4.2.3 Odor Threat Assessment

In this study, the researchers were unable to develop a way to predict when an odor event will occur from individual meteorological parameters alone; however, certain key parameters have been noted in the literature and have demonstrated empirical relationships in this study, leading to the development of a proposed "Odor Threat Assessment Index". Assessment of potential key weather conditions for occurrence of odor complaints could assist landfill personnel in deciding whether or not to alter daily operations on a particular day. Meteorological parameters considered are:

- Wind speed/wind direction
- Temperature/Humidity
- Precipitation
- Atmospheric Stability Class (A-F; with A=being extremely unstable and F=moderately stable)
- Pressure drop over the previous 24 hours

The threat level is divided into five different categories, representing the level of possibility of an odor complaint. Those five categories are as follows (Figure 78):

1. Critical: Odor complaints are expected immediately (Red color)
2. Severe: Odor complaints are highly likely (Orange color)
3. Substantial: Odor complaints are a strong possibility (Yellow color)
4. Moderate: Odor complaints are possible, but not likely (Green color)
5. Low: Odor complaints are unlikely (Blue color)

Figure 78. Odor Threat Assessment Levels based on the Possibility of an Odor Event

No wind or weak wind speeds, lower than 3 miles per hour, are identified and ranked as critical for expecting a complaint. Low wind days also contribute to finding that stable weather conditions tend to have higher frequency of odor complaints. Lowest ranked are days with strong wind speeds of 18 miles per hour or greater (Figure 79).

Rank	Beaufort Number	Wind Speed, mph	Description
Critical	5+	<3	Light calm
Severe	4	4-7	Light breeze
Substantial	3	8-12	Gentle breeze
Moderate	2	13-18	Moderate breeze
Low	0-1	>18	Strong breeze

Figure 79. Categories of Wind Speed Ranges Based on the Critical Level of Odor Complaint Occurrence

Receptors located directly downwind from the source have highest possibility of becoming sensitive to dispersed odors. Key receptor locations are ranked as follows:

1. Critical: Directly downwind
2. Severe: Slightly downwind (±45º)
3. Substantial: Crosswind (±90º)
4. Moderate: Slightly upwind (±135º)
5. Low: Directly upwind (±180º)

Warm and humid conditions enhance the human sense of smell so that odors are perceived more intensely. Dew point temperature was selected as a parameter to reflect the relationship between humidity and temperature. By knowing the values for temperature and relative humidity, a value for dew point can be easily read from Table 45, which is adapted from the ASHRAE Psychrometric Chart.

Table 45. Relationship between Relative Humidity, Temperature and the Dew Point.

Dew-Point Temperature (°F)															
Relative Humidity	Deign Dry Bulb Temperature (°F)														
	32°F	35°F	40°F	45°F	50°F	55°F	60°F	65°F	70°F	75°F	80°F	85°F	90°F	95°F	100°F
100%	32	35	40	45	50	55	60	65	70	75	80	85	90	95	100
90%	30	33	37	42	47	52	57	62	67	72	77	82	87	92	97
80%	27	30	34	39	44	49	54	58	64	68	73	78	83	88	93
70%	24	27	31	36	40	45	50	55	60	64	69	74	79	84	88
60%	20	24	28	32	36	41	46	51	55	60	65	69	74	79	83
50%	16	20	24	28	33	36	41	46	50	55	60	64	69	73	78
40%	12	15	18	23	27	31	35	40	45	49	53	58	62	67	71
30%	8	10	14	16	21	25	29	33	37	42	46	50	54	59	62
20%	6	7	8	9	13	16	20	24	28	31	35	40	43	48	52
10%	4	4	5	5	6	8	9	10	13	17	20	24	27	30	34

Adapted from ASHRAE Psychrometric Chart, 1993 ASHRAE Fundamentals Handbook

As an example, if the temperature is 32ºF with relative humidity 80%, a dew-point temperature is equal to 27ºF. Temperature values higher than 75ºF are ranked as critical, while temperature values below 50ºF as low potential for an odor episode (Figure 80).

Rank	Dew Point (°F)
Critical	>75°F
Severe	65 - 75
Substantial	60 - 65
Moderate	50 - 60
Low	<50

Figure 80. Categories of the Dew Point Temperatures Based on the Critical Level of Odor Complaint Occurrence

Rainfall accumulation from 3 days prior to an odor complaint was identified as a possible indicator for higher frequency of odor complaints. Periods experiencing a maximum of more than 15 mm/hr of rain accumulation within a 3-day window reflect the scenario of torrential rainy days (Figure 81). Those levels of rainfall are categorized as critical for odor complaint occurrence. Dry days with maximum levels of rainfall less than 0.5 mm/hr over a 3-day period are categorized as a low-level threat for odor complaint (Figure 81).

Rank	Precipitation Previous 3 days (mm/hr)	Descriptor
Critical	>15	Intense/torrential
Severe	7.5-15	Heavy
Substantial	2.5-7.5	Moderate
Moderate	0.5-2.5	Light
Low	<0.5	Dry

Figure 81. Categories of Maximum Precipitation Experienced over the Previous 3 Days, Based on the Critical Level of Odor Complaint Occurrence

The vertical temperature gradient is a function of elevation and temperature. Atmospheric stability class is identified by measuring the local environmental lapse rate and comparing to the dry adiabatic lapse rate (-10°C/km) and the moist adiabatic lapse rate (-6°C/km), which is the rate of temperature change occurring with a rising or descending air parcel (refer to Figure 82). The instability of the atmosphere increases as the temperature decreases with elevation. When the vertical temperature gradient decreases more slowly, or even momentarily increases compared to the moist adiabatic lapse rate, the atmosphere is considered stable, which means the atmosphere resists vertical movement or mixing.

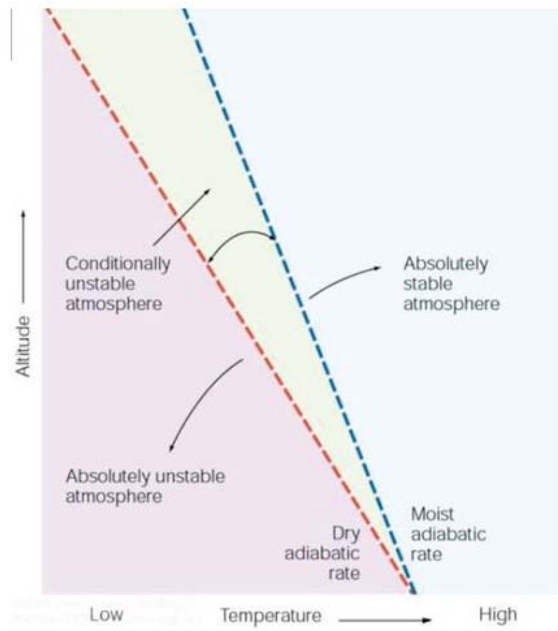

Figure 82. Diagram Showing Stability of the Atmosphere in Relation to the Dry and Moist Adiabatic Lapse Rates

This information is highly site-specific and is rarely reported at weather stations unless they are located at airports, which publish hodographs showing wind vectors at altitude. At landfills, for example, the vertical temperature gradient could be collected using multiple temperature sensors: one on the hill (landfill body) and one at the ground level (fence line). In addition, iSense has proposed to use balloon measurement devices or drones to collect this data at landfill sites. Since stable weather conditions (cloudy skies, low wind days) are related to more frequent odor complaints, those conditions were attributed with a higher level of threat for occurrence of odor complaints (Figure 83). An increase in temperature by more than 1.5ºC/100m is identified as strongly stable atmospheric class F, while a decrease in temperature by less than 1.9ºC/100m is considered as extremely unstable atmosphere class A (“Low” threat for odor complaints).

Rank	Pasquill-Gifford Scale	Vertical Temp Gradient $\Delta T/\Delta z$ (°C/100m)	Descriptor
Critical	F	> +1.5	Moderate/strongly stable
Severe	E	-0.5 to +1.5	Slightly stable
Substantial	D	-1.5 to -0.5	Neutral
Moderate	B-C	-1.9 to -1.5	Moderate/slightly unstable
Low	A	< -1.9	Extremely unstable

Figure 83. Categories of Atmospheric Stability Classes Based on the Critical Level of Odor Complaint Occurrence

Finally, the location of a temperature inversion layer must also be taken into consideration, since if an inversion layer is found aloft, then potential for fumigation of the ground level would increase the threat of odor complaints, while an inversion layer below the maximum height of the landfill source would negate any threat to residents (refer to Figure 84).

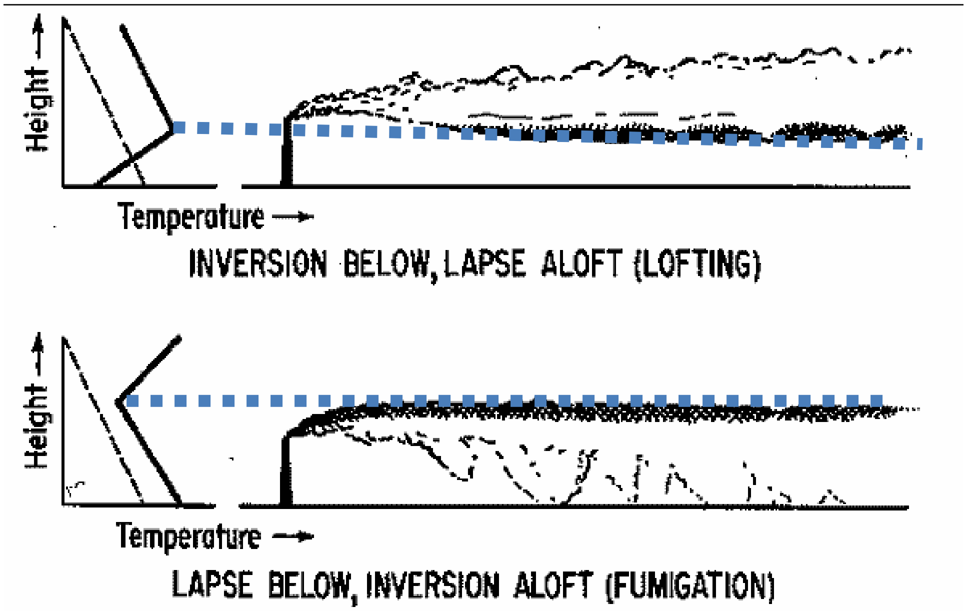

Figure 84. Depiction of Temperature Inversion Layers Below (Lofting) and Aloft (Fumigation)

Overnight pressure drop seems to be a useful indicator. However, more study is needed to develop a useful scale, which is why no numerical values appear as yet in this indicator chart (Figure 85). Low pressure days are considered as a "Critical" threat for occurrence of odor complaints.

Rank	Pressure drop	Descriptor
Critical		Low
Severe		Falling
Substantial		Neutral/normal
Moderate		Rising
Low		High

Figure 85. Categories for the Pressure Drop Based on the Critical Level of Odor Complaint Occurrence

Odor threat levels can be calibrated locally by solid waste personnel to adapt to their site-specific conditions by taking into consideration their past experiences with odor issues and by identifying weather patterns characteristic to their specific site. In the proposed model, each indicator is categorized by certain bins. For example, for wind speed, the moderate bin is 13-19 mph. Based on that, landfill managers can change the numerical values in each bin within each threat level to better represent situations relevant to their location.

An example of how odor threat levels can be used is presented in

Table 46 (without the pressure drop category, which needs more development). If the local conditions are as follows: wind speed is 1.5 mph, wind is blowing directly downwind from the odor source, temperature is 85ºF, precipitation is greater than 15 mm/hour, and the atmospheric stability class “F” or “moderately stable” is identified, the threat for a possible odor complaint is severe (all fields in red color). However, if the ambient conditions are 5 mph crosswinds with a dew point of 72F with a maximum 1.5 mm/hr rainfall over the last 3 days and atmospheric stability class of D, then we would be experiencing two indicators of “severe,” two other indicators of “substantial” and one indicator of “moderate.” In this case, based on previous experience, the landfill operator can choose to raise concern based on the worst case (2 severe indicators) or just be cautious based on the average indication being slightly below “substantial.” Of course, there are some indicators that by themselves, should raise concern, where others would be a risk based on a combination of indicators. If more facilities adopt this model, then it will become more obvious which indicators are more useful on a site-specific basis.

Table 46. Example Exercise: How to Use and Interpret "Odor Threat Levels"

WS	WD	DP	P	ASC	dP
5 mph	crosswind	72°F	1.5 mm/hr	D	-20 mbar?
<3	Directly downwind	>75°F	>15	F	
4 – 7	Slightly downwind	65 – 75	7.5 – 15	E	
8 – 12	Crosswind	60 – 65	2.5 –7.5	D	
13 – 18	Slightly upwind	50 – 60	0.5 –2.5	B-C	
>18	Directly upwind	<50	<0.5	A	

4.2.4 Alternative Technology Assessment

Once the source of odor is identified, a technology assessment can be performed to establish the preferred strategy to implement for odor control. Technologies considered in the assessment should be selected based on appropriate threshold criteria, such as minimum required removal efficiency of hydrogen sulfide, one of the most common odor-causing compound recognized for generating odors at landfill (Ko et al. 2015). Different sources of information should be accessed to gather valuable input, such as research journals, articles, U.S. EPA, and other landfills or industrial facilities practicing odor control. Since odor challenges are not exclusive to waste facilities, research articles related to technology assessment for odor control in wastewater treatment applications should also be considered. The criteria selected and ranked for the assessment should be based on sound engineering judgment, technical research, and valuable suggestions received from solid waste professionals. Some of the criteria selected could be related to:

- Odor Removal Efficiency: Technology with higher odor removal efficiency receives highest rank
- Frequency of Use: Importance of how often these technologies are successfully used in practice
- Cost Factors: Related to the capital cost and O&M cost; Detailed cost analysis should be supplied by the vendors; The technology with the lowest costs should be assigned with highest score in this criterion
- Energy Usage: Higher energy usage receives a lower score
- Land Footprint: Technology that requires smallest amount of land area receives higher score
- Chemical Requirements: Lower chemical necessity receives higher score, and
- Water Usage: Rewards those technologies that require the least amount of water for adequate performance

The scores for each of the technology options should be compiled, and an unweighted matrix constructed to identify the most preferred alternative with the highest score. Furthermore, a weighted matrix should be created by considering the assigned weight of each established criterion. The preferred option could be identified by the highest total score (unweighted and weighted), when compared to other technologies. Lastly, a sensitivity analyses should be performed by removing the highest ranked criterion since it has the highest weight on the final decision.