold anywhere within the range of 124-1070 OU m<sup>-3</sup>, the INPUFF-2 prediction was deemed satisfactory. A general conclusion of the long distance evaluation study was that INPUFF-2 performed most satisfactorily for low-intensity odor events, but tended to underestimate odor detection threshold for higher-intensity odors. The limited number of moderate- to high-intensity odor events renders this result low-confidence.

## 2.4. *Empirical setback distance - odor emission rate relationship*

### 2.4.1) CHARACTERIZING ATMOSPHERIC DISPERSION POTENTIAL

Six wind-stability classes were defined during the development of MN OFFSET, based on wind speed and Pasquill stability class (Pasquill 1961), in order of increasing potential for atmospheric dispersion or mixing (Table 1; WC1: least dispersed, WC6: most dispersed).

Table 1: Definition of MN OFFSET wind-stability classes.

Name	Pasquill Class	Wind speed (S) range
WC1	F	$S \leq 1.3 \text{ m s}^{-1}$ (2.9 mph)
WC2	F	$1.3 \text{ m s}^{-1}$ (2.9 mph) $< S \leq 3.1 \text{ m s}^{-1}$ (6.9 mph)
WC3	E	$S \leq 3.1 \text{ m s}^{-1}$ (6.9 mph)
WC4	E	$3.1 \text{ m s}^{-1}$ (6.9 mph) $< S \leq 5.4 \text{ m s}^{-1}$ (12.1 mph)
WC5	D	$S \leq 5.4 \text{ m s}^{-1}$ (12.1 mph)
WC6	D	$5.4 \text{ m s}^{-1}$ (12.1 mph) $< S \leq 8.0 \text{ m s}^{-1}$ (17.9 mph)

The Pasquill classification scheme has been widely used in dispersion applications (e.g., smoke, power plant emissions, odors) to describe the ability of the atmosphere to dilute pollutants. Different forms have been developed since the original 1961 study, but the most common form uses six classes, ordered from greatest mixing/dispersion potential to weakest mixing/dispersion potential: A (strongly unstable); B (moderately unstable); C (weakly unstable); D (neutral); E (weakly stable); F (strongly stable). This is the form used by MN OFFSET. Note that under unstable conditions (classes A-C), odors are strongly mixed with ambient air and odors become well-diluted over short distances from the source; thus, classes A-C were neglected in MN OFFSET and all subsequent OFFSET tools.

#### 2.4.2) INPUFF-2 SIMULATIONS

Setback distance (D) is defined in Guo et al. (2005) as the distance downwind of a livestock production site where the odor detection threshold is reduced to  $75 \text{ OU m}^{-3}$ , i.e., where the odor intensity is a 2 (faint odor) on a 0-to-5 n-butanol intensity scale [conversion from field-measured intensity to odor detection threshold follows from the second field experiment described in section 2.2, *Supplemental: Additional Field Studies*]. Beyond the setback distance, odor is considered to be mostly undetectable by the general population. Interestingly, when validating INPUFF-2 (Zhu et al. 2000; Guo et al. 2001), a particular odor intensity level translated to a range of odor detection thresholds (e.g., odor intensity level 2 = 42-124  $\text{OU m}^{-3}$ ), but in defining the setback distance, a single odor intensity level was assumed equivalent to a single value of odor detection threshold (e.g., odor intensity level 2 = 75  $\text{OU m}^{-3}$ ).

A relationship between D and total odor emission factor (E) under different atmospheric conditions was the primary goal of the developers of MN OFFSET. Note that E is computed as the product of odor emission reference rate (units:  $\text{OU m}^{-2} \text{ s}^{-1}$ ), odor source area (units:  $\text{m}^2$ ), and odor control factor (units: none), and has units of  $\text{OU s}^{-1}$ . Odor emission reference rates and odor control factors are obtained from the look-up tables in Fig. 1.

### Supplemental: Odor emission terminology

A few technical points about odor terminology, dimensions, and units in the MN OFFSET documentation are worth mentioning here: (1) odor detection threshold, used to compute the odor emission reference rate, was given what McGinley et al. (2000) refer to as “pseudo-dimensions” as part of the odor testing described in section 2.2, *Supplemental: Odor Testing Primer*. Although these dimensions are not physical in nature, they are the given dimensions of odor detection threshold, and the dimensions of any quantities derived from odor detection threshold are based on them; (2) The odor emission reference rate is not really a rate, but a flux [it has flux dimensions, i.e., change in quantity per unit of time per unit of area]; (3) E is referred to as a dimensionless quantity in Guo et al. (2005), but it is actually a rate, with units of  $\text{OU s}^{-1}$  [these are rate dimensions, i.e., change in quantity per unit of time].

For consistency with OFFSET literature and real-world application, E will hereafter be presented without units and scaled by  $10^4$  (e.g.,  $E=108$ ,  $E=342$ ).

Following the field experiments, an undefined number of simulations with the INPUFF-2 dispersion model were performed in which wind-stability conditions and odor emission rates (i.e., inputs) were varied independently, and odor detection threshold at various distances from the source was output by the model. Analysis of the dispersion model simulations yielded an empirical relationship between odor detection threshold at a given distance downwind of a source, odor emission rate, and wind-stability class. The odor annoyance threshold of  $75 \text{ OU m}^{-3}$  [odor intensity rating of 2 on a 0-5 scale] allowed for a determination of D from the INPUFF-2 output, and a power law relationship between D and E was subsequently developed:

$$D = aE^b \quad (1)$$

where  $a$  and  $b$  are “weather influence factors” that account for the ability of the atmosphere to mix and disperse odors. The  $a$  and  $b$  coefficients, along with resulting values of  $D$  (in meters) for a hypothetical farm with  $E=108$  are provided in Table 2.

Table 2: MN OFFSET weather influence factors  $a$  and  $b$ , along with setback distances ( $D$ ) for  $E=108$ .

Name	$a$	$b$	D [m]
WC1	1.685	0.513	2016.5
WC2	0.729	0.537	1215.4
WC3	0.446	0.540	775.1
WC4	0.180	0.584	574.5
WC5	0.131	0.583	412.4
WC6	0.051	0.626	290.8

Interpretation: in order to only barely detect the odor (and thus not generally be bothered by it) under the most stable, lightest wind conditions, an observer would need to be about ten times farther from the source than under the least stable, windiest conditions. The relationship may be visualized for a range of  $E$  as shown in Fig. 2 [reproduced from Fig. 1 in Guo et al. (2005)],

wherein each line corresponds to a different wind-stability class. The annoyance-free labels in Fig. 2 are described in section 2.4.4.

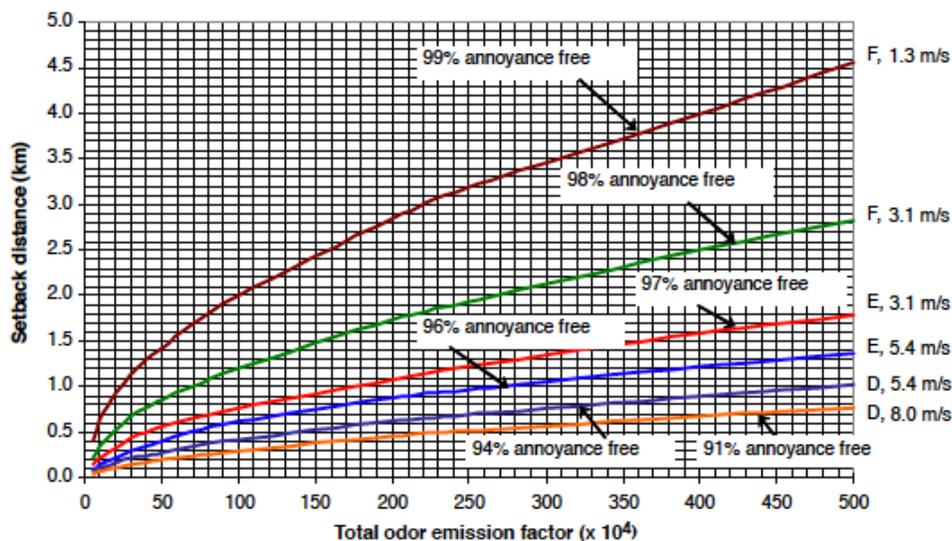


Figure 2: Setback distances for different weather conditions from animal production sites. The odor-annoyance-free frequencies are the averages for Minnesota. Weather conditions given are atmospheric stability class and wind speed. Reproduced from Guo et al. (2005).

### 2.4.3) STATE-WIDE ATMOSPHERIC DISPERSION CLIMATOLOGY

The purpose of this analysis was to determine how frequently the six wind-stability classes occur in general across Minnesota, and then assign odor-annoyance-free frequencies to each line in the setback distance chart (Fig. 2). This allows a user to estimate the minimum separation distance between source and neighbor that is necessary for the neighbor to be odor-annoyance-free some percentage of the year (e.g., 97% annoyance free), for a given total odor emission factor (e.g., E=108).

Hourly weather data from six weather stations in the upper Midwest (Duluth, MN; International Falls, MN; Minneapolis-St. Paul, MN; Rochester, MN; Sioux Falls, SD; Fargo, ND) over a 9-year period were used to construct a quasi-climatology of wind and atmospheric stability aimed at determining the annual frequency of the six wind-stability classes defined in section 2.4.1. Note that the hourly weather data used in the development of MN OFFSET, as well as MI OFFSET 2000, were obtained from the EPA Support Center for Regulatory Air Models (EPA-SCRAM) program. Note that the EPA-SCRAM dataset is limited to 1984 –1992. Pasquill class was determined using a method that takes as input 10-m wind speed, solar insolation (daytime), and cloud cover in octas (nighttime).

For each weather station, a graphic known as a windstar chart was computed depicting the cumulative frequency of the six wind-stability classes for each 22.5 degree-wide wind direction bin (Figure 3; directions indicate the direction the wind is blowing from). The cumulative frequency is

the frequency of a particular wind-stability class -or- more stable conditions. The rationale behind the use of cumulative frequency is that it represents a sort of worst-case-scenario frequency. For example, examining Fig. 3, we see that there is a 1.9% probability of WC4 ( $E \leq 5.4$ ) or more stable conditions -and- a wind from the north [between 348.75 and 11.25 degrees; see blue circle in figure]. Thus, conditions less stable and more windy than WC4, or winds blowing from a different direction, are expected to occur *at least* 98.1% of the time. If a setback distance is computed assuming WC4 conditions and a north wind, a neighbor to the south might detect odors up to 1.9% of the time, that is, they are expected to be odor-annoyance-free at least 98.1% of the time.

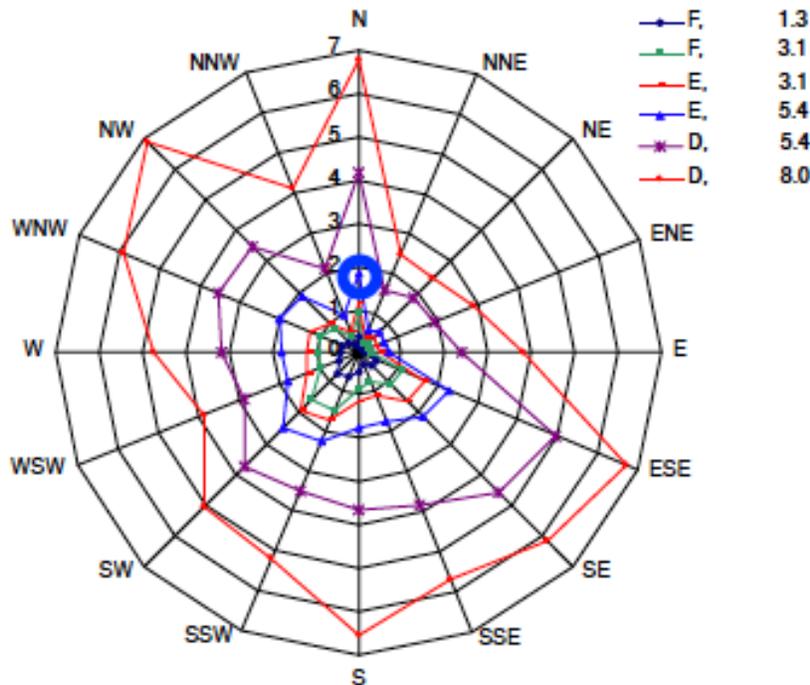


Figure 3: Annual windstar chart for Minneapolis-St. Paul, Minnesota, from 1984 –1992 [Jacobson et al. (2000), reproduced in Jacobson et al. (2005)].

#### 2.4.4) STATE-WIDE ODOR ANNOYANCE CLIMATOLOGY

Each wind-stability class was examined individually, and the highest frequency of any direction was chosen as the worst-case scenario frequency. For any other wind direction, the frequency of occurrence would be lower. For example, for  $F \leq 3.1$  (WC2; green lines and symbols), the highest frequency on the Minneapolis-St. Paul windstar chart is 1.7% (SW wind prevails). For any other wind direction, the frequency of that wind-stability condition (or more stable conditions) is less than 1.7%. This worst-case-scenario frequency was determined for each station and then averaged among the six stations. This was repeated for each wind-stability class. This yielded, for each wind-stability class, a single worst-case-scenario occurrence frequency to be applied state-wide.

The state-wide frequencies first presented in Jacobson et al. (2000), and reprinted in Jacobson et al. (2005) are as follows:

WC1: 1%; WC2: 2%; WC3: 3%; WC4: 4%; WC5: 6%; WC6: 9%

The inverse of this frequency is the frequency of conditions less stable, and thus less conducive to bothersome odors, than the particular wind-stability class. For example, under the worst-case-scenario, conditions less stable and therefore more dispersive (i.e., dilutive) than WC2 are expected to occur 98% of the time. In all likelihood, the frequency of these less-bothersome odor conditions would exceed 98%.

The calculation of the state-wide wind-stability class frequencies allowed the developers of MN OFFSET to label the setback distance lines in Figure 2, each corresponding to a particular wind-stability class, as the frequency of odor-annoyance-free conditions (for example, the WC2 line is labeled 98% odor-annoyance-free. This allows the user to estimate how much distance between their farm and their downwind neighbor is necessary for the neighbor to be odor-annoyance-free N% of the time (where N is a confidence interval). If they want higher confidence, they choose the WC1 or WC2 lines (99% and 98% odor-annoyance-free, respectively); if a higher margin of error is acceptable, they might pick the WC3, WC4, WC5, or WC6 lines (97%, 96%, 94%, or 91%, respectively). In theory, the use of the 'worst-case-scenario' approach makes these setback distance estimates conservative.

#### 2.4.5) ADAPTATION FOR LOCAL CLIMATOLOGY

An implicit assumption in the procedure used to develop the 'worst-case-scenario' frequencies is that the wind is blowing from the state-wide-average prevailing wind direction. The MN OFFSET documentation (Jacobson et al. 2005; Guo et al. 2005) indicates that if a user wishes to apply MN OFFSET for a direction not aligned with the state-wide prevailing wind direction, additional effort on the part of the user is required. Before proceeding, the user needs to obtain a windstar chart representative of the climatological conditions at their location (e.g., from a nearby airport). Armed with this information, the user can create a set of setback distance lines (i.e., create a location-specific version of Fig. 2) for any direction they desire. They do this by determining the frequency of the six wind-stability classes for the particular wind direction that might cause a neighbor to be bothered by odors (e.g., southwest wind if a neighbor is northeast of their farm).

It is critical to understand that the lines themselves in Fig. 2 are independent of the climatology of wind and stability. Each line represents a single wind-stability class, and is only a function of the *a* and *b* coefficients associated with that class, and total odor emission factor. The labeling of the lines *is* climatology-dependent, however, as the odor-annoyance labels are simply the cumulative frequency of the six wind-stability classes.

### 3. MI OFFSET 2000

#### 3.1. Background

The Generally Accepted Agricultural and Management Practices for Site Selection and Odor Control for New and Expanding Livestock Operations (Siting GAAMP) document is used for siting

decisions that result in Right-To-Farm nuisance protection. For clarification, Michigan's Right-To-Farm law may be used by GAAMP-compliant farms to defend against odor nuisance lawsuits, even if the farm's practices harm or bother adjacent property owners or the general public. Since 2005, MI OFFSET 2000 has been used by the Michigan Department of Agriculture and Rural Development (MDARD) as part of the process to extend nuisance protection to livestock farms through the siting GAAMP.

Howard Person, former MSU Agricultural Engineer, developed the original MI OFFSET tool (i.e., MI OFFSET 2000, originally referred to as Michigan Odor Print), and released documentation for the tool in September 2000 (Person 2000). He made a slight adjustment to the output in 2001, but no documentation of the changes made in that update is available.

### 3.2. Differences between MI OFFSET 2000 and MN OFFSET

MI OFFSET 2000 differs substantively from MN OFFSET in the following ways:

- New windstar charts were constructed based on data from seven Michigan weather stations (Grand Rapids, Lansing, Flint, Detroit, Muskegon, Alpena, Sault Ste. Marie), plus South Bend, Indiana, during the period 1984-1992. Note that this is the same time period used in the development of MN OFFSET [recall that this period corresponds to the time period of the EPA-SCRAM dataset, which is limited to 1984-1992]. As a reminder, Pasquill class in MN OFFSET and MI OFFSET 2000 was diagnosed using a method that takes as input 10-m wind speed, solar insolation (daytime), and cloud cover (nighttime).
- The setback distance line graph from MN OFFSET (Fig. 2) was replaced with a plan-view graphic of setback distance as a function of direction downwind of the odor source, i.e., the odor footprint (e.g., Fig. 4).
- The six odor-annoyance-free frequencies in MN OFFSET were reduced in number to three and replaced with odor-annoyance frequencies. Hereafter, this document exclusively uses the term *odor-annoyance frequency*; to compute odor-annoyance-free frequency, simply subtract the odor-annoyance frequency from 100%.
- Necessitated by the change from line graph tool to plan-view tool, a fundamental change in the relationship between wind-stability class and odor-annoyance frequency was made. The starting point in MN OFFSET is the six wind-stability classes, and the six corresponding setback distance lines in Fig. 2. Odor-annoyance frequencies are assigned to each line in the setback distance graph by computing the cumulative frequency of the wind-stability class corresponding to that particular line (e.g., WC4 or more stable conditions). Conversely, the starting point for MI OFFSET 2000 is three fixed odor-annoyance frequencies, 1.5%, 3%, and 5%. The wind-stability class whose cumulative frequency of occurrence (i.e., frequency of that class or more stable conditions) comes closest to the particular odor-annoyance frequency, without going over, is chosen, and the setback distance for that particular wind-stability class is subsequently computed. This process is repeated for each wind direction bin. This is discussed in greater detail in section 3.4.

- The concept of the 'worse-case-scenario' used in MN OFFSET was abandoned. The frequency of each wind-stability class was computed across 16 equally-spaced wind direction bins [22.5-degree wide].
- Analysis of weather data was limited to 1 April – 31 October, instead of the whole year as in MN OFFSET. The decision to limit the weather data to these seven months was based on the seasonality of odor nuisance complaints made to MDARD.

### Michigan Odor Print - Distance in Miles

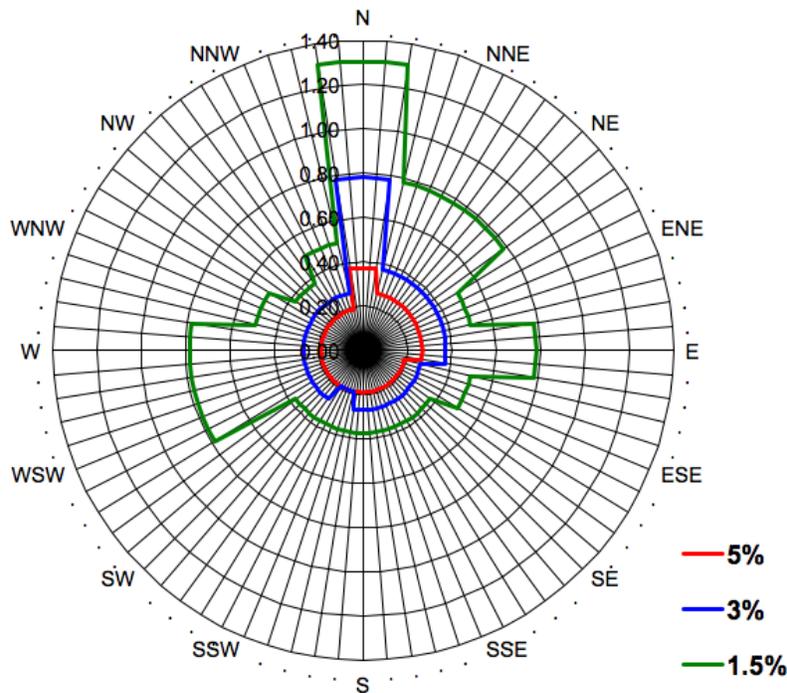


Figure 4: Example of a MI OFFSET 2000 odor footprint. The distances represented on this odor print are approximate distances that one must be away from the odor source to detect a noticeable odor or stronger up to 1.5%, 3% and 5% of the time for each of the 16 wind directions.

### 3.3. Construction of odor footprint

It is never explicitly stated in the MI OFFSET 2000 documentation (Person 2000) how the weather data from the eight surface stations was synthesized to produce a single one-size-fits-all odor print. Based on a review of the MN OFFSET documentation (Jacobson et al. 2005; Guo et al. 2005), the MI OFFSET 2000 documentation (Person 2000), and the MI OFFSET 2000 Excel spreadsheet, the following procedure has been reconstructed.

The MI OFFSET 2000 documentation states that distribution patterns were developed for each weather station, which suggests that windstar charts were constructed for each of the eight weather

stations. For each odor-annoyance frequency (e.g., 1.5%) and each wind direction bin (e.g., NW), the wind-stability class that came closest to occurring at that frequency, without going over, was chosen.

*Supplemental: MI OFFSET 2000 Odor-Annoyance Frequency Methodology*

The method of choosing the wind-stability class whose frequency comes closest to the desired odor-annoyance frequency, without going over, is inherently a conservative approach. Consider a scenario where the more stable WC3 class (or more stable conditions) occurs 3.6% of the time and the less stable WC4 class (or more stable conditions) occurs 5.4% of the time; the MI OFFSET 2000 methodology chooses the WC3 class for the 5% odor-annoyance frequency, yielding a larger setback distance than if the less stable class was chosen. Quoting the MI OFFSET documentation, “...the objective was to underestimate the distance as infrequently as possible, estimate correctly as often as possible, and choose to overestimate the distance rather than underestimate the distance without being overly conservative.”

Next, for each odor-annoyance frequency and each wind direction bin, the most common wind-stability class among the eight stations was chosen, referred to in the MI OFFSET 2000 documentation as the “representative class”. It is not clear from the documentation what was done if two or more classes were tied for most common, but it is suggested that when deciding between two wind-stability classes, preference was given to the more stable (and thus larger setback distance) class. This is consistent with the stated objective that MI OFFSET underestimate the [setback] distance as infrequently as possible, estimate correctly as often as possible and choose to overestimate the distance rather than underestimate the distance without being overly conservative. Furthermore, the procedure was designed to maximize overall agreement between the one-size-fits-all footprint and individual station footprints [i.e., across all 16 wind direction bins and all 8 stations].

Regarding agreement between the one-size-fits-all footprint and individual station footprints, the MI OFFSET 2000 documentation includes some summary statistics. For this evaluation, four additional stations (Louisville, KY; Evansville, IN; Indianapolis, IN; and Fort Wayne, IN) were added to the eight primary stations. For the one-size-fits-all 5% footprint, when comparing all 16 wind directions across all 12 stations, the setback distance agreed with the individual station setback distance 66.1% of the time, was too large 24.5% of the time, and was too small 9.4% of the time. Overall agreement was weaker for the 3% and 1.5% footprints, attributable to the sensitivity of those footprints to microclimates specific to the station location.

The outcome of this procedure was a single state-wide 3 x 16 table of wind stability-class [3 odor-annoyance frequencies and 16 wind direction bins]. When the user provides the total odor emission factor ( $E$ ) in the MI OFFSET 2000 Excel spreadsheet, the setback distance is computed for each element in the 3x16 table, using the  $a$  and  $b$  coefficients from MN OFFSET, and  $E$ . Finally, lines are drawn connecting the setback distances to create the three footprints (Fig. 4).

### *3.4. Known limitations of MI OFFSET 2000*

In the course of the years that have elapsed since the release of MI OFFSET 2000, a number of limitations have been identified by researchers and users of the tool.

- Although large differences in wind and stability climatology are known to exist across the state, MI OFFSET 2000 is based on windstar charts at only eight stations. Furthermore, the odor footprint in MI OFFSET 2000 is one-size-fits-all, the consequence of synthesizing the information contained in the individual station windstar charts into a single graphic.
- Like MN OFFSET, the windstar charts used to develop MI OFFSET 2000 are based on only nine years of observations. A considerably longer period of record (at least 30 years) is necessary to ensure that a single anomalous year does not skew the climatology.
- The method used to compute Pasquill class does not have a physical basis, having been developed in the early 1960's for use with observational datasets in which a limited suite of variables are available to diagnose atmospheric stability.
- Overlaying the odor footprint generated by MI OFFSET 2000 on maps of neighbors, roads, local communities, etc., is an important part of the siting process, but requires the user to export the footprint image from the Excel spreadsheet and overlay it on a static map or in GIS software (e.g., Google Earth). This is a cumbersome and inherently error-prone procedure.

## **4. MI OFFSET 2018**

### *4.1. Background*

A project to update the Siting GAAMP document (discussed in section 3.1), funded by the Michigan Alliance for Animal Agriculture (M-AAA), was begun in early 2016. One of the primary tasks outlined in the funded proposal was, to quote the proposal, the "Development of a user interface that, via input data, incorporates local and current historical meteorological data for site-specific odor footprint development". In other words, the project called for (1) replacing the EPA-SCRAM dataset of wind and stability with a dataset that accounts for differences in wind and stability climatologies across the state, and (2) developing an interface to allow a user to enter the location of their livestock facility and obtain siting guidance that takes into account the local wind and stability climatology. The product of these efforts is MI OFFSET 2018.

## 4.2. Updated wind and atmospheric stability climatology

### 4.2.1) INTRODUCTION TO NARR

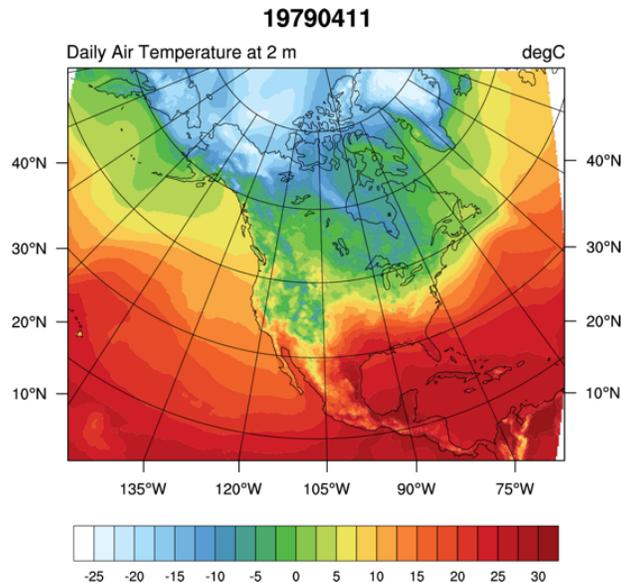


Figure 5: NARR daily mean temperature for April 11, 1979. Data are plotted on a Lambert Conformal projection. The values are the mean of eight 3-hourly values. (Climate Data Guide; D. Shea)

The North American Regional Reanalysis (NARR) meteorological gridded dataset (Mesinger et al. 2006) was chosen to replace the EPA-SCRAM 1984-1992 dataset. NARR is a three-dimensional gridded dataset that combines forecasts from a weather model [that resolves or in some way accounts for physical processes (e.g., boundary layer processes like turbulent mixing)], and ground truth from a suite of atmospheric observations. The NARR domain, as its name suggests, covers all of North America and surrounding waters (Fig. 5). NARR was chosen to replace the EPA-SCRAM dataset for several reasons. First, NARR is able to characterize lake-modified wind and stability climatologies. NARR provides weather data on a regular 32-km grid, with the spacing between adjacent grid points smaller than the average spacing of weather stations capable of providing the information required for calculation of Pasquill stability class. Second, the NARR period of record begins on 1 January 1979, affording a much longer dataset than was available for the development of MN OFFSET and MI OFFSET 2000. A longer period of record minimizes the impact of any single year on statistics computed from the dataset, reducing the risk of bias from one or two unrepresentative years (for example, the anomalously warm 1988). For the development of MI OFFSET 2018, the 30-year period from 1 January 1979 – 31 December 2008 was chosen. Third, NARR provides a larger suite of variables with which to work with, relative to the EPA-SCRAM dataset. This allows for the use of other methods of determining Pasquill stability class than the 10-m wind speed / solar insolation / cloud cover method used in previous versions of OFFSET, methods that in some cases have a more solid physical basis (section 4.2.3).

#### 4.2.2) NARR WIND ASSESSMENT AND WIND SPEED ADJUSTMENT

Due to the expected sensitivity of odor plume dispersion to wind, both directly through speed and direction, and indirectly via atmospheric stability, an assessment of NARR wind speed and direction was performed as a preliminary step in the development of MI OFFSET 2018. For this assessment, ten years of hourly observations [1 Jan 1999 – 31 Dec 2008] were obtained from eight automated weather stations (Table 3).

*Table 3: Metadata for eight automated weather stations used in NARR wind assessment.*

Station ID	Name	Latitude [deg N]	Longitude [deg W]
KANJ	Sault St. Marie	46.48	84.37
KAPN	Alpena	45.08	83.56
KDTW	Detroit	42.21	83.35
KGRR	Grand Rapids	42.89	85.52
KLAN	Lansing	42.78	84.59
KMBS	Saginaw	43.53	84.08
KSBN	South Bend, IN	41.71	86.32
KTVC	Traverse City	44.74	85.58

After pooling the data from the eight stations, and isolating every third hourly observation, to match the three-hourly NARR interval, the NARR and station wind speeds were compared in a scatter plot (Fig. 6). Before proceeding, two points of clarification are necessary. First, it is important to keep in mind that we are comparing area-average estimates to point observations and an unknown portion of the differences between the station observations and gridded estimates quoted herein can be attributed to spatial variability occurring at scales too small to be resolved by the 32-km grid. Second, analysis of the individual stations (not shown) revealed differences in the accuracy of NARR estimates between stations that are well inland (e.g., KLAN) and stations that are closer to the lakeshore (e.g., KTVC): accuracy is greatest at locations well inland and lowest at locations in closer proximity to the lakeshore. That said, pooling of the data was performed in the interest of generalizing the accuracy assessment and creating a one-size-fits-all wind speed adjustment.

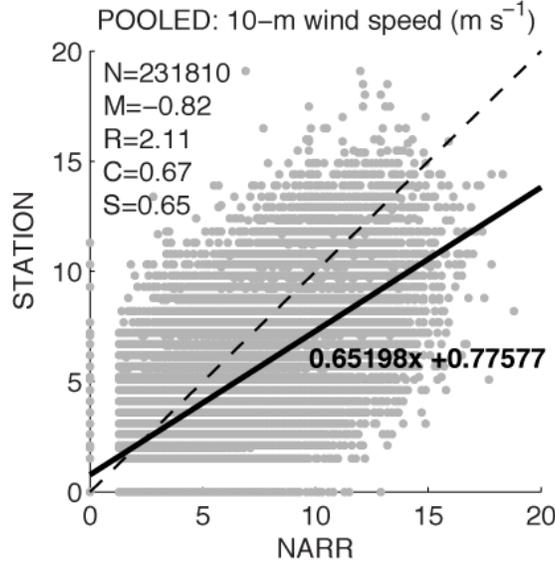


Figure 6: Scatter plot of NARR estimated and observed wind speed [ $m s^{-1}$ ], for eight stations identified in text. Statistics are overlaid on plot:  $N$  (number of data points);  $M$  (mean difference);  $R$  (root mean square difference);  $C$  (correlation coefficient);  $S$  (slope). Dashed line is the 1:1 line, and the thick line is the least squares fit (linear regression equation included).

As seen in Fig. 6, considerable random error in the NARR estimates are apparent, with a root mean square difference of  $2.11 m s^{-1}$ . This is in part attributable to the comparison of area-average estimates to point observations. The mean difference (station-NARR) of  $-0.82 m s^{-1}$  indicates a general tendency for NARR to overestimate wind speeds. Notably, the least squares fit line intersects the 1:1 line at about  $2 m s^{-1}$ , showing that NARR wind speed less than about  $2 m s^{-1}$  actually tend to be too weak, with NARR wind speeds above  $2 m s^{-1}$  tending to be too strong. The corresponding linear regression equation [ $0.65198x + 0.77577$ ] was subsequently applied to the NARR wind speed at every grid point, over the entire 30-year dataset.

Following the adjustment of the NARR wind speed, comparison of NARR estimates and individual station observations was made with both the adjusted and original NARR estimates (Table 4). The eight-station-median mean difference before and after the adjustment is  $0.69$  and  $-0.08 m s^{-1}$ , respectively. Keeping in mind that this assessment was performed with the same eight stations used in developing the regression equation, the reduction in overall mean difference increases confidence in the use of NARR for the MI OFFSET 2018 tool.

Table 4: Wind speed mean difference (NARR-station), before and after wind speed adjustment, along with eight-station median of the difference.

Mean difference [ $m s^{-1}$ ]	KANJ	KAPN	KDTW	KGRR	KLAN	KMBS	KSBN	KTVC	Eight-station median
Before	1.94	-0.20	0.54	0.19	0.84	1.83	1.23	0.20	0.69
After	0.96	-0.85	-0.26	-0.53	0.10	0.79	0.15	-0.59	-0.08

#### 4.2.3) SELECTION OF METHOD FOR ESTIMATING PASQUILL CLASS

Methods for estimating Pasquill stability class may be grouped into three broad categories, those that have a weak physical basis, but are readily computed from standard station data (10-m wind speed / solar insolation / cloud cover method), those that have a somewhat greater physical basis but that require measurements not typically available from station data (standard deviation of wind direction fluctuation method, vertical temperature gradient method, wind speed ratio method), and those that are most complete in their physical basis but are generally too complicated and too restrictive in their requirements to be computed from station data [Obukhov length method, flux Richardson number (RiF) method]. We restrict discussion in this document to the last group; for information about the other methods, see Mohan and Siddiqui (1998).

The two methods with the strongest physical basis are similar in that they compare the relative roles of shear and buoyancy in the production and/or consumption of turbulent kinetic energy (TKE). TKE is the mean kinetic energy per unit mass associated with eddies in turbulent flow, and is a useful metric for evaluating the ability of the atmosphere to mix fresh air into the plume of pollutants emanating from a source, thus diluting the plume. Knowledge of the propensity of the atmosphere to favor or oppose the development of turbulence within the planetary boundary layer is the motivating factor for using such methods to diagnose Pasquill stability class. Ordinarily, such methods are difficult to apply in practice as they require variables or quantities not easily obtained from standard surface observations, and are too complicated for rapid calculations. However, the use of a dataset like NARR allows for the potential application of such methods. The RiF method was chosen for this project based on the availability of a NARR-derived RiF dataset (section 4.2.4).

#### 4.2.4) NARR-BASED PASQUILL CLASS: METHODOLOGY

The NARR-based RiF dataset was developed as part of a climatological study of turbulent conditions favoring erratic fire spread (Heilman and Bian 2013). The authors of that study graciously offered to make their dataset available to our group.

The form of RiF used in Heilman and Bian (2013) is expressed as

$$RiF = \frac{\frac{-g}{\bar{\theta}} \overline{w'\theta'} k z_{\bar{\theta}}}{\left(\frac{k\bar{U}}{10}\right)^3} \quad (2)$$

where  $g$  is gravitational acceleration [ $\text{m s}^{-2}$ ],  $\bar{\theta}$  is the mean potential temperature [ $\text{K}$ ],  $kz_{\bar{\theta}}$  is the height above ground level at which  $\bar{\theta}$  is valid [ $\text{m}$ ],  $\overline{w'\theta'}$  is sensible heatflux [ $\text{K m s}^{-1}$ ],  $\bar{U}$  is the mean wind speed [ $\text{m s}^{-1}$ ], and  $k$  is the Von-Karman constant [0.35-0.4; dimensionless] (X. Bian, personal communication). The denominator in Eq. (2) is always a production term, representing the conversion of kinetic energy of the mean flow to turbulent kinetic energy. The numerator in Eq. (2) can be either a production (mostly daytime) or consumption (mostly nighttime) term. The relative strength of shear and buoyancy, as well as the sign of the buoyancy term itself, determine whether turbulent kinetic energy will increase, decrease, or remain steady.

To compute RiF from NARR, X. Bian developed a routine that takes three NARR variables as input: 2-m potential temperature ( $\bar{\theta}$ ) surface sensible heat flux ( $\overline{w'\theta'}$ ), and 10-m wind speed ( $\bar{U}$ ).

The dataset was provided by X. Bian in the form of text files, covering the entire NARR North American domain, and the full 30-year period (1979-2008). After obtaining the dataset, a routine was developed to convert the text files into a compressed and more portable data format: HDF-5. In addition to the vast compression advantage of HDF-5 over plain text files, use of HDF-5 files enables efficient I/O for use with the on-demand footprint tool (section 4.4).

Finally, an empirical relationship was used to assign Pasquill stability class based on the NARR RiF value (Table 5). The relationship was developed by Mohan and Siddiqui (1998) based on observations collected during a 2-year field campaign at a coal-fired power plant near Kincaid, IL.

Table 5: RiF limits for Pasquill classification, adapted from Table 7 in Mohan and Siddiqui (1998).

Pasquill stability class	Flux Richardson number
A	$\text{RiF} \leq -5.34$
B	$-5.34 \leq \text{RiF} < -2.26$
C	$-2.26 \leq \text{RiF} < -0.569$
D	$-0.569 \leq \text{RiF} < 0.083$
E	$0.083 \leq \text{RiF} < 0.196$
F	$\text{RiF} \geq 0.196$

#### 4.2.5) NARR-BASED PASQUILL CLASS: EVALUATION

Unfortunately, no validation of the NARR RiF dataset was performed in Heilman and Bian (2013). Thus, before proceeding further, an evaluation of the NARR RiF-derived Pasquill class dataset was performed. Note that the use of the sensible heat flux in the RiF formulation [Eq. (2)] necessitated the use of flux tower measurements. Tower measurements at four AmeriFlux (<http://ameriflux.lbl.gov/>) tower sites were used for this exercise. The AmeriFlux network is a community of sites and scientists measuring ecosystem carbon, water, and energy fluxes across the Americas, and committed to producing and sharing high quality eddy covariance data (AmeriFlux mission statement). The four stations were chosen based on two factors: period of record, and a desire to consider both cropland and grassland sites. Metadata for the four sites is provided in Table 6.

Table 6: Metadata for four AmeriFlux micrometeorological towers used in the NARR RiF-derived Pasquill class assessment. The last three columns indicate the height above the ground at which potential temperature ( $\bar{\theta}$ ), sensible heat flux ( $\overline{w'\theta'}$ ), and wind speed ( $\bar{U}$ ) were measured.

Identifier	Location	Start	End	Land Use	% miss	$\bar{\theta}$	$\overline{w'\theta'}$	$\bar{U}$
ARM	Lamont, OK	00Z 1/1/01	21Z 12/31/08	Cropland	44	2.15	4.28	4.28
Bo1	Bondvile, IL	21Z 8/25/96	18Z 4/8/08	Cropland	16	10	10	10
IB1	Batavia, IL	00Z 3/29/05	21Z 12/31/08	Cropland	14	4.05	4.05	4.05
SdH	Whitman, NE	06Z 1/1/04	21Z 12/31/08	Grassland	41	1.92	3.85	3.8

For each tower, Pasquill class was determined from the tower and NARR-based RiF time series using Table 5. The frequencies of the D, E, and F stability classes, as well as the combined

unstable A-C classes, were computed from the tower data and NARR; the Pasquill class frequency distributions are presented in Fig. 7. Overall, the comparison is mixed, but acceptable, with the poorest comparison at the two plains sites (ARM and SdH). At ARM, NARR overestimates class F frequency by 10% and underestimates class D frequency by just over 50%, and at SdH, NARR overestimates slightly the frequency of class F but underestimates class D by 40%. At the two Illinois towers (Bo1 and IB1), the comparison is better, lending confidence to the use of NARR RiF at sites in nearby Michigan. The climate of Michigan shares arguably more in common with Illinois than the central or southern Plains states.

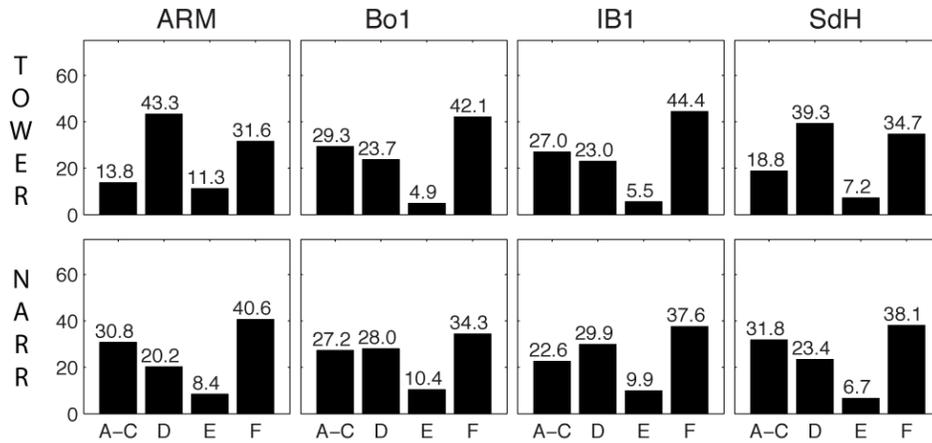


Figure 7: Frequency of Pasquill classes D, E, and F, used in OFFSET, along with the frequency of the unstable classes (A-C), at four AmeriFlux towers. Top panels are based on observed conditions, and the bottom panels are derived from NARR (with wind speed bias-correction applied).

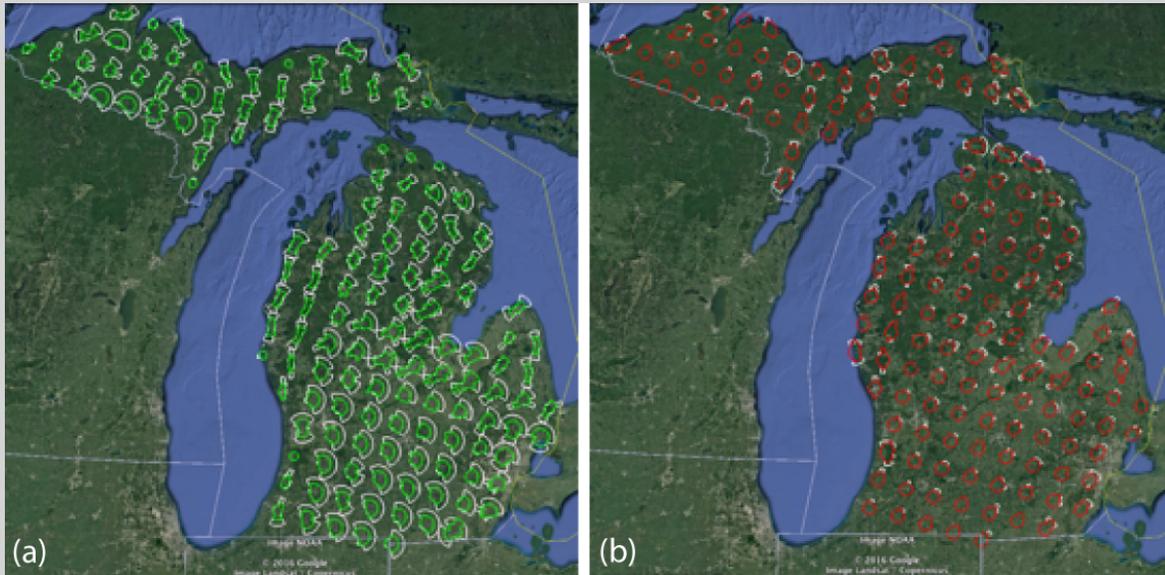
Supplemental: Evaluation of Methods for Selection of 1.5%, 3%, and 5% Classes

In developing the new version of MI OFFSET, the three odor-annoyance frequencies selected in MI OFFSET 2000 were retained, as well as the method of picking the wind-stability class whose frequency came closest, without going over, to the particular odor-annoyance frequency. As discussed in section 3.3 (*Supplemental: Odor-annoyance class - wind-stability climatology relationship*), this is an inherently conservative method.

As an experiment, an alternate method was examined wherein the wind-stability class whose frequency came closest to the odor annoyance frequency (regardless of overestimate or underestimate) was chosen. The results of this experiment are presented in Fig. 8, wherein the 1.5% and 5% footprints at all 142 NARR grid points in Michigan are visualized in Google Earth using an arbitrarily large total odor emission factor, and in Table 7 using a total odor emission factor of 108. Overall, the area of the footprint is smaller with the alternate method (colored outlines in Fig. 8) versus the original methodology (white outlines in Fig. 8). In other words, the alternate method is less conservative with smaller setback distances. The greatest sensitivity to the choice of method occurs for the 1.5% footprint, and the weakest sensitivity occurs for the 5% footprint.

Based on a comparison of 142-grid-point-median footprint area and maximum setback distance, differences between the two methods are negligible for the 5% footprint (last two columns in Table 7). Note that the percent differences between the two methods are unaffected by use of a larger total odor emission factor (not shown). A decision was made to use the original MI OFFSET 2000 method, based on three factors: (1) differences in the 5% footprints generated between the original and alternate methods were negligible, (2) the existing method is the more conservative approach, and (3) by retaining the MI OFFSET 2000 method, continuity is maintained between MI OFFSET 2000 and 2018.

Evaluation of Methods for Selection of 1.5%, 3%, and 5% Classes (continued)



*Figure 8: Google Earth overview of footprints at all 142 NARR grid points in Michigan. White lines indicate footprint generated using the MI OFFSET 2000 method for determining the (a) 1.5% and (b) 5% footprints (closest to without going over). Colored lines indicate footprint generated using an alternate approach in which the wind-stability class that came closest to the odor-annoyance frequency was chosen, regardless of over- or underestimation. Note: for this visualization, a very large total odor emission factor was used. Thus, the absolute setback distances do not have physical meaning.*

## Evaluation of Methods for Selection of 1.5%, 3%, and 5% Classes (continued)

*Table 7: Comparison of 142-grid-point-median footprint area and maximum setback distance between footprints generated using the MI OFFSET 2000 “closest to without going over” approach to choosing wind-stability class, and an alternate method of choosing the wind-stability class wherein the wind-stability class that comes closest to the odor-annoyance frequency, regardless of over- or underestimation, is chosen. For this table, a total odor emission factor of 108 was used. Note that the percent differences between the two methods are unaffected by use of a larger total odor emission factor.*

Method	1.5% median footprint area	1.5% median maximum setback distance	3% median footprint area	3% median maximum setback distance	5% median footprint area	5% median maximum setback distance
Closest, without going over	4.76	1.31	0.56	0.50	0.28	0.27
Closest, either over or under	2.18	0.78	0.46	0.37	0.25	0.27

### 4.3. Construction of odor footprint

The odor footprint is generated by MI OFFSET 2018 based on odor source information and source location provided by the user. The underlying program takes as input the source location, determines the closest NARR grid point, constructs a 30-year climatology of wind and atmospheric stability at the NARR grid point, and, as in MI OFFSET 2000, generates a 3 x 16 table of wind stability-class [3 odor-annoyance frequencies and 16 wind direction bins]. However, unlike MI OFFSET 2000, this table is location-specific rather than one-size-fits-all. At this point in the program, the steps are identical to that of MI OFFSET 2000. Based on the total odor emission factor ( $E$ ) computed from the user-provided odor source information, the setback distance is computed for each element in the 3x16 table, using the  $a$  and  $b$  coefficients from MN OFFSET, and  $E$ . Finally, lines are drawn connecting the setback distances to create the three footprints.

### 4.4. On-demand odor footprint tool

#### 4.4.1) TRANSITION FROM MICROSOFT EXCEL SPREADSHEET TO WEB TOOL

In transitioning from MI OFFSET 2000, a one-size-fits-all tool, to MI OFFSET 2018, a location-specific tool, a decision was made to terminate use of the Microsoft Excel platform. This decision was made for a number of reasons. First and foremost, the location-specific nature makes the use of

Microsoft Excel impractical, as the NARR dataset is three-dimensional, varying in the north-south, west-east, and time dimensions, and is therefore quite large (37 Gb). Furthermore, the desire to output the footprint for visualization using GIS software made the abandonment of the Microsoft Excel platform all the more necessary.

Given the large size of the dataset, a subsequent decision was made to make MI OFFSET 2018 a web tool, rather than a stand-alone program downloaded to the user's personal computer. The web tool replicates the functionality of the MI OFFSET 2000 Microsoft Excel spreadsheet, with the addition of an entry form for providing the location of the odor source, and options to export output for GIS applications.

#### 4.4.2) WEB TOOL INTERFACE

The MI OFFSET 2018 web tool is housed within Enviroweather (<https://enviroweather.msu.edu>), an interactive information system linking real-time weather data, forecasts, and biological and other process-based models for assistance in operational decision-making and risk management associated with Michigan agriculture and natural resource industries.

Upon entering the MI OFFSET 2018 URL, <https://enviroweather.msu.edu/mioffset>, you are directed to the front page (Fig. 9), consisting of a brief summary of MI OFFSET 2018, basic instructions for using the web tool, a location entry form, and a link to download the MI OFFSET 2000 Excel spreadsheet. Note that the MI OFFSET 2000 spreadsheet is provided as a courtesy to users who wish to compare odor footprints between the original and revised versions of MI OFFSET. However, **MDARD will not accept results of MI OFFSET 2000 as evidence of siting conformance.**

## MI OFFSET 2018

**A tool for evaluating odor setback distance to minimize odor nuisance complaints.**

Developed in cooperation with and sponsored by [Michigan Alliance for Animal Agriculture \(M-AAA\)](#) and [Michigan Department of Agriculture and Rural Development \(MDARD\)](#).

MI OFFSET is a planning tool for assessing potential odor impacts from livestock facilities. Output from this tool, called an odor footprint, is a radial plot which represents approximate distances that one must be away from the odor source to detect a noticeable or stronger odor up to 1.5%, 3% and 5% of the time for each of the 16 compass directions. MI OFFSET 2018 is a revised version of the previous release of MI OFFSET (originally known as Michigan Odor Print) that improves its ability to minimize odor nuisance risk when siting new or expanding livestock operations, through changes to the existing climatological dataset of wind and atmospheric stability. MI OFFSET 2018 will be implemented in the [2018 Siting Generally Accepted Agricultural and Management Practices \(GAAMPs\) document](#).

No data on your operations is stored by this website. A record of locations analyzed may be stored by Bing Maps if addresses are used (see Bing Terms of Use for full details).

You will receive odor footprint plots and a table of setback distance, and have an opportunity to download the odor footprint as a KML file or a Shapefile, for export to GIS applications.

### To use this tool:

[Page 1: Enter your location](#) » [Page 2: Enter details about animal units and waste storage](#) » [Page 3: View and download results](#)

## Page 1: Enter your location

[Page 1: Enter your location](#) » [Page 2: Enter details about animal units and waste storage](#) » [Page 3: View and download results](#)

Enter a name for the site:

Enter address	Enter latitude and longitude
Latitude:	<input type="text" value="42.729256"/>
Longitude:	<input type="text" value="-84.472938"/>

[Next Page >>](#)

[Download the previous version of MI OFFSET, MI OFFSET 2000 \(also known as Michigan Odor Print\).](#)

MI OFFSET 2000 was implemented in the Siting GAAMP document from 2005 to 2017; in 2018, it was replaced with the current tool as part of the 2018 Siting GAAMP update.

Warning: The link to the MI OFFSET 2000 Excel spreadsheet is provided as a courtesy to users of MI OFFSET 2018. MDARD will not accept results of MI OFFSET 2000 as evidence of siting conformance.

Figure 9: MI OFFSET 2018 web tool front page.

**Page 1: Enter your location**  
Page 1: Enter your location » Page 2: Enter details about animal units and waste storage » Page 3: View and download results

Enter a name for the site:

Enter address **Enter latitude and longitude**

Address:

---

**Page 1: Enter your location**  
Page 1: Enter your location » Page 2: Enter details about animal units and waste storage » Page 3: View and download results

Enter a name for the site:

Enter address **Enter latitude and longitude**

Latitude:   
Longitude:

Figure 10: MI OFFSET 2018 web tool location entry form, with address entry tab highlighted (top) and latitude/longitude entry tab highlighted (bottom).

Below the instructions, an entry form is provided to allow you to enter the location of your livestock facility (e.g., barn, storage basin) (Fig. 10). The facility location may be specified in two ways, postal address (e.g., 673 Auditorium Road, East Lansing, MI 48824) or latitude/longitude in decimal degrees (e.g., 42.728784, -84.473112). If a postal address is entered for the location, Bing Maps API geolocation technology is used to obtain latitude and longitude, which is required by the MI OFFSET 2018 program. Note that in order to proceed to the next stage (odor source entry), a valid location somewhere inside the NARR domain must be provided. Recall from section 4.2.1 that NARR is a dataset covering all of North America and surrounding waters (Fig. 5). If the address is unknown to Bing Maps or the latitude/longitude entered is not valid, or a valid

location outside the NARR domain is provided, an error message will appear instructing you to try again. Two additional words of caution regarding the latitude/longitude entry are needed before continuing. First, the longitude must be provided with a minus sign (“-”) preceding the value, to indicate degrees west longitude. Second, a minimum of six digits to the right of the decimal point is recommended (six digits yields approximately 10 cm precision).

Once a valid address is entered in the form, proceed to the odor source entry table by clicking “Next Page >>”.

**MICHIGAN STATE UNIVERSITY**  
**Enviroweather**

Tools for: [Field crops](#) | [Fruit](#) | [Landscape & Nursery](#) | [Trees](#) | [Turfgrass](#) | [Vegetables](#) | [More weather](#)

**MI OFFSET 2018**  
**Page 2: Enter details about animal units and waste storage**  
 Page 1: Enter your location » Page 2: Enter details about animal units and waste storage » Page 3: View and download results

**MI OFFSET Livestock Operation**  
 Latitude: 42.728784, Longitude: -84.473112

[Add animal units](#) | [Add waste storage](#) | [Manual entry](#)

Step 1	Step 2	Step 3
Species: <input type="text" value="Select species"/>	Technology adjustment: <input type="text" value="No Technology Adjustment"/>	Area (sq. ft.): <input type="text" value="0"/>
Animal type: <input type="text"/>	Odor control factor (calculated): <input type="text" value="1"/>	
Building or manure storage type: <input type="text"/>		
Odor emission number (calculated): <input type="text" value="0"/>		Comment (optional): <input type="text"/>

[+ Add odor entry](#)

**Summary of Odor Emission Factors: Animal units and waste storage entries**

No odor emission factors entered

Total Odor Emission Factor:

[Get Results >>](#)

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Figure 11: MI OFFSET 2018 web tool odor source entry form.

Add animal units   Add waste storage   Manual entry		
<b>Step 1</b> Species: Swine Animal type: Finishing Building or manure storage type: Deep Pit, Natural or Mech. Vent. Odor emission number (calculated): 34	<b>Step 2</b> Technology adjustment: Oil Sprinkling Inside Swine Barns Odor control factor (calculated): 0.5	<b>Step 3</b> Area (sq. ft.): 40000 Comment (optional): Swine barn <input type="button" value="+ Add odor entry"/>
Add animal units   Add waste storage   Manual entry		
<b>Step 1</b> Storage: Steel Tank Above or Below Ground Odor emission number (calculated): 28	<b>Step 2</b> Technology adjustment: Geotextile Cover (>=2.4mm or 1 inch) Odor control factor (calculated): 0.5	<b>Step 3</b> Area (sq. ft.): 25000 Comment (optional): <input type="button" value="+ Add odor entry"/>
Add animal units   Add waste storage   Manual entry		
Total Odor Emission Factor (manual): 136 <b>(This will discard information from animal units and waste storage entries)</b> <input type="button" value="Change Odor Emission Factor"/>		

Figure 12: MI OFFSET 2018 web tool odor source entry form, with animal units tab highlighted (top), waste storage tab highlighted (middle), and manual entry tab highlighted (bottom).

After clicking “Next Page >>” you are directed to the odor source entry page (Fig. 11). Note that the same odor source information required by MI OFFSET 2000 is required by MI OFFSET 2018. However, in MI OFFSET 2018, odor source information is entered via a series of pull-down menus. Tabs above the entry table allow you to toggle between animal housing and waste storage entry tables. Upon choosing the species, animal type, and housing (in the case of animal housing), or storage facility type (in the case of manure storage), values from the MI OFFSET 2000 look-up tables are automatically entered in the form; clicking an “i” symbol in the entry form opens a pop-up window containing the corresponding look-up table. For each source, odor control technology may also be specified, with values again obtained from the look-up tables and entered automatically in the form. If no odor control technology is entered, the program defaults to no technology. When all information for a particular source has been entered, clicking the “+”

symbol computes the odor emission factor for that source and adds it to the running total, i.e., the total odor emission factor. As many additional sources as desired may be entered, clicking the “+” button after each additional source to add the emissions for that individual source to the running total. For convenience, a summary of odor sources is provided below the entry form. To remove an odor source already entered, click the “Delete this entry” button next to the particular source in the summary table.

Experienced users may opt to bypass the pull-down menus and manually enter the total odor emission factor by clicking the tab “Manual entry”, entering the desired value, and clicking “Change Odor Emission Factor”. Note that checking the manual entry box will clear out any information already provided via the pull-down menus.

Once you are done entering odor source information, proceed to the MI OFFSET 2018 output page by clicking “Get Results >>”.

#### 4.4.3) WEB TOOL OUTPUT

Upon clicking “Get Results >>”, the odor source information you provided is sent to a remote server where a Python (<https://www.python.org/>) program reads in the source information, performs a number of internal calculations, and generates odor footprint images, setback distance tables, and GIS-software-compatible files. The output is transferred to the web server, and then displayed in your web browser. The entire process takes about 10 seconds to complete.

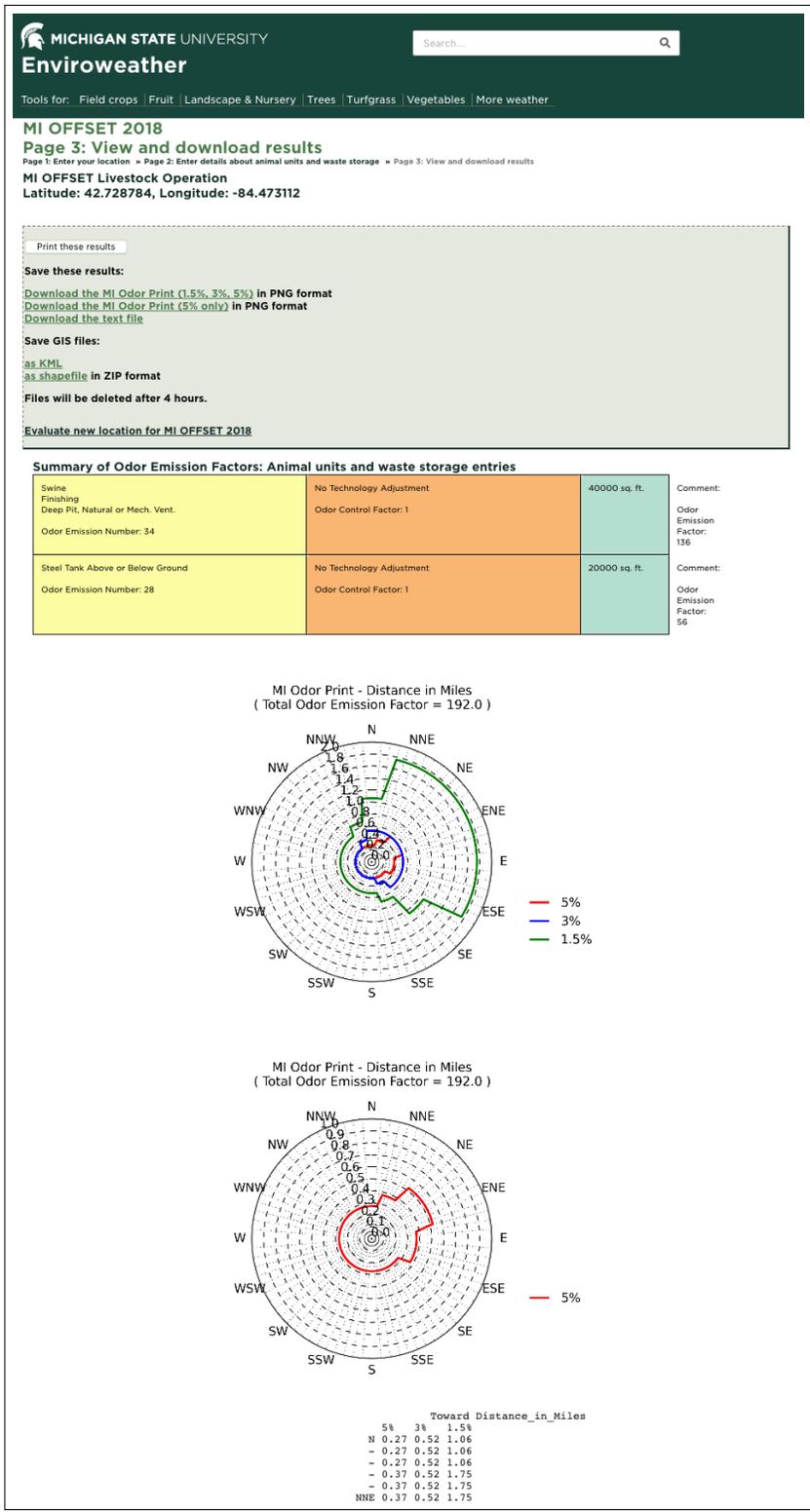


Figure 13: MI OFFSET 2018 web tool output. Note that only a portion of the setback distance table is displayed here.

**Save these results:**

[Download the MI Odor Print \(1.5%, 3%, 5%\) in PNG format](#)  
[Download the MI Odor Print \(5% only\) in PNG format](#)  
[Download the text file](#)

**Save GIS files:**

[as KML](#)  
[as shapefile in ZIP format](#)

Files will be deleted after 4 hours.

Figure 14: MI OFFSET 2018 web tool output: Links to download footprint images and setback distance table, and export footprints for use with GIS software.

Summary of Odor Emission Factors: Animal units and waste storage entries			
Swine Finishing Deep Pit, Natural or Mech. Vent.  Odor Emission Number: 34	No Technology Adjustment  Odor Control Factor: 1	40000 sq. ft.	Comment:  Odor Emission Factor: 136
Steel Tank Above or Below Ground  Odor Emission Number: 28	No Technology Adjustment  Odor Control Factor: 1	20000 sq. ft.	Comment:  Odor Emission Factor: 56

Figure 15: MI OFFSET 2018 web tool output: Odor source summary

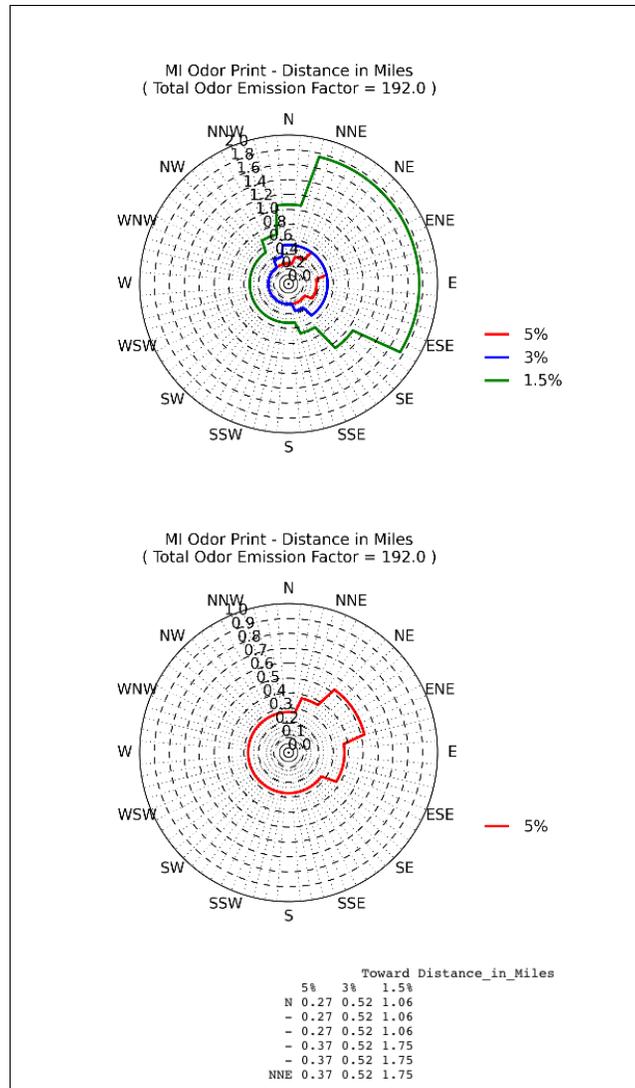


Figure 16: MI OFFSET 2018 web tool output: Odor footprint images and setback distance table. Note that only a portion of the setback distance table is displayed here.

As seen in Fig. 13, the output page includes, from top to bottom: the odor source location, a button to print a formatted version of the output page (or save it as a PDF document), links to download images and GIS-software-compatible files (Fig. 14), a button to return to the location entry form, a summary of odor source information provided (Fig. 15), and footprint images and the corresponding setback distance table (Fig. 16). Note that the footprint images and setback distance table are equivalent to the output from MI OFFSET 2000: a static image of the 1.5, 3, and 5% footprints overlaid on a polar plot, a static image of the 5% odor footprint only, and a table of setback distance as a function of direction downwind of the source. Unlike MI OFFSET 2000, you may also choose to download the footprint in a format compatible with GIS software, including Google Earth (KML format) and ArcGIS (shapefile format) (discussed in section 4.4.4).

Note that at any time, you may return to the location entry form or odor source entry form by clicking on the links “Page 1: Enter your location” or “Page 2: Enter details about animal units and waste storage”. Assuming you have cookies enabled in your web browser, the information you entered previously will be there and can be modified as desired.

#### 4.4.4) EXPORT TO GIS APPLICATIONS: GOOGLE EARTH AND ARCGIS

##### i. Preliminary steps

Before downloading the KML file or shapefile to your computer, you must obtain the relevant GIS software to view the odor footprint.

In the case of a KML file, you must first obtain Google Earth. Three Google Earth versions were available as of January 2018 - Google Earth for Chrome: <https://www.google.com/earth/>; Google Earth Pro (desktop): <https://www.google.com/earth/desktop/>; and Google Earth for mobile devices (available via iTunes and Google Play). Although the KML files generated by MI OFFSET 2018 are compatible with all three versions of Google Earth, the Google Earth Pro version is the only version with full functionality, and was the version used in developing this documentation. When ready, proceed to section 4.4.4.ii.

Finally, if shapefiles are desired, the user must install GIS software capable of displaying them (e.g., Esri’s ArcGIS, <https://www.arcgis.com/features/index.html>). When ready, proceed to section 4.4.4.iii.

##### ii. Visualizing footprints in Google Earth

Note that the following instructions were developed using Google Earth version 7.3.0.3832 on a MacBook Air running macOS Sierra (10.12.6).

- Displaying the odor source and footprint. After downloading the KML file to your computer, double-click on the file to launch Google Earth and display the contents of the file. Google Earth will automatically zoom to the odor source location, marked with a black circle. The total odor emission factor ( $E$ ) is displayed on the map, along with the 5% footprint, indicated by a red polygon. Note that to display the 3% and 1.5% footprints, you must click the small triangle to the left of the filename (In the Sidebar, in the “Places” panel) and toggle the other footprints on.



- Modifying the odor source marker. To change the marker denoting the odor source, right-click the source marker (labeled E=n, where n is the total odor emission factor) under the filename, in the “Places” panel, then choose *Get Info*. To change the marker, click on the icon symbol to the right of the name, and in the *Icon* dialog box that appears, choose a new icon, and if desired, change the icon color, scale, and opacity. You can also change the label for the odor source by entering a new name at the top of the *Edit Placemark* window.



- Modifying the odor footprint polygon. To change the appearance of the odor footprint, for example, to distinguish between multiple footprints in the same Google Earth session, right-click on the footprint name in the “Places” panel, and choose *Get Info*. In the *Edit Polygon* dialog box that opens up, click on the *Style, Color* tab and choose the desired color, width, and opacity of the polygon. You can also change the label for the footprint by entering a new name at the top of the *Edit Polygon* window.



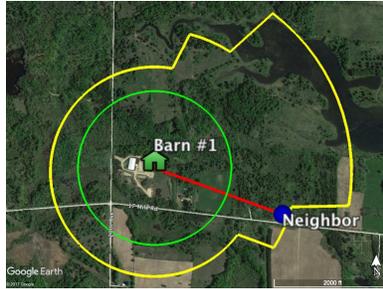
- Adding placemarks. To add a placemark, for example to mark the location of a neighboring farm, click on the yellow push-pin icon (*Add Placemark*) located on the left side of the task bar, above the viewing window. Next, hold the left mouse button down and drag the icon to the desired location. In the New Placemark dialog box, enter a name for the Placemark, and if desired, change the icon used to denote the Placemark by clicking on the *Style/Color* tab, and clicking the box to the right of the Placemark name. The new window that opens up displays a collection of icons, with options for changing the size, color, and opacity of the icon. When done choosing an icon, click *OK* on all the remaining windows and return to the viewing window.



- Measuring distance. To measure the distance between two points, click on the ruler icon on the task bar above the viewing window and make sure that the “Line” tab is highlighted. Click once on the map to reveal a yellow measuring line, and click a second time to terminate the line. The distance in miles is displayed in the Ruler dialog box; the pull-down menu on the right side of the dialog box allows distance to be displayed in a number of units. When done, click *Save* to save the measurement for later review (and, if desired, change the line properties), click *Clear* and begin another measurement, or close the Ruler dialog box by clicking the red X in the upper left corner of the window.



- Overlaying a circle with a specified radius. To overlay a circle with a fixed radius (for example, to count the number of buildings within 0.25 mile of the odor source), click on the ruler icon again, but this time click on the “Circle” tab to highlight it. Click once on the map to reveal a circle, move the cursor away from the point where you clicked, monitoring the radius in the ”Ruler” dialog box. When the desired radius is achieved, click a second time to complete the circle. Finally, click *Save* to open up the “New Path” dialog window. The circle may be given a name, and the properties of the circle path (color, width, and opacity) may be modified as desired. When done, click ”OK” to close the “New Path” dialog window.



- Saving work. To save any placemarks, lines, or other objects along with the odor source marker and footprint polygon in a file for later use, first drag all objects in the “Places” panel onto the filename, so that they are one tab to the right of the filename. Then, right-click the filename and choose *Save Place As* in the dialog box that appears, choose a name for the new file, choose the file format (KML or KMZ, which is a compressed version of KML), and click save.

### iii. Visualizing footprints in ArcGIS

Note that the following instructions were developed using ArcGIS Desktop 10.5, on a PC running Windows Server 2012R2.

- Shapefiles. Two shapefiles are generated by MI OFFSET 2018, a footprint shapefile (shp\_footprint\_FY.shp), and a source location shapefile (shp\_source\_FY.shp), along with supporting files required by ArcGIS software (\*.shx, and \*.dbf). Before proceeding with footprint visualization in ArcGIS, the user must place the shapefile (and supporting files) in a directory accessible by ArcGIS programs (e.g., ~/Documents/ArcGIS)
- Adding a basemap. To begin, open up the ArcMap application, which is the main component of ESRI’s ArcGIS suite of products. If this is your first time opening ArcMap, a *Getting Started* dialog box will open, prompting you to choose between opening an existing map, or making a new map using a template. This dialog box may be disabled for future use by checking the box in the lower-left corner of the dialog window. With *Blank Map* highlighted, click *OK*. Before displaying the odor footprint, add a basemap layer by clicking the small triangle to the right of the *Add Data* icon (below the “Selection” menu), and choosing *Add Basemap*. The *Add Basemap* dialog box that opens provides a number of basemaps to choose from. Click on the desired basemap and it is automatically added under *Layers* in the *Table of Contents* window to the left of the viewing window. If unsure of what basemap to choose, suitable basemaps include *Streets* and *Imagery with Labels* (i.e., aerial imagery, showing land use, buildings, roads, etc.).
- Navigating the map. Depending on what basemap you have chosen, the entire Earth may be displayed, or the map may be zoomed in to an unfamiliar location. If the entire Earth is displayed, click on the magnifying lens icon in the upper-left corner of the ArcMap window, click on the map and, holding the left mouse button down, drag

to create an inset box. Upon letting go of the mouse button, ArcMap will zoom into the region you have specified. Alternatively, the map may be centered and zoomed to a specified location by searching for an address or landmark. To do this, click on the *Find* (i.e., “binoculars”) icon below and to the left of the *Customize* menu to open a *Find* dialog box. In the dialog box, click on the *Locations* tab, disable the option *Use Map Extent* if it is checked, enter any location information you have (e.g., postal address, landmark, zip code) in the *Single Line Input* entry line, and click *Find*. The results of the search are displayed at the bottom of the dialog box. To zoom to the location, right-click any row in the results list and click *Zoom To*. When done zooming to the location, click the red “X” in the upper-right corner of the *Find* dialog box to close it. If a latitude/longitude search is preferred instead, click on the *Go to XY* icon to the right of the *Find* icon, enter the latitude/longitude in decimal degrees, and click the magnifying lens above the longitude entry box. When done zooming to the location, click the red “X” in the upper-right corner of the *Go to XY* dialog box to close it.

- Displaying the odor source and footprint. The next step is to add the odor source and odor footprint as layers on top of the basemap. In order to add the shapefiles as layers in ArcGIS, a projection and coordinate system must be defined using the *Define Projection* tool in ArcToolbox. The easiest way to access this tool is to open the *Search* window by holding down “CTRL-F”, searching for *Define Projection*, and double-clicking on *Define Projection (Data Management)*. In the *Define Projection* dialog box that opens, the input dataset is specified by clicking on the folder icon to the right of the *Input Dataset or Feature Class* entry line, and choosing a shapefile (either the odor source or odor footprint). The coordinate system is defined by clicking on the icon to the right of the *Coordinate System* box, and choosing the desired coordinate system. Note that a Geographic Coordinate System must be used, as opposed to a Projected Coordinate System, since the shapefiles were created in MI OFFSET 2018 with decimal degree units (i.e., no projection). If unsure of what geographic coordinate system to choose, a suitable coordinate system is WGS 1984 under the *World* heading. The *Define Projection* tool automatically adds the shapefile layers under *Layers* in the *Table of Contents* window. Note that this procedure must be done for both shapefiles (odor source and footprint).
- Modifying the odor source marker. To modify the marker used to denote the odor source, click the marker below *shp\_source\_FY* in the *Table of Contents* window. The *Symbol Selector* dialog box that opens allows the user to choose different symbols, colors, and sizes for the marker. Once done modifying the odor source marker appearance, click *OK* to close the dialog box.
- Modifying the odor footprint polygon. To modify the appearance of the odor footprint, click the shaded rectangle below “shp\_footprint\_FY” in the *Table of Contents* window. A slightly different version of the *Symbol Selector* window opens up, allowing the user to change or eliminate the fill color and change or eliminate the outline color. Once done modifying the odor footprint appearance, click *OK* to close the dialog box.
- Adding markers. To add a marker, for example to mark the location of a neighboring

farm, first enable the *Draw* toolbar by accessing the *Customize* menu, then accessing the *Toolbars* sub-menu, and toggling *Draw* on. Then, on the *Draw* toolbar, click on the small triangle to the immediate right of the rectangle shape to access a pull-down menu, and choose *Marker*. To place the marker, click on the desired position on the map, then hold down the left mouse button and drag the marker to relocate it as necessary. Finally, right-click the marker, and choose *Properties* to access the *Properties* dialog box. The color, size, and type of marker may be adjusted, and when done, click *OK*.

- Adding text labels to map. To add text labels (e.g., road names, source name) to the map, first enable the *Draw* toolbar by accessing the *Customize* menu, then accessing the *Toolbars* sub-menu, and toggling *Draw* on. Next, click on the *Text* (“A”) icon on the *Draw* toolbar, click on the map where the label is to be placed, enter the desired text, and press enter. To edit label properties (e.g., font, text color), click the label to highlight it, then adjust the properties via pull-down menus on the *Draw* toolbar. To move the label, hold down the left mouse button and drag the label to the desired location; to rotate the label, click the rotate icon on the *Draw* toolbar, then hold down the left mouse button and rotate the label to the desired angle.
- Measuring distance. To measure the distance between two points on the map, click on the ruler icon on the *Tools* toolbar above the viewing window to access the *Measure* utility. Click once on the map to begin measuring, and double-click a second time to terminate the measurement line. The distance in meters is displayed in the *Measure* dialog box. To change units, click on the third button from the right in the dialog box to access the *Choose Units* pull-down menu. When done with the *Measure* utility, click the “x” in the corner of the dialog box to close it.
- Saving work. To save any markers, lines, or other objects along with the odor source marker and footprint polygon in a file for later use, access the *File* menu, and choose *Save As*. In the *Save As* dialog box that appears, provide a name for the file and click *Save* to save the workspace as an ArcMap document.

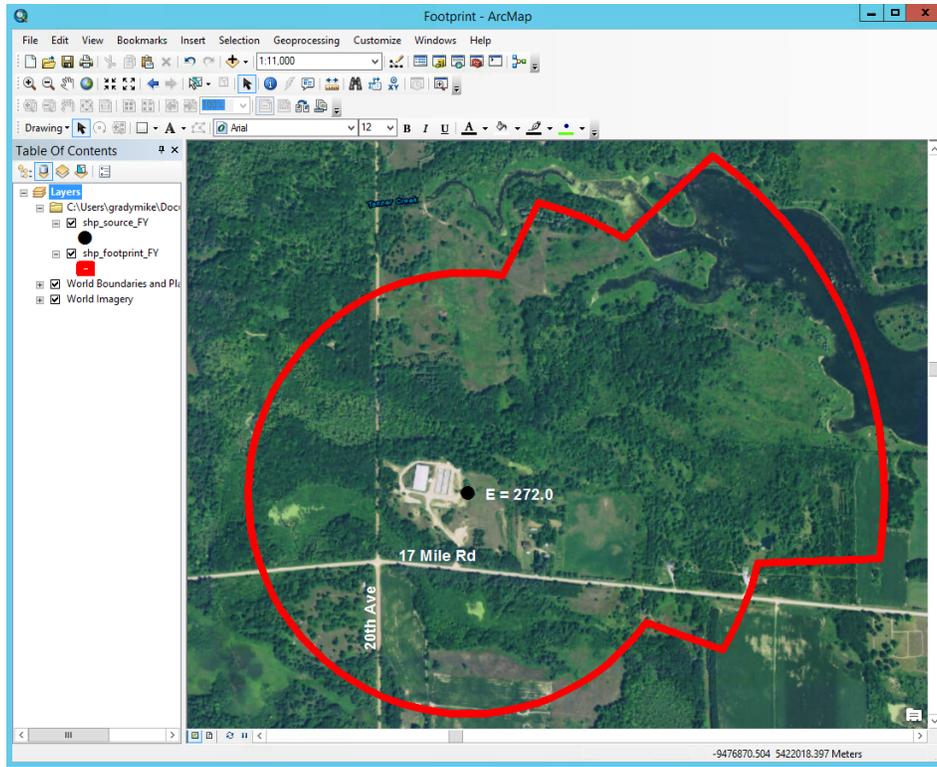


Figure 17: ArcMap display of a MI OFFSET 2018 footprint.

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