Odor Management in Agriculture and Food Processing

A Manual of Practice for Pennsylvania

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Odor Management in Pennsylvania
A Reference Manual

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PREFACE

While the total population in Pennsylvania is relatively stable, there is a clear migration trend toward lower density, rural communities where agricultural operations are located (Johnson, 1995). At the same time, food processing facilities have grown and livestock and poultry production units have become larger and more concentrated. Because volatile odorous compounds are an inherent part of many agricultural operations, odor complaints have become a major concern for producers. The situation is complicated since there is no universal agreement on what constitutes an objectionable odor.

Odors, once considered simply an inconvenience to agricultural production, now threaten the survivability of some operations. The future clearly demands that producers learn to understand and manage odors more effectively, and better appreciate community concerns.

This document summarizes, in an easy-to-read format, current information on odor management for agricultural and food processing operations. The intent was to develop an educational tool, not to provide detailed prescriptions for process design or regulatory control. After providing the legal and social framework for odor management, coverage is given to significant odor sources in agriculture, odor characteristics and measurement, and a summary of the various strategies for odor avoidance and control.

It will be obvious to the reader that an issue of such complexity is not amenable to a one-size-fits-all solution. Resolving odor issues will require creative solutions that are both highly effective as well as equitable. Key to this process is the development of mutual understanding for both producers and neighbors. Our hope is that the information in this manual will promote a broader understanding so that producers can deal effectively with odors while maintaining profitable and sustainable agricultural operations.

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CHAPTER 1:
INTRODUCTION

1.1 Rural Migration

According to the US Department of Agriculture, the population of rural counties across the U.S. grew by nearly 880,000 people between April 1990 and July 1992. Subsequent estimates from the U.S. Census Bureau show that the migration of urban residents to rural areas is accelerating, as rural counties gained about 1.2 million people from July 1992 to July 1994 (Johnson, 1995). More recently, the USDA's National Resources Inventory shows that the rate of farmland loss across the country has more than doubled, up to an astounding 3.2 million acres annually (Greenleaf, 2000).

As shown in the following figure, southeastern Pennsylvania is identified as one of the top *critical areas* most threatened by urban sprawl.

The current growth in rural areas arises from a gradual dispersal of the population into less dense areas. This migration is mainly driven by the conviction that small-town life is better and safer than big-city life. Urban residents are seeking simpler lifestyles. They are fleeing congestion for the clean air and open spaces that urban areas cannot offer.

1.2 Prized Real Estate

The qualities that constitute "Prime Agricultural Land" also make this same land highly sought for real estate development. Rural development is steadily consuming open space that once served as a "buffer" between agriculture and competing land uses. At the same time farm operations are becoming more "intensified" to remain competitive and meet the growing demand for commodities. As development pushes closer, a number of nuisance problems have emerged. Unpleasant odor emissions originating from farm operations are perhaps the number one complaint. This problem will continue to grow with the intensity of farming operations and development pressure on rural communities.

Many food processors and mushroom producers face the same development pressures as farm operators. Here again, odor management issues often top the list of nuisance problems.

In the mid-1960's an article entitled "Manure odors can land you in court," summarized the agriculture related nuisance odor problem as follows: "Nearly all of the complaints are originating in towns or housing developments that have sprung up near farms. At the same time, the number of animals being kept on many of those farms has increased drastically." Today, over 30 years later, these words are even more applicable.

1.3 The Odor Struggle

The rise in odor nuisance complaints has occurred, in part, because urban residents have moved to the country determined to have fresh air. Once there, they find that the "clean country air" often contains many odors, some not so pleasant. Residents complain that odors are more than just annoying. They claim that such odors diminish their comfort, quality of life, and property values.

There are practical limits to what farmers and food processors can do. Some odor is unavoidable in certain agricultural operations. Producers argue that they have as much right to the air as the newcomers, and since they were there first, they should be allowed to continue doing their work in the same fashion. After all, odor was not an issue until the residents began to live near them.

Odor problems often arise from a lack of understanding and tolerance from both sides. Differences in the perception of odors play a role too. Because odor detection and evaluation varies among individuals, one person cannot determine whether a smell is offensive for an entire population. A person whose livelihood depends on animal agriculture and has been working around a certain smell for years may not regard the odor as offensive. It is important to realize that people tend to adjust to smells over time. A person acclimated to a particular smell doesn't even notice a routine odor while a new resident will become immediately aware of a smell.

Odor problems often occur when an existing farm or food processing facility dramatically increases the size of the operation. Perhaps the most difficult situation occurs when a new large-scale animal operation moves into an area where it had not previously existed. These situations require the highest degree of odor emission control.

1.4 Addressing the Issue

The non-farming community views odors as strictly a nuisance. A farmer or food processor however sees odors as an unavoidable consequence of their livelihood. In order to live as neighbors, each side must first acknowledge the other's point of view. Neighbors need to be more tolerant of the odors from agriculture and related activities. However, farmers and food processors must take decisive action as well. There are ways to limit odors escaping from production operations, and reasonable control measures need to be employed.

Addressing this issue requires that producers better understand the generation, behavior, and management of odors. This manual, compiled from many sources, provides an overview of odors and their management in agricultural operations. Emphasis is given to providing up-to-date information on the range of approaches to odor control. Producers are also given guidance on selecting the most appropriate options for their operations. The ultimate goal is to promote a better understanding of odor generation and control strategies and, in turn, enhance the sustainability of agricultural operations at the rural-urban interface.

CHAPTER 2:
ADMINISTRATIVE APPROACHES FOR ODOR MANAGEMENT

Agricultural odor emissions are becoming a contentious issue in some areas, spurring increased efforts to address the problem. Virtually all administrative initiatives aimed at addressing the problem have been at the state and local level. This chapter provides an overview of current administrative approaches to manage nuisance complaints and examines how the courts have handled odor complaint suits. The chapter concludes with a recommended method for responding to and resolving agricultural complaints that has been particularly successful in parts of Pennsylvania.

2.1 Federal and State Legislation

Federal environmental regulations are administered by the United States Environmental Protection Agency (U.S.EPA). The U.S.EPA has no standards specifically pertaining to malodors (Sweeten and Levi, 1996). Rather, federal regulators view odors as a local problem best handled through local oversight. This position is founded on the belief that most agricultural odors are of transient importance and are "merely a nuisance unless the ingredients are toxic" (Sweeten and Levi, 1996).

Essentially all odor emission regulation is administered at the *state and local levels*. Most states have requirements for livestock waste management, but these regulations may or may not address air quality (Sweeten and Levi, 1996). For example, Pennsylvania's 1993 *Nutrient Management Act* (NMA) provides guidance for appropriate storage, handling and land application of plant nutrient materials, including livestock manure. Despite the fact that odors are not mentioned in the Act, odor emission issues unavoidably arise during practical application of the NMA.

The primary driving force behind the Pennsylvania NMA is a *water quality*-based environmental concern. Final regulations implementing the Act became effective on October 1, 1997 (Beegle et al., 1997). These regulations contain no specific requirements relative to livestock manure odors. The law does, however, provide protection for farm operators against local ordinances and/or regulations that may place more stringent requirements on livestock manure storage and use (Beegle et al., 1997). This prohibition against local regulation of manure practices that conflict with the NMA, at least indirectly, offers a certain level of uniformity and protection for farm operators. Moreover, full compliance with the Pennsylvania NMA Regulations is a critical prerequisite for defending manure practices that may be subject to odor complaints by neighbors. The following discussion reinforces this point.

The Pennsylvania Right-to-Farm Act (RFA) was enacted in 1982. The intent of this legislation is to reduce the loss of agricultural resources by limiting the circumstances under which agricultural activities may be subject to nuisance suits and ordinances that restrict farming. The act does not prohibit lawsuits by neighbors. The RFA establishes a one-year period (from the inception or substantial change to an agricultural operation) within which a nuisance suit may be upheld. Alternatively, a nuisance suit may be based on a violation of Federal, State, or local statutes or regulations (Feirick, 1999).

In May 1998 the Pennsylvania RFA was amended to exclude new or expanded farm operations from nuisance law suits as long as the operation has an approved *Nutrient Management Plan* and is in compliance with the NMA (Feirick, 1999). This latest legislative action forges an unmistakable link between the RFA and NMA relative to nuisance complaints and affirms the importance of following sound nutrient management strategies.

Non-farm citizens of the Commonwealth have rights too. Article 1, Section 27 of the state Constitution gives Pennsylvanians the right to clean air, water, and preservation of the aesthetic values of the environment. Each resident of Pennsylvania is a trustee of the state's natural resources and responsible for conserving them for future generations. In the present context, the difficulty comes when the right to clean air conflicts with the right of agricultural enterprises to operate.

2.2 Local Zoning and Ordinances

Pennsylvania's planning code gives municipalities the authority to regulate affairs that influence safety, health, and welfare, and land use within their boundaries. Municipalities exercise this authority primarily through zoning. Ideally, zoning rules must be established in advance of the activity that is to be regulated. A business, industry, or farm legally established before zoning has the right to operate according to the rules in effect at the time of establishment. Zoning standards will only apply to operations established after an ordinance goes into effect (Abdalla and Becker, 1998).

However, farm operations located in agriculturally zoned areas are not immune from nuisance lawsuits. *Unreasonable* interference with a neighbor's *enjoyment* of his or her property is an issue independent of zoning (Sweeten and Levi, 1996). If a livestock operation is in an area zoned for agricultural use, it is easy to make the case that the land use is reasonable. Agricultural zoning keeps the number of people living nearby at a minimum, and this in itself may limit the likelihood of nuisance lawsuits. But failure to use land consistent with zoning standards constitutes a public nuisance in many states, and injunctions may be granted on the basis of nonconformance (Sweeten and Levi, 1996).

2.3 What is a Nuisance?

When common law was first developed, an overriding principle was that a landowner had the right to use and enjoy his land as he wished. The concept of nuisance had no legal basis. With time it became obvious that neighboring landowners might choose incompatible property uses. The use of land by one landowner can clearly conflict with the responsibility not to interfere with another's right to enjoy his own property. Nuisance laws attempts to solve this conflict with the concept of "reasonableness". An unreasonable interference with a person's right to enjoy their property is now legally a nuisance. The rules governing unreasonable interference are similar in all states (Sweeten and Levi, 1996).

A typical approach is to consider that an agricultural enterprise in operation for at least a year without causing a nuisance is not considered a nuisance even when new neighbors arrive. If farm operations are conducted in a *reasonable* manner consistent with statutory requirements, the courts routinely rule in favor of the operator.

There are two basic types of nuisance lawsuits, a *private* nuisance claim filed by a single neighbor, or a *public* nuisance claim filed by a group of people such as the residents of a subdivision. A nuisance lawsuit will not succeed in most jurisdictions unless that complaining party (the plaintiff) can demonstrate one or more of the following (Fershtman, 1999):

1. The action in question was carried out in a wrongful or unreasonable manner, for example, a legitimate activity in an unsuitable location;
2. The action resulted in substantial harm to the plaintiff or his property; or
3. The action materially impeded the use and enjoyment of the plaintiff's property.

In a civil lawsuit where a jury is involved, what constitutes "unreasonable interference with enjoyment of property" may vary. Some jurors might deem an activity to be "unreasonable interference with enjoyment" even though all air and water pollution regulations and standards are being met. Thus it is possible for a livestock operation to be sued under nuisance laws despite compliance with the state regulatory agency. Even the threat of a nuisance lawsuit may change waste management practices at an agricultural operation. Such threats serve as a form of "private regulation" (Sweeten and Levi, 1996).

A nuisance lawsuit can involve a request for an injunction, for damages, or for both. In an injunction, the court seeks to be equitable to both parties. The court weighs the plaintiff's allegations that the operation creates intolerable living conditions, is hazardous to health, or lowers the value of the land, versus the defendant's assertions that sizeable investments and perhaps community jobs would be lost if operations ceased (Sweeten and Levi, 1996).

2.4 Approaches in Other States

Each state has a Right-to-Farm Law, intended to protect farmers from nuisance suits that may arise from normal agricultural operations. A few states and the District of Columbia have enacted air quality standards, which stipulate the odor threshold in ambient air at the property line. Even if a state does not have air quality regulations, existing water pollution and solid waste regulations, as well as any new enforcement acts may be applicable. (Sweeten and Levi, 1996).

North Carolina

Next to Iowa, North Carolina is the second leading hog-producing state. In 1993, the Swine Odor Task Force (SOTF) was formed because the state recognized the seriousness of swine odors. The SOTF was charged with determining the primary sources and causes of odors as well as how those odors could be reduced (SOTF, 1995).

In 1995, North Carolina began placing restrictions on where hog farms could be located. Mandatory setbacks were imposed, which specified distances between the source of the odor and the property line. This buffer distance reduced odor intensity at adjacent properties for newly established hog houses, waste lagoons, and spray fields. Hog confinement facilities and lagoons were also prohibited in floodplains. These new requirements have not totally eliminated odor complaints, particularly in areas where older hog facilities have long existed (Abdalla and Becker, 1998).

A two-year moratorium was imposed in 1997 on new and expanded hog farms to permit alternative hog waste management methods to be developed. The state also directed a gradual replacement of open-air waste lagoons and spray fields with more effective systems. The original plan developed by state agricultural officials fell short of meeting all requirements. Another plan, developed by the Environmental Defense Fund has been proposed to guide the state in phasing out these systems (SOTF, 1995).

As of 1997, local governments in North Carolina have zoning authority over pork production facilities. Most of the states 2500 hog farms were already in existence, however, and zoning restrictions only apply to the largest farms (>4500 hogs) (SOTF, 1995).

Iowa

In Iowa, new requirements have been enacted which dictate minimum separation distances between buildings, nearby neighbors, and any other sensitive areas. Construction permits are also required for certain facilities, and permit fees have been used to establish an indemnity fund (Abdalla and Becker, 1998).

Iowa's Animal Feeding Operations Act (1996) provides operators with a mechanism to defend against nuisance lawsuits. A defendant is entitled to rebut a claim by providing evidence that he/she has obtained all required permits for an animal operation. If this is done, the facility cannot be considered a nuisance under either Iowa's statutory or common law (Abdalla and Becker, 1998).

Colorado

A state constitutional amendment was approved in 1998 which contained air and water quality regulations specific to swine operations (Marbery, 1999). Under these laws, the Colorado Air Quality Commission has the authority to require producers to obtain odor permits. Operations that began before March 1999 and with more than 800,000 pounds live-weight capacity, must be approved by the state. Property-line threshold levels and specific dilution factors form the basis of odor rules. These rules have increased interest in technologies for odor control. New or expanding operations must employ technology that will control odors to the *greatest practicable extent* (Marbery, 1999).

Because the state regulatory agencies cannot police every facility, enforcement relies on public involvement. Regulators and producers agree that the new law is a complex experiment that will involve much "give and take" on all sides (Marbery, 1999).

Texas

Construction and operation of livestock feedlots require a permit from the Texas Air Control Board (TACB). New livestock feeding operations with more than 1,000 head (any size or types of animal) must obtain a permit prior to beginning construction. Permit issuance considers facility location relative to surrounding land uses, prevailing winds, waste management design, and other factors (Sweeten and Levi, 1996).

The TACB odor nuisance regulation states that: "No person shall discharge from any source whatsoever one or more air contaminants or combinations thereof, in such concentrations and such duration as are or may tend to be injurious to or to adversely affect human health or welfare, animal life, vegetation or property, or as to interfere with the normal use and enjoyment of animal life, vegetation or property" (Sweeten and Levi, 1996).

2.5 Noteworthy Legal Cases

In order to understand how odor complaints are resolved in court, it is useful to review a few noteworthy cases. The following cases demonstrate that the *Right-to-Farm* is still a useful defense and new neighbors cannot expect pre-existing operations to be shut down. But as the character of a neighborhood changes, what constitutes "common sense" and "ordinary sensibilities" may change too (Purdue, 1998). While producers should be protected from unreasonable demands, neighbors rights to unreasonable interference with the enjoyment of their property must also be respected (Purdue, 1998).

Horne v Haladay (Columbia Co., Pennsylvania)
[Source: Feirick, 1999]

In November 1993 the Haladay brothers stocked 122,000 laying hens in their poultry housing located in Columbia Co., Pennsylvania. In November 1995 Horne (a neighbor) filed suit claiming that the Haladays failed to take reasonable steps to control flies, odors, and noise. Horne sought $60,000 in damages for alleged depreciation to his home.

In responding to the Horne suit, the Haladays cited the Pennsylvania *Right-to-Farm Act* and requested that the complaint be dismissed. Moreover, the Haladays claimed that the nuisance suit had not been filed within one year of the commencement of the agricultural operation (or substantial change thereto) as allowed by the Act. The Haladays noted that their operation had remained substantially unchanged since November 1993, a full two years prior to the suit being filed. The Columbia County Court of Common Pleas found in favor of the Haladays and barred the Horne suit, based on the RFA argument.

On appeal, the Pennsylvania Superior Court focused on the one-year period allowed for filing of nuisance actions as provided by the RFA. The court found that in order to overcome the one-year time limit, Horne needed to show that the Haladays' agricultural operation violated local, state, or federal statutes. No such evidence was produced. Furthermore, the Haladays introduced a report from a Pennsylvania Department of Agriculture veterinarian stating "that the farm was taking an aggressive, proactive management approach to controlling flies and farm odors" (Feirick, 1999). Accordingly, the Horne suit was dismissed on March 30, 1999.

Herrin vs. Opatut (Atkinson Co., Georgia)
[Source: 248 Ga. 140 (1981)]

Opatut bought 57 acres in 1977 and built 26 *chicken layer* buildings over the next two years. On March 15, 1979 40,000 layers were stocked in the housing. By April 1980 500,000 chickens were housed in the facility and residents *(neighbors)* in the surrounding area filed a nuisance suit complaining of odors, flies, and manure runoff. The neighbors argued that they were living on the land next to the Opatut's poultry operation prior to its establishment.

Opatut defended his operation by arguing that his management was *state-of-the-art*. He also relied upon the Right-to-Farm statute, which protected agricultural operations in Georgia. Under Georgia's Right-to-Farm statute, Opatut argued, his operation was protected as it existed at least one year prior to the plaintiff's filing of the lawsuit. The trial court dismissed the lawsuit in favor of Opatut.

Eventually this decision was reversed on appeal when the court ruled that the surrounding non-agricultural land uses did not encroach on the Opatut egg farm. Rather, the reverse was true, despite that fact that the operation functioned for greater than one-year prior to the suit filing.

Shatto vs. McNulty (Jennings Co., Indiana)
[Source: 509 N.E. 2d 897 (Ind.App.1987) as cited by Purdue, 1998]

McNulty raised swine on his farm since 1956, except when the facilities were being rebuilt in 1970-71. In 1968, the plaintiffs (Shatto) purchased 15 acres and built a home directly across from McNulty's hog barn. Odor complaints began in 1970 but the suit was not filed until 1986. The plaintiff acknowledged being aware of the barn and not making any effort to discover its use. The appeals court upheld the lower court's application of the Right-to-Farm Law (Purdue, 1998) finding in favor of McNulty.

Laux vs. Chopin Land Associates, Inc. (Whitley Co., Indiana) [Source: 550 N.E. 2d 100 (Ind.Ct.App.1990) as cited by Purdue, 1998]

Laux owned and farmed 123 acres in Whitley County, Indiana. He sold 113 acres in December 1986 to Chopin Associates. In August, 1986 Laux began feeding hogs on the remaining ten acres. The operation eventually grew from 29 feeder hogs to a 300-350 sow farrow-to-finish operation by mid-1987. Chopin claimed to have first learned of the operation in June, 1987. Chopin served Laux with a notice requesting an end to the nuisance. After Laux refused, Chopin filed suit in 1988.

Despite Laux's reliance on the Right-to-Farm Law, the trial court ruled that the operation was a nuisance and that livestock should not be raised on the property. In appeal, Laux claimed the operation was active more than one year before the suit and should be protected. The appeals court agreed that so long as the farm was not a nuisance initially and had been operating for more than one year, a change in the surrounding area did not make it become a nuisance. However, the court noted that the *change in type of operation* provision of the law applies any time, even after the first year. The court concluded "the effect of a significant change in either hours of operation or type of operation is to again invoke the statutory conditions and recommence the running of the one year statutory clock."

The court held, however, that even though this was a change in operation type, it had been operated for more than one year and was thus protected. The court recognized that the law specifies changes in type rather than size of operation, noting "it follows that merely increasing or decreasing the size or numbers of an operation will not serve to change the type of operation."

Yeager and Sullivan Inc. v. O'Neil (Fulton Co., Indiana)
[Source: 324 N.E. 2d 846 (Ind.App.1975) as cited by Purdue, 1998]

The O'Neil residence was approximately one thousand feet from the hog operation buildings of Yeager. The O'Neils and other witnesses stated that the "odor was so pungent that you just couldn't get your breath," and that their properties were plagued by flies and rats following the commencement of the hog feeding operation. Although the O'Neils acknowledged their property was not free of flies and rodents prior to the operation of the hog facility, conditions had reportedly gotten significantly worse in the preceding two years. Drainage of solid wastes into ditches and accumulations of waste were also noted.

The appeals court decided the term "nuisance" was impossible to define in any way that could apply to all the aspects of the case. The court found insufficient evidence to support the trial court's opinion that the odors were possibly injurious to the health of the plaintiffs, but also noted that the determination of nuisance does not depend on proving injury to health.

A claim for damages was based on a realtor's calculation of the reduced rental value of the plaintiff's property. The appeals court let the lower court damages award stand holding that the defendant was responsible for a decline in property value.

Rust v. Guinn (Monroe Co., Indiana)
[Source: 429 N.E. 2d 299, 300 (Ind.App.1981) as cited by Purdue, 1998]

The trial court determined that odors and flies from the manure on a 495,000 hen laying operation constituted a nuisance to the neighbors. An injunction was not issued but the jury awarded $9,500 in damages. The appeals court ruled that damage awards are appropriate if measured by: 1) the reduction in the property's rental value for the period the nuisance existed; 2) actual expenses incurred in attempting to reduce the effects of the nuisance conditions;

and 3) damages for health injuries directly attributable to the nuisance.

2.6 Future Implications

Legal actions are often the most powerful force in odor management. Courts ultimately interpret laws and regulations are interpreted when deciding individual odor complaint cases. Thus the public plays an important role in regulation of odors (Sweeten and Levi, 1996).

Because of the technical difficulties of defining a maximum allowable odor value, the existing regulatory framework does not easily address odors. Technology is being developed to determine quantitative values for odors, which would enable regulatory agencies to establish maximum emission rates for odorous compounds. The potential therefore exists that agricultural operations could fall under regulations like the federal Clean Air Act. Under the Clean Air Act, the operations would be required to have a permit if classified as a major source of air pollution.

An unresolved issue is the effect of odors on public health. Research is already underway as to the potential human health effect, if any, of malodors. If serious effects are found, the odors may be categorized under the Clean Air Act and could be added as a noxious air pollutant.

2.7 Odor Complaint Resolution

Perhaps the most effective means of resolving farm-based odor problems is found in the Environmental Resource Coordinator Program, an outgrowth of a Pennsylvania Farm Bureau (PFB) initiative that originated over 30 years ago in northwestern PA. Today, this program operates statewide as a partnership between the PFB and the Pennsylvania Department of Environmental Protection (DEP). The initiative has earned a reputation for resolving a variety of farm-based environmental problems, including farm odor problems (PFB, 1999).

The success of the Environmental Resource Coordinator Program is based on volunteer PFB county Coordinators who investigate farm complaints. Coordinators are familiar with normal farm operations and can quickly assess the validity of a particular complaint. The investigation is performed in a non-threatening, farmer-to-farmer manner, aimed at getting results. If a complaint is found to be accurate, the coordinator works with the operator to obtain a commitment to resolve the problem and helps to identify a solution strategy. The farm operator is given the opportunity to resolve the problem without formal regulatory action and fines, thus allowing resources to be targeted to solutions, not punishment (PFB, 1999).

Administration of the Environmental Resource Coordinator Program involves a PFB appointed Regional Chairman in each of the DEP's six statewide regions. Each PFB Regional Chairman maintains a list of county Coordinators who are responsible for site visits within their respective counties. A complaint triggers a series of actions, which may be summarized as follows (PFB, 1999):

1. The DEP regional office receives a complaint.
2. The DEP contacts the PFA Regional Chairman and forwards the complaint particulars.
3. The PFB Chairman forwards the complaint to the county Coordinator within whose county the subject farm operation is located.
4. The county Coordinator visits the farm operation and assesses the validity of the complaint.
5. If the complaint is valid, the Coordinator obtains the farm operator's commitment to pursue a resolution and assists in identifying potential alternative solutions.
6. The Coordinator reports back to the regional chairman, who in-turn notifies the regional DEP office.

The Environmental Resource Coordinator Program is specifically aimed at solving farm-based environmental problems. As such, this approach ordinarily would not apply to food processing operations unless such facilities were small-scale and located on-farm. However, expansion of this model (or similar model) beyond the farm setting to include at least some food processing operations could be beneficial.

CHAPTER 3:
ODOR SCIENCE BASICS

In this chapter we consider basic concepts relevant to odor generation, release and transport. The *odor problem pathway*, common terminology used in odor management, and biological considerations will be introduced.

3.1 The Odor Pathway

For an odor to become a nuisance, four basic ingredients are required:

A **malodor source –** unstable organics generally exposed to anaerobic conditions that facilitate decomposition of easily biodegradable materials resulting in the generation of malodorous gasses

Odor release to the atmosphere – malodorous gasses generated as a result natural escape or mechanical introduction into the atmosphere

Off-site odor transport – odorous emissions are conveyed from the point of generation / release to nearby properties which are not under the control of the facility operator

odor perception – odors are detected by people off-site who judge them to be offensive and register a complaint

If any of these four factors are absent, no odor problem exists. Hence, it follows that management involves examination of these factors to find the best point(s) at which to interrupt the odor pathway and avoid complaints. The following sections examine the first three of these factors. Chapter 4, *Odor Detection and Measurement*, looks at the last factor.

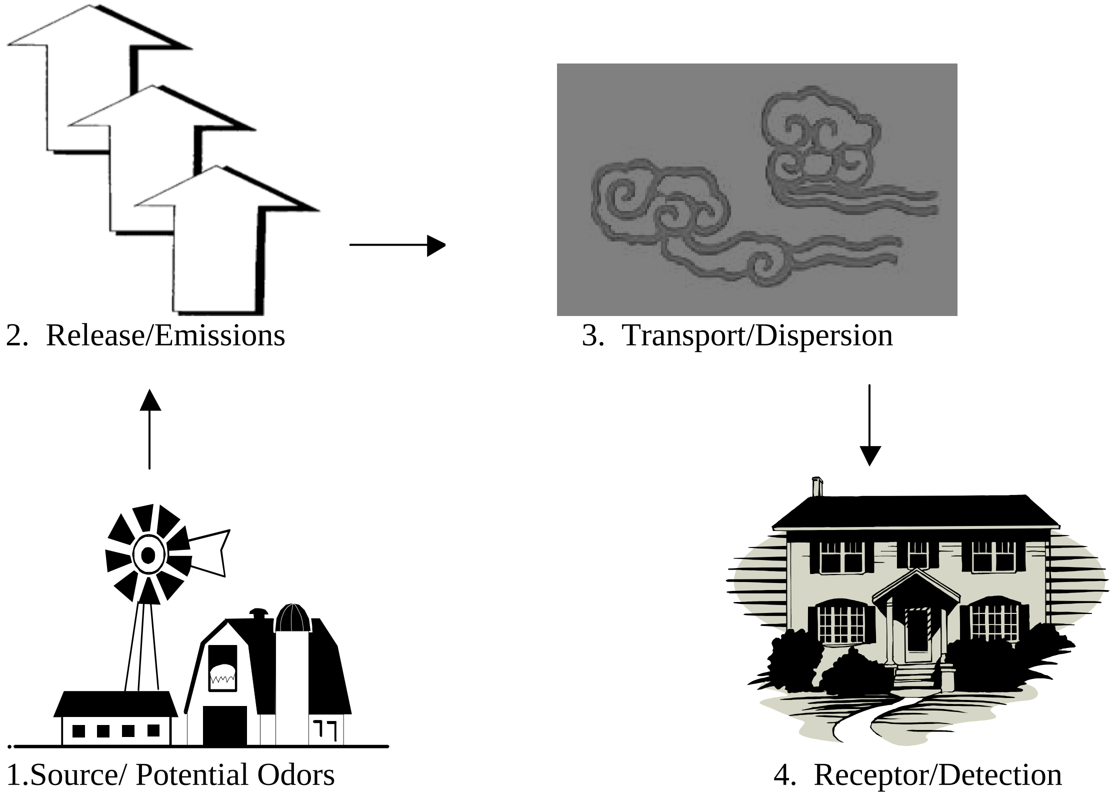


Figure 3.1 The Odor Pathway

3.2 Generation and Nature of Agricultural Odors

Malodors usually include a mixture of numerous offensive compounds. Agricultural and food processing odors are no exception. Over 160 chemical compounds have been identified in livestock wastes or in nearby air (O'Neill and Phillips, 1992). Researchers have used various approaches to categorize odorous compounds to facilitate measurement and control (Mackie, 1994; Zhu and Jacobson, 1999). Table 3.1 presents an abbreviated list of odorous compounds contained in four major categories, which are briefly described in the following sections.

Table 3.1 Select Odorous Compounds in Manure [1]

Compound Name	Chemical Formula [2]	Molecular Mass [2]	Odor Detection Threshold (mg/m^3) [3]	Odor Description [3]
Volatile Fatty Acids (VFAs)				
Acetic acid	CH_3COOH	60	0.025-10	Vinegar-like, Pungent [1]
Propionic acid	C_2H_5COOH	74	0.003-0.89	--
Butyric acid	C_3H_7COOH	88	0.0004-42	Rancid butter
Iso-butyric acid	$(CH_3)_2CHCOOH$	88	0.005-0.33	--
Formic acid	$HCOOH$	46	2-640	Pungent [1]
Valeric acid	C_4H_9COOH	102	0.0008-0.12	Unpleasant, offensive [1]
Iso-valeric acid	$(CH_3)_2C_2H_3COOH$	102	0.0002-0.0069	
Caproic acid	$C_5H_{11}COOH$	116	0.02-0.52	Unpleasant, offensive [1]
Capric acid	$C_9H_{19}COOH$	172	0.05	--
Indoles and Phenols				
Indole	$C_6H_4(CH_2)_3NH$	117	0.0006-0.0071	Fecal, nauseating
Skatole	C_9H_9N	131	0.00035-0.00078	Fecal, nauseating
Cresol	C_7H_8O	108	0.00005-0.024	Phenol-like, medicinal
4-ethylphenol	$C_8H_{10}O$	122	--	Phenol-like, medicinal
Ammonia and Volatile Amines				
Ammonia	NH_3	17	0.03-37.8	Pungent, irritating
Putrescine	$NH_2(CH_2)_4NH_2$	88	--	Putrid, nauseating [4]
Cadaverine	$NH_2(CH_2)_5NH_2$	102	--	Putrid, decaying flesh [4]
Methyl-amine	CH_3NH_2	31	0.0012-6.1	Putrid, fishy
Ethyl-amine	$C_2H_5NH_2$	45	0.05-0.5	Ammonia-like
Volatile Sulfur-Containing Compounds				
Hydrogen sulfide	H_2S	34	0.0001-0.27	Rotten eggs
Methyl-mercaptan	CH_3SH	48	0.0000003-0.038	Rotten cabbage, skunk
Ethyl-mercaptan	C_2H_5SH	62	0.000043-0.00033	Decayed cabbage, skunk

(1) After Zhu and Jacobson (1999)
(2) WEF (1995)
(3) O'Neill and Phillips (1992)
(4) Lue-Hing, et.al. (1998)

Volatile Fatty Acids (VFAs)

Volatile fatty acids are produced during the decomposition of proteins and carbohydrates. The pH of the decomposing material will, to a certain extent, determine breakdown products. For example, at a pH of 6-7 (normal pH in the intestinal tract), protein breakdown produces VFAs, CO_2, H_2, and ammonia. Odorous compounds belonging to the VFA group include acetic, proprionic, butyric, *iso*-butyric, formic, valeric, *iso*-valeric, caproic, and capric acids. Odor descriptors associated with these compounds range from pungent to distinctly unpleasant to offensive (Zhu and Jacobson, 1999).

The general consensus among odor researchers is that VFAs are well correlated with odor intensity, and as such may be a suitable odor indicator. However, this relationship does not always hold true, leading some investigators to postulate that long C-chain (containing more than 10 carbon atoms) VFAs are mostly responsible for odor generation (Zhu and Jacobson, 1999).

Indoles and Phenols
Four compounds are identified as major odor contributors in this group: indole, skatole, cresol, and 4-ethylphenol. These and other related compounds are produced by microbial (bacterial) decomposition in the intestinal tract of animals (Zhu and Jacobson, 1999). Fecal, nauseating odors are characteristic of compounds in this group (indole and skatole).

Ammonia and Volatile Amines
The common structural feature among compounds in this category is an amine group ($-NH_2$). The most notable of these are ammonia, putrescine, cadaverine, methyl-amine, and ethyl-amine. Bacterial decomposition of proteins (amino acids) and urea hydrolysis (resulting in ammonia release) are the primary mechanisms for the formation of these odorous compounds (Zhu and Jacobson, 1999). Characteristic odors range from pungent, irritating, and *ammonia-like* to decaying animal tissue, and putrid fishy.

Volatile Sulfur-Containing Compounds
Odorous compounds in this group include sulfides (reduced form of sulfur) and methyl- and ethyl-mercaptans. These compounds are produced by bacterial activity involving sulfate reduction and metabolism of sulfur-containing amino acids (Zhu and Jacobson, 1999). Odors like decayed cabbage, putrid garlic, and rotten eggs are characteristic of this group.

A Word about Odor Detection Thresholds
The *odor detection threshold* is the minimum odorant content required to perceive a smell in ambient air. This is distinguished from the recognition threshold, at which point an odor can be identified. Because individuals detect odors at different levels, the range for detection thresholds can be wide (Table 3.1). The minimum detection threshold for compounds can be drastically different. For example, at the lowest end of the detection range, methyl-mercaptan may be detected at concentrations 1000 times lower than that required for detection of hydrogen sulfide. Accordingly, methyl-mercaptan is a much more pervasive compound requiring many, many dilutions to reach a *non-detect* level. Management of odor emissions containing low detection threshold compounds is considerably more problematic. Hence, avoiding conditions which favor

formation of such compounds is the best solution, when this is possible.

Nearly all odorous compounds result from biological degradation of organic matter (primarily proteins) (Zhu and Jacobson, 1999). Hence, it is helpful to have a fundamental understanding of this connection to biological activity. The following section provides an overview of this *biological link* that plays such a critical role in odor generation.

The Biological Link

Organic matter decomposes through two basic biological mechanisms. In aerobic decomposition, microorganisms that require an oxygen rich environment perform the breakdown of proteins and carbohydrates to smaller molecular forms needed for metabolism. The primary gaseous end-product is carbon dioxide. In anaerobic decomposition, a different set of microorganisms uses compounds other than oxygen for metabolism. Under these conditions, the end products of decomposition can include highly odorous compounds such as hydrogen sulfide (rotten egg odor).

Digestion of organic matter by higher animals is a controlled anaerobic process. The relatively constant warm temperature, existing microbial population, and digestive enzymes present in the gut provide an ideal environment for anaerobic decomposition. Formation of odorous gasses therefore begins even before manure is voided (Miner, 1997). Immediately upon excretion, volatilization of low molecular weight compounds begins and the odor of fresh manure is recognizable. While this odor is disagreeable, most people consider fresh manure to be considerably less offensive than aged, septic material.

Continued manure decomposition and the rate at which decomposition progress depend on environmental conditions. If aerobic conditions predominant, then initial odors dissipate and further generation of malodors is minimized. If anaerobic conditions predominate, then formation of odorous gases continues or even accelerates. Changing environmental circumstances, such as from aerobic to anaerobic conditions or visa versa, will change the nature of odor emissions from a particular source.

While there are exceptions, the typical temperature and pH range required for proliferation of bacteria responsible for odor generation is 68 to 104 degrees F (20-40 degrees C), and a pH of 6 to 8. The majority of odor-generating bacteria thrive at around 86 degrees F (30 degrees C) and neutral pH. This observation helps to explain why odors are much more pronounced during warm weather conditions. While elevated pH (above 9.0) significantly reduces biological activity, it also enhances ammonia release due to chemical equilibrium factors (not a biological phenomenon).

3.3 Odor Release

When an unstable organic waste (e.g. manure) is in a liquid or slurry form, decomposition gasses accumulate until fluid saturation is reached, beyond which point vapors are released. Whenever such material is agitated, gas release is dramatically increased. This fact helps to explain why odor emissions can actually increase when aeration is first added to anaerobic treatment facilities, and why manure storage pit agitation and spreading is often accompanied with severe malodor emissions.

If odor release is suppressed, even though source gasses are particularly noxious, the risk of odor complaints are significantly reduced or totally avoided. For example, covered storage and treatment facilities contain odor release. In some cases, covered containment is the most effective and practical means of odor control.

3.4 Odor Transport and Dispersion

Odors are often low-density gasses. Once released into the environment they are transported by wind, and diluted and dispersed by atmospheric turbulence.

Wind is responsible for the rapid horizontal transport of humidity, warm air, pollutants, and odors while turbulence is responsible for vertical transport. Wind turbulence can be visualized as eddies of different sizes that cause fluctuations in concentration over short time intervals.

The human olfactory system is able to detect variations of concentration within very small lapses of time. We know that for short exposures, the efficiency of our sense of smell is high. Even though the mean concentration lies under the olfactory perception threshold, our fast reacting and sensitive olfactory system will detect peak concentrations of odor. Hence, concentration fluctuations can be very important in odor problem situations. Two factors contribute to these variations: the meandering of the source plume, and the concentration profile inside the plume (Miner, 1997).

Internal concentration variations within a plume are created by *puffs* of air. The turbulence caused by these eddies diffuse the plume. Large eddies cause meandering of the plume near the source, normally in a lateral direction. As the plume is *torn* by the introduction of pure *air puffs*, a concentration profile develops within the plume (Miner, 1997).

Plume *eddies* also act in a vertical direction, serving to mix and diffuse the plume over distance. As a result, odor concentration fluctuations become less important with distance from the source (Miner, 1997).

Odor Dispersion Factors
Under typical atmospheric conditions, area source odorants undergo fairly rapid dilution as the distance from the source increases. Under such conditions, odorants are less likely to be objectionable to neighbors. Conversely, pervasive odorants can be detected at considerable distances from the source. Rough terrain, valleys, and other topographical features can increase the complexity of airflow patterns.

Odors emitted from ground-level sources remain most concentrated during periods of high atmospheric stability associated with air temperature inversions and stagnant conditions at night and early morning. This means that odor complaints may be higher during non-business hours. Dispersion is enhanced once the sun has warmed the soil surface.

Many models have been developed that will predict the extent to which pollutants and odors can be dispersed downwind of a source. In general, air quality models are divided into two classes: (1) mathematical and (2) statistical or empirical.

Mathematical models are often used by regulatory agencies to assess potential impacts from new or proposed expansions of existing industrial facilities. Regulatory agencies use these results to make judgments concerning the issuance of air quality permits.

Empirical models differ from mathematical dispersion models in that they are based on more direct measurements rather than theory.

Dispersion Modeling
Ground level concentrations of odorous compounds downwind from a source or planned facility can be predicted using complex dispersion models. These models have been developed for regulated air pollutants but are potentially useful for any gaseous compounds, including odors. Meteorological, topographical, and source emission variables must be supplied to use these models.

Odor modeling differs from traditional pollutant modeling in at least three important ways: (1) the nature of the source, (2) transport, and (3) the target (the human nose).

Often the methodology used for an odor assessment will be based upon consideration of only one of these factors without regard to the other factors. This can lead to results that appear to overlook the physical phenomena associated with a particular situation.

The ultimate goal of an atmospheric dispersion model is to predict concentrations downwind of a source (or sources) under any and all atmospheric conditions. The selection of the appropriate dispersion model for odor assessment starts with the source type and release scenario.

Continuous odor source emissions (release rate of minutes or longer) are most often responsible for complaints. Instantaneous sources (release rates on the odor of seconds) such as manure agitation or land application can also pose problems, but neighbors are usually much more tolerant of these short-lived events.

Puff Models

Puff Models
Short-term releases are frequently viewed as "puff" releases. With these models, source emissions are treated as a series of puffs emitted into the atmosphere. Constant conditions of wind and atmospheric stability are assumed during a given time interval. Most puff models ignore internal puff concentration differences and assume a normal concentration distribution within the plume. This assumption limits the usefulness of puff models for agricultural odor generation.

Plume Models
Continuous releases are generally modeled as a plume. Agricultural odors are usually continuous sources. Because of this, plume models are necessary to simulate odor dispersion from an agricultural site. For odor modeling, the fluctuating plume-puff model and the Gaussian model are most frequently used.

Fluctuating Plume-Puff Model
The fluctuating plume-puff model is a hybrid model that simulates source emissions as a continuous series of puffs. The model predicts puff movements for various atmospheric conditions and estimates puff concentrations at specific downwind locations.

One problem with this type of model is that little data is available to determine the parameters needed to estimate the spread of the puff *disks*. Another problem is that fluctuations within the instantaneous plume are not considered.

Gaussian Plume Model
As a plume moves downwind, it spreads out. The odorous compounds in the plume often have a Gaussian (or bell-shaped) distribution with the highest concentrations on the centerline and progressively lower with distance from the centerline.

Gaussian plume models have been used to model odor dispersion from agricultural sources because of the ability to predict average downwind concentrations. While the mathematics of such models is fairly straightforward, a great deal of site specific input data is needed (Gassman, 1992).

Similar to the puff model, the Gaussian model assumes an average distribution in the plume and constant meteorological conditions as the plume travels from source to receptor – potentially leading to under estimation of odor concentrations. However, Gaussian models do have their advantages, as the site-specific nature of the equations employed allow their use for several source types.

Determining which model to use for an odor assessment can only be made after the characteristics of the source and the site are understood.

Dispersion Modeling - Practical Application
Dispersion models can be very helpful because they allow us to predict air quality impacts. Using these models, we can determine the distance pollutants travel before dissipating. Accordingly, facility operators may plan appropriate cost-effective control strategies with this information. One of the biggest advantages of using standard dispersion models is that most have substantial validation, peer-review, and regulatory approval. However, most dispersion modeling has been for pollutant gasses not common odors.

Unfortunately, dispersion models involve complex mathematical equations and computer expertise beyond the experience of the average person. These models often require collection of odorous air samples and testing via gas chromatography. Another problem, which occurs in modeling, is that odor episodes can happen so quickly that the odor causing a complaint may not be present in the same concentration by the time an air sample can be collected for odor assessment.

While current odor dispersion models are capable of determining odor concentrations, their application is limited. Standard models are not designed to simulate odor transport over rough terrain, around objects, or vegetated landscapes. An agricultural air dispersion model capable of predicting odor intensity at distances from the source is under development. Several have already been suggested but still need validation before they become fully functional.

In the coming years, we can expect dispersion models to play a role in odor regulation. The information generated through dispersion modeling combined with odor emission data could be used to determine setback distances for odor sources. In other countries, models have already been used to predict the movement and dispersion of animal waste related odors and, subsequently, have led to required setback distances.

CHAPTER 4:
ODOR DETECTION AND MEASUREMENT

In this chapter we examine some of the more common methods used to describe, characterize and quantify odors. Despite impressive scientific advances in the last 100 years, practical, objective methods for detection and quantification of malodors continue to elude scientists. The human olfactory system remains the ultimate odor sensor.

4.1 The Human Olfactory System: The Ultimate Sensor

Some believe humans can detect over ten thousand different odors even though we can identify only a small percentage of these. Because of our ability to sense so many different odors, the nose remains our best means of detecting and rating malodors.

Scientists believe that odor perception involves both a *biological* response and a *psychological* response (Miner, 1995). The physical sensing mechanism of *olfactory process* (sensation of smell) represents the biological response. In this process, highly specialized nasal cavity receptors are stimulated and a signal is transmitted to the brain. A person's response to the signal is based on association. Our instinctive reaction may be to avoid further exposure due to an association with an undesirable or dangerous situation (e.g. smoke—fire—flight). On the other hand we may associate a smell sensation with a positive situation and want to stay (e.g. perfume used by a loved one).

Early in life, we each develop a sense of likes (good smells) and dislikes (bad smells). In effect we learn how to categorize odors according to our own experiences (both direct and indirect). Hence, the psychological response of different people to the same odor may be vastly different. For example, some people find swine odors to be intensely unacceptable, while others find such odors only mildly objectionable. Reactions to an odor are influenced by several factors including: the odor duration, frequency, previous associations, and the nature of the source (Miner, 1995).

It is unclear whether negative responses to odors are so intense due to an objection with the odor or with the odor source. Observations suggest that there are fewer objections within a community to odors that are a traditional part of the community.

4.2 Characterization of Odors

In this technological age, many mistakenly believe that odors can be readily detected, characterized and quantified. While such equipment exists, our current technology is woefully cumbersome and largely inadequate in many cases. The problem is that environmental odors are not pure compounds, but rather a complex mix of several (perhaps dozens) malodorous gases. The mixture of these compounds may yield a unique character that differs from the component gasses. The problem odor may be even more objectionable (or less) than each of the component gasses alone.

Most odors are so complex and detectable by humans at such low concentrations that current quantitative analytical methods are impractical or largely inadequate. Hence, the most common methods for characterizing odors today revolve around perception by people, based on the human olfactory system and subjective reactions (Miner, 1995).

Odor perception is commonly subdivided into four sensory properties: detection, intensity, character, and acceptability. In this section, we will examine each of these properties.

Detection

Odor detection is typically expressed in terms of the *odor threshold*. It is important to note at the outset that two threshold levels are commonly acknowledged: the *detection threshold* and the *recognition threshold*. The detection threshold is the concentration at which individuals become aware of an odor sensation, but do not necessarily recognize the odor. The *recognition threshold* is the concentration at which panelists recognize a characteristic

odor that can be described, such as ammonia. The recognition threshold is typically 2 to 10 times higher than the detection threshold. Remaining discussion in this section refers specifically to the *detection threshold*.

The *odor threshold* is the point at which 50% of pre-selected panelists can detect an odor. This property provides a measure of the rate at which odor intensity (see following section) decreases as odorous gas concentrations decrease. This relationship is used to predict the dilutions with ambient (non-odorous) air necessary to reduce the intensity of malodors to a non-detectable level. Some odors, such as hydrogen sulfide, butyl acetate and amines are more pervasive and require many dilutions. Ammonia and aldehydes require considerably less dilution to reach non-detect levels, and are accordingly less problematic to manage.

Odor thresholds are typically expressed as *dilutions to threshold* (DT). DTs are the volumes of fresh air that must be added to one volume of odorous sample air to dilute the sample to a level where it is just beyond detection, the odor detection threshold. A large DT indicates a strong odor and conversely, a small DT signifies a weak odor.

Odor Intensity

Odor intensity is defined as the perceived strength or *punch* of an odor. Several methods of assessing odor intensity have been used. Two of these, the *scaling method* and *reference intensity method*, are introduced below. The *odor threshold*, which was discussed in the previous section, is also sometimes included as a measure of odor intensity.

The ***scaling method*** of assessing odor intensity involves assigning numerical values ranking intensity by an unbiased person. An example would be a scale of 0-6, where 0 would indicate no odor is detected and 6 would mean a very strong odor. A very strong or *intense* odor might be viewed as one that is overpowering, causing ones eyes to tear and nose to run.

The ***Reference intensity*** method requires a group of pre-selected panelists to compare the intensity of an unknown odor with a reference odor. The panelist indicates whether the odor being evaluated is more, less, or of the same intensity as a particular standard. The most common standard used is 1-butanol because of its highly purified form, low toxicity, high stability, and its reasonably agreeable odor.

Character

Odor character or quality distinguishes one odor of equal intensity from another by assigning odor *descriptor* terms, such as tar, leather, manure, musty, rancid, sewer, ammonia, etc. In other words, character is what an odor smells like. Character is a useful classification when attempting to convey the nature of an odor to others. Several lists have been developed and used for describing character.

Table 4.1 presents an odor character list containing 146-descriptors (Dravnieks, et al., 1978), representing a substantial expansion over previously used tables in popular use. Dravnieks, et al. (1978) created this expanded table when researchers found that many characterized odors were in fact very different from one and other. This comprehensive table contains a certain level of redundancy, allowing people who are unfamiliar with certain odors to find others that may be familiar.

To characterize an odor, one runs through the list identifying appropriate descriptors and ranks the *degree of presence* of that odor, which is noted next to the descriptor. The degree of presence is rated using a scale from 1 (slight similarity) to 5 (extremely similar). Note that more than one descriptor may be used for a single odor, resulting in a unique *odor profile* for a particular odor under consideration. Careful characterization of an odor should not take more than 5-10 minutes, despite the comprehensive nature of the table.

Table 4.1 Odor Characterization List

Rating Scale

1	2	3	4	5
slightly		moderately		extremely

MATERIALS		CHEMICALS		OUTDOORS	
dry, powdery		sharp, pungent, acid		hay	
chalky		sour, acid, vinegar		grainy	
cork		ammonia		herbal, cut grass	
cardboard		camphor		crushed weed	
wet paper		gasoline, solvent		crushed grass	
wet wool, wet dog		alcohol		woody, resinous	
rubbery, new		kerosene		bark, birch	
tar		household gas		musty, earthy, moldy	
leather		chemical		cedarwood	
rope		turpentine, pine oil		oakwood, cognac	
metallic		varnish		rose	
burnt, smoky		paint		geranium leaves	
burnt paper		suphidic		violets	
burnt candle		soapy		lavender	
burnt rubber		medicinal		laurel leaves	
burnt milk		disinfectant, carbolic			
creosote		ether, anaesthetic			
sooty		cleaning fluid, carbona			
fresh tobacco smoke		mothballs			
stale tobacco smoke		nail polish remover			

Table 4.1 Odor Characterization List, continued

Rating Scale

1	2	3	4	5
slightly		moderately		extremely

COMMON		**MEATS**		**SPICES**	
sweet		meat seasoning		almond	
fragrant		animal		cinnamon	
perfumery		fish		vanilla	
floral		kippery, smoked fish		anise, licorice	
cologne		blood, raw meat		clove	
aromatic		meat, cooked good		maple, syrup	
musky		oily, fatty		dill	
incense		**FRUITS**		caraway	
bitter		cherry, berry		minty, peppermint	
stale		strawberry		nut, walnut	
sweaty		peach		eucalyptus	
light		pear		malt	
heavy		pineapple		yeast	
cool, cooling		grapefruit		black pepper	
warm		grape juice		tea leaves	
FOUL		apple		spicy	
fermented, rotten fruit		cantaloupe		**BODY**	
sickening		orange		dirty linen	
rancid		lemon		sour milk	
putrid, foul, decayed		banana		sewer	
dead animal		coconut		fecal, manure	
mouse-like		fruity, citrus		urine	
FOODS		fruity, other		cat urine	
buttery, fresh		**VEGETABLES**		seminal, like sperm	
caramel		fresh vegetables			
chocolate		garlic, onion			
molasses		mushroom			
honey		raw cucumber			
peanut butter		raw potato			
soupy		bean			
beer		green pepper			
cheesy		sauerkraut			
eggs, fresh		celery			
raisins		cooked vegetables			
popcorn					
fried chicken					
bakery, fresh bread					
coffee					

Acceptability
Acceptability, or *hedonic tone*, of an odor is a subjective judgement of the relative offensiveness of a particular odor. Due to psychological factors, the perception of odor varies dramatically among individuals. Since no person is the same, it is fair to say that no nose is the same either. What one person deems intolerable, another finds pleasing.

Factors that contribute to acceptability include the frequency, character, and intensity of an odor. It is common experience that even a pleasant fragrance can become objectionable over time.

4.3 Sampling Odorous Air for Off-Site Evaluation

Odor measurement data can be used to:

1. Provide information on the strength and intensity of odors.
2. Identify the causes of an odor problem and quantify the scale of odor emission from a particular source.
3. Predict odor impact in the vicinity of an operation for odor impact assessment purposes.
4. Measure the performance of a pollution reduction program implemented by an operator.
5. Evaluate the removal efficiency of odor control technology.

Odor measurement requires representative samples of the air to be drawn into a sample bag and rapidly transported to an odor laboratory for testing. Sampling strategies and techniques depend on emission source characteristics.

Odors originate from various sources such as stacks in an industrial process, aeration tanks in wastewater treatment plant, substrate preparation piles in a mushroom facility, livestock housing and feedlots. Each type of source has special sampling requirements.

Point sources
Typically a point source will be a stack or fan with a known flow rate such as a discharge stack from abattoir or a vent from a swine housing. It is important that the pattern of flow rate and odor concentration be estimated using an appropriate procedure. Where key factors are unknown, a study can be conducted to access gas flow and

concentration fluctuation patterns on a daily, monthly or yearly basis.

Odor samples are obtained using Tedlar sampling bags fed by Teflon tubing. Air is drawn through the tubing into the sample bag by means of a vacuum drum. The tubing opening is inserted into the airflow at predetermined points. The number and location of sample points is based on the nature of the point discharge. As a rule of thumb, the number of sampling points needed to average air velocity across a stack cross section can be used as a guide.
It is important that air velocity, dimensions of the vent, temperature and humidity are measured before a sample is taken. For those samples with a high temperature and pressure, the gas flow rate is calculated and adjusted to NTP (Normal Temperature and Pressure i.e. 20^0C and 1 atmosphere) or STP (Standard temperature and Pressure i.e. 20^0C and 1 atmosphere) conditions.

Building sources
Some point sources, such as poultry and swine housing, have multiple openings. Prior to about ten years ago determination of odor emissions from buildings was rare. For building sources, measurements of both odor concentration and air ventilation rate are required. The air ventilation rate from animal housing is dependent on operational conditions (e.g. opening or closure of side flaps or shutters), and ambient wind speed and direction.

For animal sheds, odor samples are normally taken from several points within a shed. Experience indicates that one composite sample is sufficient to represent a single shed at a particular time. Additional samples can be taken at different times of the day or week to understand the periodic fluctuation of the odor concentration levels. Similarly sampling may be carried out for different weeks during a grow-out cycle or for different seasons during a year or longer.

Area sources
Typically an area source will be a water or solid surface such as the surface of a slurry storage tank or a cattle feedlot. A portable wind tunnel system can be used to determine specific odor emission rates. The principle of the wind tunnel system is that controlled air, filtered by

activated carbon through a series of devices, forms a consistent flow over a defined liquid or solid surface. Convective mass transfer takes place above the surface as odor emission happens in the natural atmosphere. The odor emissions are then mixed with clean air and vented out of the hood. A proportion of the mixture is sucked into a Tedlar bag via Teflon tubing using a sampling vessel.

The Specific Odor Emission Rate (SOER) is the quantity (mass) of odor emitted per unit time from a unit surface area. The quantity of odor emitted is not determined directly by olfactometry but is calculated from the concentration of odor (as measured by olfactometry) which is then multiplied by the volume of air passing through the hood per unit time. The volume per unit time is the measured velocity multiplied by the known cross sectional area of the wind tunnel.

4.4 Odor Evaluation by Human Response

Two basic types of odor measurement employing human response are commonly used, olfactometry and scentometry. The following sections describe these techniques.

Olfactometry

Although much progress has been made in the area of developing instrumentation for measuring odor, olfactometry, which relies on human detection, is currently the most accepted procedure for odor measurement. Olfactometry involves collecting odor samples (odorants are contained in a volume of air or adsorbed onto a media such as cotton fabric), presenting the samples to an odor panel (a group of people trained to detect odor), recording the panel responses, and analyzing the resulting data.

Samples of odorous air are collected in the field, and then transported to an odor panel for off-site analysis. In some cases samples can be analyzed on site, eliminating the need for storage and transport. In either case, odor-containing air is diluted with nonodorous air to determine the DT level. An instrument called a *dynamic olfactometer* is used to dilute odorous air with nonodorous air.

Recent developments in the methodology of olfactometry have dramatically improved the repeatability of measurements. Developments of particular importance include refined dilution instrument calibration and panel management techniques. Olfactometry can provide an effective way to measure the concentration of complex odors.

Olfactometry employs a panel of human sensors. In this procedure, a diluted odorous mixture and an odor-free gas (as a reference) are presented separately from two sniffing ports to a group of eight panelists in succession. In comparing the gases emitted from each port, the panelists are asked to report the presence of odor together with a confidence level such as guessing, inkling, or certainty. The gas-diluting ratio is then decreased by a factor of two (i.e. chemical concentration is increased by a factor of two). The panelists are asked to repeat their judgment. This continues for 5-6 different dilution levels, resulting in a total of 8 x 6 x 2 = 96 judgments (sniffings) from the eight panelists. Using panelist responses over a range of dilution settings, odor concentration expressed as odor unit per cubic meter can be calculated from individual threshold estimates.

Scentometry

The scentometer is a hand-held device that allows on-site sampling of odorous air. The scentometer device allows air to be divided into two streams, one for odorous air and a second (equipped with a charcoal filter) for nonodorous air. The device is equipped with multiple holes of varying sizes through which odorous air travels. The size of the non-odorous port remains the same. As the user changes the hole through which odorous air travels, different dilutions are achieved. Typical dilutions for a six-hole scentometer are 2, 7, 15, 31, 170 and 350 parts of filtered, nonodorous air to one part odorous air.

There are no standards for describing various scentometer DT levels. However, one researcher has described a DT of 170 as *very strong odor*, 31 DT as a *moderate odor*, 7 DT as a *significant odor* and 2 DT as a *weak but noticeable odor* (Sweeten and Miner, 1993).

As scentometer readings are performed on-site, avoiding breathing odorous air before the scentometer is used requires special consideration. The problem is to avoid *sniffer* odor fatigue, which occurs when a person is continually subjected to an odor until it is no longer apparent. To avoid odor fatigue, a respirator mask to shield a scentometer user from odorous air is often recommended.

There is presently no standard method for qualifying scentometer users. Hence, readings can not be statistically compared and evaluated with confidence. Further, restricted dilution options offered by the scentometer tends to limit the potential utility of the device. Problems with individual *user bias* also arise, which can be mitigated by using a second person to control dilution sampling holes in the device, with out the knowledge of *sniffer*. Despite limitations, the scentometer is an economical and useful on-site screening device.

4.5 Odor Evaluation by Chemical Means

Wet Chemistry
If odorous compounds are water soluble, wet chemistry can be used for indirect odor evaluation. The primary analytical tool of the wet chemistry laboratory is the ion-specific electrode (ISE). ISEs are designed to detect a particular charged molecule with a minimal contribution from other ions in solution. The ISE can provide a direct measurement of the presence and concentration of a particular type of ion in solution.

Detector Tubes
Detector tubes are intended for the measurement of transient gas concentrations. They provide the user with a simple test, giving an immediate result for a wide range of gases and vapors at a low cost.

The sealed glass tubes are filled with a solid carrier material containing reagents that discolor on contact with certain gasses. The chemical reagents in each detector tube are provided in various concentrations so that a range of gas concentrations can be detected.

Electrochemical Sensors
One of the most useful detection techniques for contaminants is the use of substance-specific electrochemical sensors installed in compact, portable survey instruments.

Substance-specific electrochemical sensors consist of a diffusion barrier which is porous to gas but nonporous to liquids, a reservoir of acid electrolyte (usually sulfuric or phosphoric acid), a sensing electrode, a counter electrode and (in three electrodes designs) a third reference electrode. Gas diffusing into the sensor reacts at the surface of the sensing electrode. The sensing electrode is made to catalyze a specific reaction. Depending on the sensor and the gas being measured, gas diffusing into the sensor is either oxidized or reduced at the surface of the sensing electrode. This reaction causes the potential of the sensing electrode to rise or fall with respect to the reference electrode. The current generated is proportional to the amount of reactant gas present.

Electrochemical sensors are fast, stable, long lasting, require very little power, and are capable of resolutions of 0.1-ppm in many cases (depending on the sensor and contaminant being measured). The chief limitation is interference by other gas components. Most substance-specific electrochemical sensors have been carefully designed to minimize the effects of common interfering gases. Substance-specific sensors are designed to respond only to the target compound. The higher the specificity of the sensor, the less likely the interference by other gases.

Semiconductor Sensors
Metal oxide semiconductor (or MOS) sensors may be used for gas monitoring. In clean air the electrical conductivity is low, while contact with reducing gases such as carbon monoxide or combustible gases increases conductivity. Changing temperature may alter sensitivity of the sensing element to a particular gas.

MOS sensors are "broad range" devices designed to respond to a group of chemically similar compounds, including chlorinated solvent vapors and other gases difficult to detect by other means. This nonspecificity can be advantageous in situations where unknown gases may be present, and a simple "presence/absence" determination of toxic contaminants is sufficient.

MOS sensors offer the ability to detect low (<100-ppm) concentrations of toxic gases over a wide temperature range. The chief limitations are the difficulty in the interpretation of positive readings, the potential for false positive readings, and the effect of humidity on sensor output. As humidity increases, sensor output increases as well. As humidity drops to very low levels, sensor output may fall to zero even in the presence of gas.

Gas Chromatography and Mass Spectroscopy
Gas chromatography (GC) entails the separation of various components of a gas mixture so they can be identified and quantified. A mass spectrometer (MS) is often used in conjunction with gas chromatography (GC/MS) for positive identification of organic compounds. This is a powerful tool in identifying the individual compounds in a complex odorous gas mixture.

The Electronic Nose
Electronic/artificial noses are being developed as systems for automated detection and classification of odors, vapors, and gases. An electronic nose is generally composed of a chemical sensing system (e.g., sensor array or spectrometer) and a pattern recognition system (e.g., artificial neural network). Electronic noses are already being used for the automated identification of volatile chemicals for environmental and medical applications.

The major differences from standard analytical chemistry equipment are that electronic noses (1) produce a qualitative output, (2) are often easier to automate, and (3) can be used in real-time analysis.

An electronic nose may eventually prove to be the convenient, objective, inexpensive, and portable tool needed to measure odor in the field. Researchers have demonstrated that at least with regard to one data set (one odor experiment), the electronic nose can produce the same perceptions of odor intensity, irritation, and pleasantness as the human nose. However, if the electronic nose is to be considered reliable, the same training procedure must be carried out with additional data sets. This is a time consuming process. Human perceptions of odor from trained odor panels must be used to train the electronic nose under various conditions (at different times of year and under various weather conditions, for example).

Moreover, the sensors used thus far are capable of detecting odor only from point sources such as a swine building or lagoon. More sensitive devices are currently under development. It is thought that an electronic nose equipped with these more sensitive sensors would be capable of detecting odors from nonpoint sources such as at the boundary line of a swine farm (SOTF, 1998).

Summary

Odor measurement is difficult because no instrument has been found to successfully measure an odor and all its components. Over 160 compounds have been identified in manure or the surrounding air (O'Neill and Phillips, 1992). Each individual compound contributes to the overall odor character either by making the odors more offensive, easier to detect, or harder to measure. Odor reduction efforts often concentrate on individual components such as ammonia or hydrogen sulfide, but may fail to describe the overall odor offensiveness. Odor is not well represented by individual components thus requiring a measurement technology that measures "odor" directly.

Currently, the human nose is the only device that can really measure odor, and even then personal preference affects what is considered acceptable or offensive. Modern instruments can measure some compounds that make-up odor, but odor is a combination of many compounds. The measured concentration of just one compound is not a reliable indicator of whether or not offensive odor is present.

CHAPTER 5:
ODOR SOURCES IN AGRICULTURE AND FOOD PROCESSING

This chapter reviews components of agriculture and food-processing operations traditionally associated with malodors. Basic factors that contribute to odor emission are also identified. The significance of a particular odor source is invariably related to operational practices. This connection makes the distinction between a *source* and a *control strategy* difficult to articulate in some cases. Because of this connection, fundamental control strategies are provided where these situations occur. Additional detail on *management practices* is provided in Chapter 8.

5.1 Agriculture/Processing Categories

Agricultural operations in Pennsylvania with high odor potential have been divided into four major categories: animal agriculture, land application, mushroom production, and food processing. A brief description of each category follows.

Animal Agriculture
Animal agriculture operations involve the care and raising of dairy, poultry, swine, or other livestock. Such operations generate income from the sale of food, fiber, pharmaceutical, or other products derived from the animals. Odor conflicts arising from animal agriculture invariably involve housing, ventilation, and/or manure management.

Land Application
Land application includes all situations where materials such as manure, food processing residuals (FPRs), organic industrial residuals, or municipal wastewater biosolids are land-applied. Besides accomplishing waste disposal, the purpose of these operations is to improve soil characteristics and/or fertilize cropland. Potential malodors are usually linked to residuals transport, storage, staging, and field spreading activities.

Mushroom Production
Because of its importance to Pennsylvania, mushroom production is considered as a separate category. Here

mushroom production includes substrate preparation, bed preparation, spawning, harvest, and handling/disposal of spent substrate. Substrate preparation is the component of mushroom production most often associated with objectionable odors. Spent substrate odors can also cause problems in some cases.

Food Processing

Food processing facilities comprise all operations where the conversion of raw agriculture, aquaculture, and seafood commodities to food products occurs. Food processing includes the slaughtering of poultry and livestock, processing or converting of fish, seafood, milk, meat, eggs, fruits vegetables crops and other commodities into marketable food items. Malodors are not normally associated with the actual preparation of food products except for some activities like cooking and drying. Process wastewater treatment at food plants and management of animal manure (at slaughtering facilities) can also generate malodors

Most emissions arise from the handling, storage, and disposal (or recycling) of *food processing residuals (FPRs).* "An FPR is an incidental organic material generated by processing agricultural commodities for human or animal consumption. The term includes food residuals, food coproducts, food processing wastes, food processing sludges, or any other incidental material whose characteristics are derived from processing agricultural products. Examples include: process wastewater from cleaning slaughter areas, rinsing carcasses, or conveying food materials; process wastewater treatment sludges; bone; fruit and vegetable peels; seeds; shells; pits; cheese whey; off-specification food products; hide; hair; and feathers" (Brandt and Martin, 1996).

It is noteworthy that the basic concepts governing odor emission and management are common to the above-mentioned operations. In most cases, an operation will fit into one of the above categories. If your operation does not precisely fit into one category, you can still benefit from the following information. In such cases, review all of the information contained in this chapter and identify those concepts that are appropriate. Sometimes an operation encompasses more than one category. For example, a food processing facility that employs land application recycling of FPRs at a distant site would be addressed in both the *food processing* and *land application* categories.

The remainder of this chapter describes typical odor sources and factors associated with each of the four categories.

5.2 Animal Agriculture

Four primary areas of potential odor generation are identified for animal agriculture and all relate to manure management. These facilities or operations include 1) confined housing; 2) feedlots; 3) manure handling and storage; and 4) manure treatment. Secondary sources include animal feed, milk house waste water handling, silage leachate, and dead animal disposal. *Land application* is addressed separately (Section 5.5).

Before discussing each of the above primary sources, a brief overview of manure management and odor production is provided.

Manure Management in Pennsylvania

The three major types of livestock in Pennsylvania are cattle, swine, and poultry, with cattle-based agriculture holding a wide margin over all others. Other animal agriculture operations account for less than 2% of the manure produced in the Commonwealth. The following discussion of the three major livestock categories is taken from Elliott *et al*., (1990).

Dairy

Dairy manure is managed as a liquid (<12% solids), a slurry (12% to 16% solids), or as a solid (>16% solids). Pennsylvania dairy manure management systems employ various storage and treatment methods that require handling all three forms. Table 6.1 lists principal manure storage and treatment components. In practice, these components are combined in a wide variety of ways. For example, picket dams are sometimes incorporated into storage facilities to separate solids from the liquid fraction. Due to the expense and nature of aerobic treatment, anaerobic treatment, and composting, these facilities are used less frequently in the dairy industry. Of these, aerobic treatment systems are the least popular due high costs.

Table 5.1 Dairy Manure Storage/Treatment Systems

Daily hauling
Storage basin
Earthen w/ earthen floor
Earthen w/ concrete floor
Concrete on earthen grade throughout
Tank storage (silo or rectangular)
In-ground, Above ground, Covered, Uncovered
Beneath slotted floor in confinement structures
Anaerobic treatment basin
Anaerobic digestion w/ biogas collection
Aerobic treatment basin
Stack storage
Bedded pack storage
Picket-dam storage
Roofed vertical wall storage
Composting

Source: Elliott *et al*., 1990 after PaDER, 1986a

Beef

Due to its high solids content, and therefore lower storage space requirements, beef manure is often held for up to six months. Storage alternatives include: bedded packs, concrete tanks under a slotted floor, earthen storage with or without a concrete floor, or steel or concrete above-ground tanks. Aerobic and anaerobic treatment is not typically used because of high solids content. However, the high solids content of beef manure (> 50% solids) makes composting a desirable option for some operators.

Table 5.2 Beef Housing and Manure Handling Systems

Housing Type	Features	Manure Handling
Feedlot with shelter and bedded pack	Paved or unpaved	Solid, w/ runoff managed
Scrape system w/ Bedding	Paved alley	Scraped 2-3 times weekly; solid manure
Scrape system w/o bedding	Pitched floor directs manure to alley	Scraped as a slurry; runoff managed
Slotted floor system	Pit directly beneath floor	Slurry manure

Source: Elliott *et al*., 1990 after PaDER, 1986c .

Poultry

The nature of poultry manure dictates special management considerations. Its high ammonia content results in higher volatilization rates than for other livestock manures. As a result, poultry housing often includes mechanical ventilation.

As illustrated in Table 5.3, poultry manure management systems fall into four basic categories depending on the type of housing system. Manure is virtually always handled as a solid. Addition of water and handling as a liquid is specifically discouraged due to severe odors and other limitations.

Poultry manure treatment and utilization includes: aeration and drying, solid fuel use, composting, and biogas production. Aeration and drying results in a low odor, low moisture material that can be easily hauled. Composting manure and manure-litter mixtures also reduces odors and can be partially accomplished within the poultry house. Biogas generation using anaerobic digestion of liquid manure in air-tight heated tanks is uncommon.

Table 5.3. Poultry Housing and Manure Handling Considerations

Housing Type	Features	Manure Handling
Cages above pits		
	4” to 8” deep concrete channel	Daily flushing or scraping
Deep pit	2’ to 6’ deep concrete and/or block channels	Dry storage (several months)
High-rise	Similar to deep pit, but above ground	Same as deep pit
Floors w/ litter	2” to 6” litter layer (shaving, straw)	In-place drying and aeration
Slat/wire floors	Slat or wire floors over storage pit	Same as litter floors
Outdoor ranges	Field or pasture land	None

Source: Elliott *et al*., 1990 after PaDER, 1986h .

Swine

Swine manure management is also usually dictated by the type of confinement. Three operating methods used: pastures, open lots with shelters, and roofed confinements. Pasture systems allow for open swine grazing on land areas free of steep slopes, drainage ways, or streams. Waste management in pastures includes spreading manure over the fields to decrease concentration and sustain vegetation. In the open lot shelter system, manure accumulations usually contain 15% to 30% solids. The manure is periodically scraped and either stacked for later field application or immediately land applied. Due to the high pollution potential of open lot manures, runoff from the surfaces must be carefully managed. For roofed confinement, manure is managed as a liquid (<4% solids), slurry (4% to 15% solids), or solid (>15% solids). Confinements often incorporate slotted floors with under floor storage pits for handling liquids and slurries. Sometimes, mechanical gutter scrapers or periodic channel flushing devices are used in conjunction with these systems to convey wastes into external tanks or basins.

Field application of swine manure employs conventional manure spreading equipment appropriate for the manure consistency (e.g. liquid, slurry, or solid). Cropland irrigation is often used for application of liquid manure. Aerobic or anaerobic treatment of swine manure is sometimes employed to reduce odor nuisances prior to land application.

Primary Odor Sources

Confined Housing

In confined housing, high animal density results in a concentrated accumulation of manure. Several factors contribute to the odor hazard in this situation. The first factor to consider is *livestock sanitation*. Body heat promotes bacterial growth and volatilization of odorous compounds in manure. Hence, keeping livestock free of manure will reduce odor emissions. Separating livestock from manure through the use of facilities such as slotted floors and flushing gutters helps to keep livestock clean. Practices involving frequent removal of manure and replenishment with fresh bedding will also help to keep animals clean and dry. These measures not only result in reduced odor emissions, but also yield health benefits and assist in fly control.

Housing sanitation is the next step in minimizing odor emissions. Keeping livestock housing facilities clean and dry through frequent and thorough manure removal and periodic cleaning will reduce odor potential. Removal of accumulated dust can also help to control odors, as a majority of malodors, particularly in poultry and swine housing, are associated with particulate matter (Miner, 1995). When housing is well maintained, ventilation exhaust air quality is improved. It is important to isolate intake and exhaust points from manure storage and/or treatment facilities so as not to aggravate odor emissions from these sources (Bottcher *et al.*, 1999).

Aside from the substantial benefits realized from removing odor source material, a well-maintained building gives the impression that things are in order. Remember there is a psychological side to this issue too. People perceive that odors are not quite as offensive when things are in order. Sloppy, unkempt facilities convey a negative impression of the entire operation, and result in heightened awareness for malodors.

In general, reduced manure water content results in lower odor potential. For example, d*ry stack* manure storage facilities are typically much lower in odor emission compared to uncovered liquid storage facilities. When a solid *top crust* is formed and maintained in a liquid or slurry storage facility, significant odor reductions are realized (refer to *Manure Storage* below).

High moisture conditions generally favor anaerobic decomposition, which is responsible for most malodors associated with decomposing organic matter. Hence, any situation that results in floor accumulations of liquids or the uncontrolled addition of water to manure should be avoided. Low spots that puddle liquids or make cleaning difficult should be corrected. Places where water is inadvertently added to manure from leaky livestock waterers, rainwater, or ground water intrusion should be corrected.

In summary, the key to minimizing malodors from confined facilities is animal/housing sanitation and intentional efforts to keep manure as dry as possible. Any relaxation in these areas may elevate odor emissions and increase risk of odor complaints from neighbors.

Feedlots

Pastures grazed at normal stocking rates do not usually generate significant malodors. Areas where animals congregate in pastures such as watering areas, feed bunks, and shady spots receive heavier manure accumulations, but are not usually a major source of odor complaints with neighbors.

Conversely, high density feedlots are potentially problematic. As with *confined* housing, a key to minimizing emissions from feedlots is water management. Surface water *run-on* (i.e. upland water drainage or roof leader discharges into the feed lot) should be minimized to reduce the opportunity for excessive water contact with manure. Feedlot grading should facilitate rapid and unimpeded drainage of precipitation. In addition, feedlot layout and aspect should take advantage of direct sunlight for rapid drying.

Runoff water from feedlots or other areas subject to manure accumulations should be directed to manure storage/treatment facilities or settling basins (holding ponds). When settling basins are used, the liquid fraction is directed to a storage or infiltration area as soon as possible after rains (Miner, 1995; PaDER, 1986c). Settling basin/storage contents and overflow liquids are enriched with nutrients. As such these liquids can become a nuisance odor source if not properly managed.

Accumulated manure from feedlots should be periodically removed. Paved areas require more frequent scraping to prevent odors and flies. As with confined housing, feedlot appearance can have a positive or negative impact on perceived malodors. Well maintained structures and vegetation help to project the impression of a well managed operation.

Manure Handling and Storage

The variety of alternative manure handling and storage methods defy use of a *one-size-fits-all* strategy. However, consideration of the general approaches listed below can assist in the development of site-specific odor management practices:

1. High protein livestock diets promote the generation of anaerobic conditions and malodors. For example, poultry and swine manures are generally considered to be more offensive than cattle manure (Leggett *et al*., 1998).

2. Reduced manure moisture content yields lower odor emissions. Hence, stacked or windrowed manure should be shaped in a manner that avoids pockets where water may accumulate.

3. Sheltering piled manure from exposure to precipitation and run-on helps to minimize odor emissions.

4. More frequent cleaning and removal of manure from livestock housing reduce odor emissions.

5. Smaller exposed manure surface area leads to lower odor emissions.

6. Covered manure storage facilities can effectively block odor transmission.

7. Manure storages that have developed a top crust of dried material tend to contain odors. Management strategies that promote formation of a floating organic mat layer should be employed.

8. Bottom loading of liquid or slurry manure storage facilities minimizes volatilization losses, and thus odor release.

9. Top loading of liquid or slurry manure storage facilities results in higher manure surface area exposure and temperatures, thus promoting volatilization of gasses.

10. When liquid or slurry manure storage facilities are top-loaded, odor emissions are less with one large addition than with several smaller additions.

11. Elevated manure pH leads to increased ammonia volatilization but reduced hydrogen sulfide odor emissions. Hence, lime addition usually will not eliminate odors; rather it changes the type of odors being emitted.

12. The most intense and objectionable odor emissions from animal operations are often associated with manure pit agitation and loading of field spreading equipment.

Manure Treatment

Several manure treatment methods are available, but at present they are rarely used in Pennsylvania. These methods include aerobic treatment, anaerobic treatment (biogas generation or anaerobic lagoon treatment), and composting. Of these, anaerobic lagoons and composting have significantly higher potential for malodor emissions. However, all treatment methods can lead to odor complaints under certain conditions. As with most potentially odorous operations, appropriate siting is perhaps the most important step.

In the case of biogas generation, a closed vessel is used. When functioning properly, odor emissions are minimal. Lagoon odors are often associated with settled solids and/or floating scum layer accumulations, leading to excessive *pockets of* anaerobic decomposition. If done correctly, aeration of anaerobic lagoons can reduce odor emissions from these facilities. However, it is important to note that aerobic conditions do not guarantee absence of odor.

On-farm composting can be a particularly intense odor source, especially if the mix is high in nitrogen and/or aerobic conditions are not maintained throughout the material (PaDEP, 1997b).

Other Potential Odor Sources

Other potential sources of odor conflict related to animal agriculture operations include milk house wastewater disposal, feed odors, and dead animal disposal (Miner, 1995; Leggett and Graves, 1998). Feed odors are most often associated with use of fermented feed materials, silage effluents, and *Food Processing Residual* (FPR) feeding operations, such as the use of potato residuals for feed (Miner, 1980). Dead animal disposal must be promptly addressed to avoid problems. While these are generally considered secondary odor sources, they can become significant if proper cleanup, disposal, or water pollution control management strategies are not followed.

5.3 Food Processing

The processing of raw commodities for human food is not normally associated with malodors. However, odors are produced during some processing operations, particularly in the meat industry. Major sources of malodor in food processing are usually related to activities such livestock manure management, FPR management, and process wastewater treatment. Other odor sources at food plants may include uncontrolled refrigeration system ammonia discharges and livestock transport vehicles. (USEPA, 1973)

This section discusses the potential sources of significant malodor emissions at *food* processing facilities. Rendering operations are not considered in this document.

Processing Operations
Food processing operations that produce malodors include hog carcass singeing, rendering, and plant areas concerned with cooking, drying, and evaporation operations. Convenience food preparation, boiling, and searing or smoking of meat are examples of operations that can produce malodors (USEPA, 1973). While the examples given here can be significant odor sources, they are generally minor compared to odors produced by *sidestream* activities, which are discussed in the following sections.

Manure Management
Any meat packing operation that handles live animals must have a means of removing and disposing of manure. Livestock unloading areas and stockpens must be regularly and thoroughly cleaned to minimize odors. All manure collected during cleaning must be promptly removed off site or stored in a manner that contains odors (USEPA, 1973).

FPR Management
Perhaps more than any other activity at a food plant, management of sidestream residuals (FPRs) will determine whether you have odor complaints from neighbors. Due to the nature of the commodities being handled, biological decomposition and odor generation will rapidly occur in any materials that are not properly preserved. Hence, any material that does not become a part of the final packaged product must be promptly cycled to some other byproduct, disposed, or recycled.

Process Wastewater Treatment
Municipal wastewater treatment utilities have gained considerable experience in identifying and managing fugitive emissions. This experience provides an excellent model for evaluation of malodor sources in process wastewater treatment facilities at food plants. This information, together with industry wastewater treatment experience, provides a strong foundation for identifying

and correcting process wastewater odor problems. Principal references used in this section (Katsuyama, 1979; Rozich *et al*., 1995; USEPA, 1973; and WEF, 1995) should be consulted for additional information.

Table 6.4 provides an *odor potential* rating for various malodor sources encountered in municipal wastewater treatment. As this table was originally developed with municipal sewage treatment in mind, some minor modifications have been made to eliminate processes from the list that clearly do not apply to food processing wastewater treatment.

Table 5.4 Potential Odor Generation from Common Unit Processes in a Wastewater Treatment Plant

Process	Odor Potential
Liquid Stream Processes	
Flow equalization	High
Sidestream returns	High
Preaeration	High
Screening	High
Grit removal	High
Primary clarification	High
Stabilization	
Suspended growth	Low
Fixed film	Moderate
Chemical	High
Secondary clarification	Low
Tertiary filtration	Low
Disinfection	Low
Solids Processing	
Thickening/holding	High
Aerobic digestion	High
Anaerobic digestion	High
Thermal conditioning	High
Storage lagoons	High
Dewatering	
Vacuum filter	High
Centrifuge	High
Belt filter	High
Filter press	High
Drying beds	High
Composting	High

Source: After WEF, 1995 after USEPA, 1985.

The above table illustrates that there are numerous potential odor sources at wastewater treatment facilities. While a detailed coverage of all these sources is beyond the present scope, some principles of odor generation can be listed:

1. Anaerobic conditions lead to elevated malodor emissions. Such conditions often result from excessive detention times, high-strength (i.e. high

BOD) wastes, high sulfate wastes, and unintended accumulations of solids.

2. Putrescible organics and debris accumulated in lift stations, metering stations, and pretreatment screening devices lead to increased odor emissions if they are not regularly removed.

3. Wastewater turbulence caused by drops, flumes or similar structures lead to increased odor emissions if odorous gases are entrained in the wastewater.

4. High fat, oil, and grease (FOG) content in wastewater can coat the walls of facilities creating increased odors.

5. Low pH wastewater can result in elevated odors from increased hydrogen sulfide emissions.

6. High pH wastewater can result in elevated odors from increased ammonia emissions.

7. Sidestream flows from solids-treatment units such as thickening and digestion are often significant odor sources.

8. Accumulations of scum or other solids on treatment unit walls, weirs, and in troughs can cause increased odor emissions.

9. Treatment lagoons will cause significant odor emissions when aerobic conditions are not maintained. Odors are potentially a problem when any of the following situations occur:

- When water turns over in the spring and fall (for deep ponds)
- When algae dies
- During periods of excessive organic loading
- When scum accumulates
- When solids removal is inadequate

10. Physical-chemical wastewater treatment is particularly susceptible to odor generation because such systems often do not provide an opportunity

for oxidation of sulfides. As a result, hydrogen sulfide emissions can be elevated.

11. All wastewater residuals release odors to some degree. The majority of common odorous compounds are by-products of anaerobic decomposition. Hence, the intensity of fugitive emissions is largely dependent on the degree to which aerobic conditions have been and are being maintained.

12. Of all the possible odor sources associated with wastewater treatment, anaerobic digestion represents the most likely cause of complaints. Digester cover gas leaks are responsible for a majority of these emissions.

13. Dewatering facilities can be a major source of odor. Odors are attributable to solids and/or or chemical conditioning. Amine-based polymers, commonly used for conditioning prior to dewatering, can also contribute to nuisance odors.

14. In general, the higher the solids content of a wastewater treatment residual, the lower the potential for off-site odor effects.

5.4 Mushroom Production

Mushroom production involves the use of partially composted materials (e.g. manure, straw, etc.) as a growth medium (substrate) for mushrooms. Preparation of substrate has the potential for significant odor emissions. The initial composting phase takes 7 to 16 days to complete. One of the signs that this phase is completed is the strong ammonia odor that is emitted. Other odor sources include: raw material storage; preparation of feed stocks; storm water collection lagoons which receive nutrient enriched runoff from substrate preparation areas; and handling, storage, and disposal of spent mushroom substrate.

Factors that can impact odor emissions from mushroom production operations include:

1) Virtually every phase of substrate preparation is prone to odor emissions. Phase I substrate preparation has the highest potential for off-site odor complaints.

2) Excessive use of nitrogen-rich ingredients in substrate production increases odor potential.

3) Anaerobic conditions in substrate preparation piles leads to increased odor emissions. Thorough mixing of ingredients, avoiding over-watering, maintaining small substrate preparation piles, frequent turning and use of aerated floors can all help to reduce anaerobic conditions.

4) Puddles of standing water must be avoided. Thorough drainage must be maintained in all areas where surface water may contact stored raw ingredients, or may become enriched with nutrients.

5) Trap and remove solids from runoff before entering runoff collection facilities.

6) Maintain aerobic conditions in runoff collection basins. Use mechanical aeration if necessary.

7) Spills in receiving and filling areas can contribute to odor emissions. Prompt cleanup is essential.

8) All equipment should be regularly and thoroughly cleaned, including transport vehicles.

9) Raw material and substrate in transport vehicles can be a source of odors. Use of box trucks or covers may be necessary.

10) Make sure transport vehicles are not leaking fluids or tracking mud or decomposing odorous materials off site.

11) Placement of covers over substrate preparation piles will reduce emissions.

12) Enclosure of substrate preparation facilities and treatment of exhaust air provides the highest degree of odor control. Unfortunately this practice also has the highest costs.

Further information sources for this section include: Wuest *et al*. (1999), PaDEP (1997a), Labance (1998a), and Ministry of Agriculture and Food (1999).

5.5 Land Application

While manure storage agitation and equipment loading operations are prone to malodor emissions, field application is responsible for a majority of odor complaints (Miner, 1995). Although odors associated with spreading are normally short-lived, they are often intense. The significance of this source is directly related to timing, location, and manner of application. In livestock operations, manure is typically loaded directly onto field application equipment, transported to the application site, and spread by the same vehicle.

In contrast, farms without livestock do not ordinarily involve activities that generate significant malodors. On these farms the principal source of odors involves importing soil amendments such as livestock manure, FPRs, organic industrial residuals, or in some cases municipal wastewater biosolids. Such operations differ from animal operations in that storage or staging areas may be required prior to field application. Such facilities allow accumulation of enough material so that equipment can be used efficiently. This difference aside, land application odor issues are the same as those encountered in animal agriculture.

Odor sources associated with land application can be placed into four categories: residuals transport, residuals staging, residuals storage, and field application activities. Each of these will be discussed in this section.

Transport
Odors associated with residuals transport are related to the nature of the residual itself, the nature of the transport vehicle, vehicle sanitation, and the transport route.

Particularly offensive materials require a vehicle that provides containment, such as a tank truck, or box container that can be covered or sealed. *Over-the-road* hauling requires that vehicles be cleaned frequently to remove accumulations of mud and clinging odorous materials. Dual use vehicles that both haul and land apply residuals can be particularly problematic when public roads are used.

The entrance point to and from a land application area accessed by public roads must be carefully selected to afford clear view allowing for safe ingress/egress. Proper drainage is important to avoid muddy conditions that would result in *mud tracking* onto public roads.

While vehicles used exclusively on remote farms may not need frequent cleaning, they should still be washed down periodically. As noted earlier, well-maintained equipment and field condition will project the image of a well managed operation, and will impact perceived odors.

Staging Areas

A *staging area* is a carefully selected location where transport vehicles are unloaded and field application equipment is loaded. This operation is intended to facilitate field application by maximizing use of the right equipment for the right job. For example, over-the-road trucks are best employed for hardtop road transport, while field application equipment is best reserved for this specific task. Spreading equipment is inefficient for any lengthy hauling, particularly over hardtop roads. Whenever possible, staging areas should be located immediately adjacent to application fields. Liquids or slurries should be pumped directly from the transport vehicle (or storage facility) to a land application spreader.

Temporary piling of *stackable* residuals in the field is sometimes performed. Temporary piles should be field-applied as soon as possible, preferably within seven days of placement. Extended holding periods are more appropriately termed *storage* (see next section). Piles should be kept small to promote aerobic conditions. The total amount of material placed in a single staging area should be limited to the quantity needed for adjacent fields. Hence, several small staging areas are often employed for larger operations.

Staging areas should be located only after considering vehicle access, potential for *mud tracking*, proximity to neighbors, predominant wind direction, and water management. Run-on must be limited to prevent excessive water contact with piled material. Runoff likewise must be managed to prevent downgradient problems. Material placed in staging areas should be field applied as soon as possible to minimize anaerobic decomposition and associated odors.

Storage Areas
In contrast to staging areas, storage areas are intended to hold material for up to one year and the material volume is much greater. The extended residence time at storage areas results in further biological and chemical breakdown, potentially yielding higher odor emission. Accordingly, storage locations are more carefully selected and managed due to the increased potential for environmental degradation and nuisance odors. The volume of material and length of time residuals are exposed to the environment make storage facilities particularly problematic, especially when liquid or slurry facilities are agitated or when stockpiled materials are broken down for loading.

Major staging/storage area issues discussed above also apply for imported soil amendments (e.g. biosolids, FPRs, etc.). It is generally is advisable to avoid mixing highly biodegradable materials such as FPRs with livestock manure, unless specific odor management measures have been put in place. Such mixtures are often highly malodorous. Addition of milk house waste or nutrient enriched runoff to manure storage facilities is a common practice. (PaDER, 1986a)

Field Application
The following list provides a summary of factors that can impact odor emissions during field application. More information regarding the timing and location of field-spreading activities is provided in Chapter 7.

1) Land application of unstabilized residuals containing significant amounts of easily biodegradable (putrescible) material that has become septic (anaerobic) often results in

particularly offensive odors. Such material should be promptly applied and incorporated.

2) Direct subsurface injection of liquid or slurry materials minimizes odor emissions (Elliott *et al*., 1990; Leggett and Graves, 1998; Miner, 1995).

3) When direct subsurface injection is not feasible, incorporation of surface-applied manure as soon as possible after application will minimize odor emissions. Tillage delayed more than 48 hours will do little to control odors (Miner, 1995).

4) Land application through *spray irrigation* results in the greatest release of volatile compounds and accompanying odor emissions (Elliott *et al*., 1990; Miner, 1995).

5) Field application of *digested* manure (e.g. from an anaerobic digester), results in lower odor emissions relative to undigested residuals (Miner, 1995).

6) Higher field application rates yield higher odor intensity (Miner, 1995).

7) Regular and thorough cleaning of all manure handling equipment can help to reduce this odor source and project the image of a well-run operation. This is particularly true for equipment used to haul manure over public roadways.

8) Weather conditions that are conducive for *hay drying* are also prone to rapid volatilization of manure water and odorous compounds (Elliott *et al*., 1990).

9) Field application in uniform thin layers promotes quick drying and minimizes odor emissions.

CHAPTER 6:
CONDUCTING AN ODOR ASSESSMENT

An odor assessment provides the facility operator with a uniform and systematic means of examining his/her property for potential odor problems. The assessment can be a useful tool in decreasing odor complaints. It is also a method of record keeping that could prove useful in case of legal action. This chapter presents a suggested *self-evaluation* odor assessment methodology that has been fashioned to address four areas: (1) animal agriculture, (2) food processing, (3) mushroom production, and (4) land application.

6.1 What is an Odor Assessment?

An odor assessment examines production units and practices to determine if odor is a problem and if so, which areas generate the most offensive odors. The odor assessment methodology presented in this chapter is intended to be a self-evaluation by the facility operator.

The timing of an odor assessment will have a significant effect on the findings. It is best to conduct such assessments before, during, and after odor producing activities in order to gain an understanding of the duration and intensity of malodors arising from specific activities. An example of such an activity might include manure storage agitation and land application.

Conducting an odor assessment can be very beneficial as it assists in identifying areas where improved production unit operations and practices may be appropriate. Improving areas identified as potential odor problems can help avoid neighbor complaints. Investing the time to conduct and document periodic odor assessments, including consideration of possible remedial actions when judged appropriate, will create a historical record that could become quite important in the event of a legal complaint.

The remainder of this chapter describes the odor assessment format and basic reasoning behind the suggested approach. Four versions of the odor assessment methodology are presented: (1) animal agriculture, (2) food processing, (3) mushroom production, and (4) land application.

6.2 Odor Assessment Format

This section describes the basic components of an odor assessment. Each type of the odor assessments contains questions that are directed toward a specific type of production process, however, the general structure is the same.

Production Practices and Siting
Production practices and siting play a crucial role in odor emissions. Evaluating production unit locations and typical practices/routines can help determine where odor problems are occurring. Important factors are divided into two categories: (1) site information, and (2) production unit conditions. Site information refers to the entire production facility and all areas used by the facility operator. Production unit conditions relate to management/maintenance practices employed for animal holding areas, buildings, treatment facilities, and manure storage/staging areas.

Odor assessment questions in each category are designed to be answered in a yes, no, or not applicable manner. Questions where “No” is answered may signify an area where management changes could lower potential for odor complaints. If a question concerns a production unit or practice that is not used, then the answer should be “N/A” or not applicable.

Site Information
The location of a production facility with respect to neighboring residences or public facilities, such as parks, schools, institutions, and businesses, is very important. Location plays a major role in the transport and dispersal of odors. As the distance between the production facility and neighbors increases, more dilution can occur resulting in a less intense odor.

In ideal situations, the production facility layout considers *prevailing winds* in the area and is constructed so that the winds carry odors away from neighboring residences and communities. The most important wind direction occurs during warm weather, when outdoor activities are greatest and windows are open. In Pennsylvania, these *warm weather* winds generally originate from the west, northwest, and southwest (Kephart and Mikesell, 1999). (Also see discussion on thermal air inversions in section 6.6 herein.)

Windbreaks also play a crucial role in the transport of odors. Obstructions that can intercept and redirect air flow, and tends to promote mixing, producing lower odor concentrations. Windbreaks also provide *visual screening* which tends to modify the psychological perception of malodors, yielding fewer complaints (Barth and Melvin, 1984).

Production Unit Conditions

The term *Production Unit* refers to the holding areas, buildings, treatment facilities and storage units used for various purposes on a production facility. Some examples include animal housing, mushroom growing buildings, residuals storage/staging areas, feedlots, and food processing facility buildings. The term *residuals* includes food processing residuals (FPRs), manure, dead animals, or any other potentially odorous material produced as a result of the *primary* product being produced for commercial value.

The condition of production units greatly influences the odor that may be released. For example, it is important to minimize dust accumulation and release from buildings because dust particles can themselves can be a source of odor (Barth and Melvin, 1984). Maintaining clean facilities, machinery, and animals helps to reduce waste build-up and, thus, odor (Barth and Melvin, 1984). Hence, cleaning and removal of residuals should be done on a regular cycle. Each facility operator must decide on the cycle that best suits his/her needs, whether it is once a day, once a week, or even longer.

Odor Offensiveness Rating
To rate *odor offensiveness*, a methodology originally developed by A. G. Williams in 1984 has been used. William's method involves assigning numerical values to signify odor offensiveness, with higher values indicating higher offensiveness. Table 6.1 summarizes the numerical values used in the recommended assessment methodology, provides a short description, and offers a general interpretation of the numerical offensiveness rating with regard to potential neighbor complaints.

A meaningful odor offensiveness rating requires the person conducting the assessment (the facility operator) to understand and appreciate the definition of *offensiveness* as used here. For the purpose of this assessment, offensiveness is defined *as a disagreeable odor that causes unpleasant sensations to the average person upon exposure*. The phrase "average person" is used instead of "a person" because an "average person" is not accustomed to odor emitted from a production facility and, therefore, more likely to be offended by the odor.

Table 6.1 Odor Offensiveness Rating and Interpretation

Rating	Description	Probability For Odor Complaints From Neighbors
0	Non-Detectable	Low
1	Inoffensive Odor	Low
2	Very Faintly Offensive Odor	Low
3		
4	Faintly Offensive Odor	Moderate
5		
6	Definitely Offensive Odor	Moderate
7		
8	Strongly Offensive Odor	High
9		
10	Very Strongly Offensive Odor	High

The *assessment odor rating* process involves two steps: (1) an initial on-site *odor source survey* of production facilities, and (2) a *site perimeter survey*.

Odor Source Survey
The survey section of the odor assessment form requires a determination of odor offensiveness rating for various odor source areas on the production facility. This process involves walking around each of the source areas (approximately 25 feet distant) and rating the odor offensiveness at the *worst location* during the walk-around circuit. The place with the worst odor is the rating for that source area.

After rating an area, a short break in a neutral smelling location is recommended to prevent adaptation to the odorant (2). However, some bias cannot be avoided and, as a result, the most odorous areas should be surveyed first. The assessment format lists areas with the expected strongest odors first, but this order is not true for every farm. Facility operators conducting this assessment should feel free to survey source areas in the order he/she prefers.

Site Perimeter Survey
The site perimeter odor survey is intended to give the facility operator an indication of the odor offensiveness of the facility to adjacent neighboring areas. As a first step for this survey, a diagram of the facility is prepared. Offensiveness ratings are indicated on the diagram, both for odor sources and from the perimeter survey. Information presented on this diagram helps to graphically link sources with complaint locations and assists in identifying identify potential solutions.

Begin the perimeter survey by sketching the general shape of the production facility property on the compass axis provided in the odor assessment blank (See Appendix). If two separate parcels are involved in the operation, sketch the second on the axis below. If several parcels are involved, copy the blank and prepare separate diagrams for each.

Once the parcels are drawn on the axis blanks, sketch-in production units in their appropriate relative locations using the symbols provided in the legend below. Label the odor offensiveness rating of each unit, as determined in the odor source survey, next to the corresponding symbol on your diagrams.

Draw in the nearest occupied dwelling or public facility, the predominant wind direction, and areas of previous odor complaints on your diagrams using the symbols in the legend. Write the distance from your property boundary to the nearest occupied dwelling or public facility next to the symbol.

Take odor offensiveness ratings on each side of the production facility (north, south, east, and west) at the point where you feel the strongest odor exists and mark it with the appropriate symbol from the legend. Label each diagram with the site name, date of survey, and activity. The activity could include land application of manure, manure storage agitation, etc.

6.3 Animal Agriculture Odor Assessment

The animal agriculture odor assessment was developed for farmers who raise livestock. Most of the questions in this audit were adapted from work done by Barth and Melvin (1984). The assessment asks for site information and production unit conditions. Production unit conditions may include maintenance of animal housing, cleanliness of feedlot, and proper manure storage. The assessment form blank is in the Appendix.

After assessing the animal agriculture portion of the property, it may be necessary to conduct a land application assessment as well. A separate land application assessment form may be found in the Appendix.

6.4 Food Processing Odor Assessment

The food processor assessment asks for site information such as the proximity of neighbors and prevailing wind direction. It also requests information about the maintenance of buildings, storage practices, and the treatment of wastewater. The food processing odor assessment form blank is contained in the Appendix.

It may be necessary to assess one or more parcels for potential odor problems stemming from land application.

The land application odor assessment form can be found in the Appendix.

6.5 Mushroom Production Odor Assessment

Similar to the other assessments, the mushroom production odor assessment requires information about the site such as proximity of neighbors, prevailing wind direction, and wind block existence. This assessment also asks for production unit conditions. The conditions include maintenance of buildings, proper storage, proper turning, water drainage, and aeration concerns. The assessment also inquires about the disposal of spent mushroom compost and the transport of mushrooms and mushroom debris. The mushroom production odor assessment form blank is contained in the Appendix.

As with animal and food processing operations, a mushroom producer may need to conduct a land application odor assessment. The land application odor assessment form can be found in the Appendix.

6.6 Land Application Odor Assessment

This assessment was designed for farm fields that import manure, biosolids, or other organic material residuals for land application. This assessment requires information about the site as well as production unit conditions. The main difference between this assessment and the others is the section titled *field application*. This section asks for necessary information about spreading residuals. The information asked for includes weather conditions when spreading, time of spreading, etc. The land application assessment form blank is contained in the Appendix.

Given the potential for odor complaints, spreading residuals on fields should be carefully planned. Using weather forecasts to help determine when to spread residuals is very helpful. Cool, windy days are best for spreading because fewer odorous compounds are released and more dilution occurs. Early morning (after sunrise) is also a good time to spread residuals. During this time, air warms and rises, allowing for better odor dispersal (Barth and Melvin, 1984). Spreading residuals before nightfall provides less than ideal conditions. In the evening, air begins to cool and sink to the surface and warmer air forms a lid on top of the cooler air (Barth and Melvin, 1984). This is called a thermal inversion, and is the is opposite of what occurs during the day. During an inversion, odorous air will be trapped near the surface with cool air. This allows odor to travel in a concentrated form along the ground surface (Kephart and Mikesell, 1999).

Selecting times when winds blow away from populated areas will decrease or eliminate complaints. To the maximum extent possible, avoid spreading close to highways, residences, or other public facilities. Incorporating residuals into the soil immediately after spreading greatly reduces odor emissions. In addition, equipment used to spread residuals on fields should be regularly cleaned.

Maintaining good relations with neighbors is extremely important. As such, call neighbors before land application and avoid spreading on or before holiday weekends.

6.7 Example Odor Assessment – Offensiveness Rating

The remainder of this chapter illustrates the use of site sketches and odor offensiveness ratings for an example livestock farm. Figure 6.1, which immediately follows this text, includes land application fields immediately adjacent to animal containment and manure storage facilities. The example further assumes that there are land application fields located in another area, three miles distant. Accordingly, a second site diagram is prepared for the distant land application field.

As shown in Figure 6.2, the on-site ***source survey*** identified areas exhibiting *definitely offensive* to *strongly offensive* odor ratings (ratings of 6 and 9 respectively). The ***perimeter survey*** for the home farm parcel (where livestock is housed) shows potentially problematic ratings at the property line in more than one location. Of particular concern is the offensiveness rating at the southwest property line, which is immediately upwind of a residence occupied by neighbors who have registered a complaint in the past, approximately 560 feet distant.

Since no land application activities are taking place, it is not surprising that land application fields are exhibiting no offensive odors. The fact that offensive odors are reaching the home farm property line during a period when no specific odor producing *activity* is being performed, and that neighbors are relatively close, suggests that the operator should consider use of more aggressive odor management practices. At a minimum, the operator should do everything practicable to prevent further deterioration of buffer distances between odor sources and neighbor residences.

Example: Livestock farm with fields in another location:

Example: odor offensiveness rating diagram showing sources and perimeter survey:

CHAPTER 7:
SITING AGRICULTURAL AND FOOD PROCESSING ACTIVITIES

Appropriate site selection has proven to be one of the best methods for avoiding odor problems and litigation. Site selection becomes more important as production facilities get larger. In this chapter we examine some of the factors important for siting agricultural and food processing facilities.

7.1 Regulatory Considerations

State and local governments vary widely in their approach to regulation. Few have attempted to write regulations specific to odors. Policy options range from programs encouraging voluntary compliance to statewide regulation.

One tool for promoting facility productivity and avoiding litigation is the establishment of an environmental management plan. Such a plan addresses a broad range of environmental issues, including odor management. The fundamental premise is that facilities should be designed to promote efficient operation while minimizing adverse environmental effects, in full compliance with all applicable regulations (Purdue, 1998).

A most effective technique for avoiding odor complaints is the establishment of adequate setback distances. Separation distances that regulate buffer zones from animal production facilities have proven quite successful in controlling odor nuisance complaints in the Netherlands. Similar policies have been adopted in the US by several states, with North Carolina at the forefront.

Use of a single uniform setback distance will not guarantee the elimination of nuisance complaints. Effective buffer areas need to be based on local conditions. Setback considerations should include the size and type of operation, the facilities covered by the setback (such as lagoons, fields, and houses), as well as the proposed sites and methods for applying wastes to land. Local vegetation, prevailing winds, weather patterns, and neighboring land uses may also be considered.

7.2 Proximity to Sensitive Areas

Facility location plays a paramount role in odor issues. Facilities should be located as far as practical from residential developments, commercial enterprises, recreational areas or other prime areas for nonagricultural uses. Despite otherwise favorable operational factors, a site may be fraught with odor management problems due to existing or potential future development (SOTF, 1995).

When possible, production facilities should be located near the center of a tract of land large enough to allow manure to be applied to the land at agronomic rates (SOTF, 1995). Pollution control and waste treatment facilities should be located as far as practical from areas of high environmental sensitivity such as drainage ditches, streams, or estuaries.

Locating a facility in a traditional livestock production area will alleviate nuisance claims as well. Be aware of the local laws and zoning ordinances.

7.3 Local Climatic Conditions

Weather patterns, humidity, and temperature largely determine odor transport and detection, all of which can change with the season, the day, or even the time of day. Warm temperatures and high humidity increase the potential for odor nuisances, while cold, dry conditions reduce the potential for nuisance complaints.

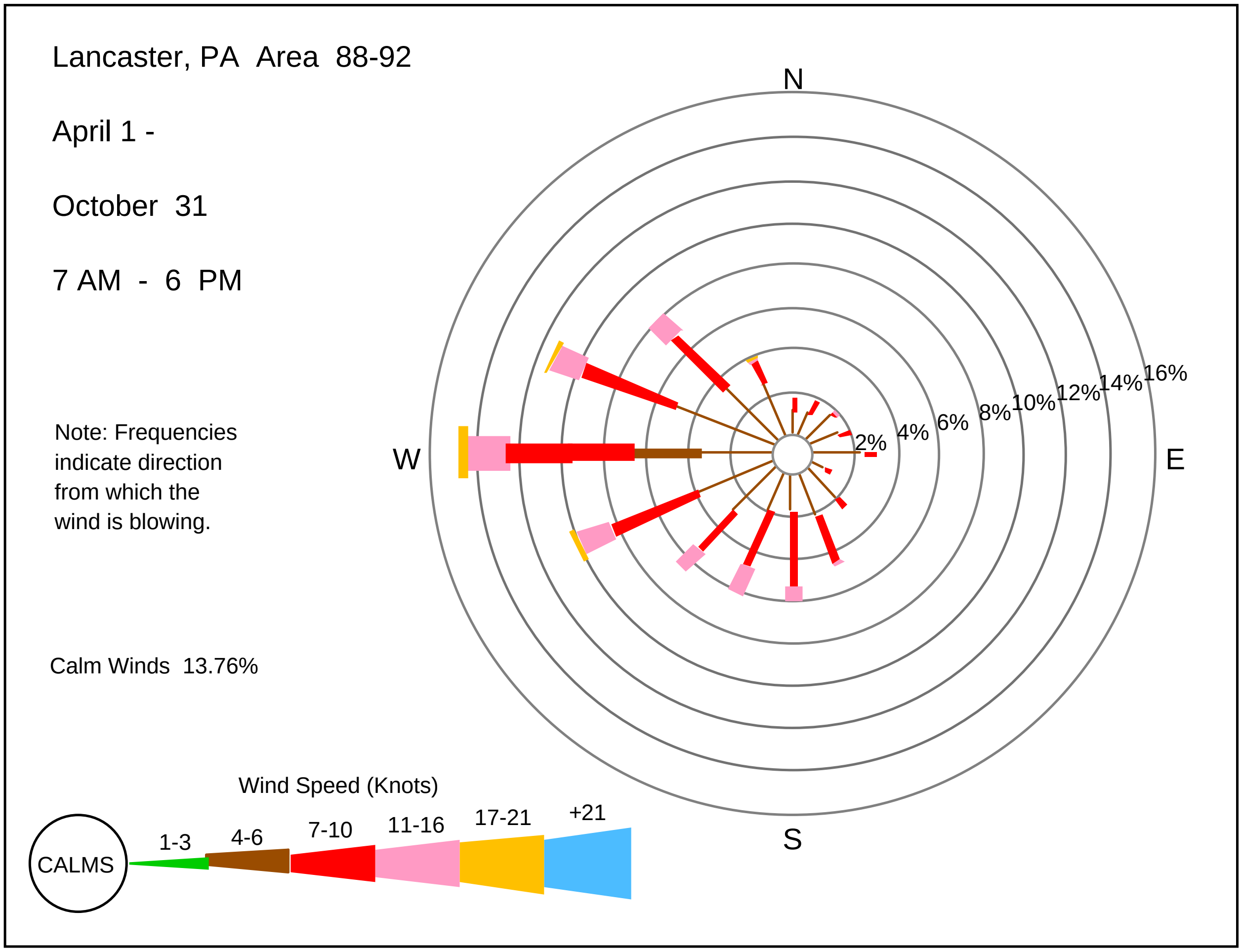
Weather conditions differ from farm to farm, just as they do from state to state. It is necessary to gather information closely related to the area of interest since meteorological conditions can change over even small distances. Monitoring the actual site is best, but weather station data is freely available. Although not as accurate as a site-specific study, the local weather station provides temperatures, wind direction, wind speed, humidity, and other conditions. Such information can be used to time key operation activities (e.g. manure storage agitation) to reduce odor production and nuisance complaints.

Facilities should be located so that prevailing winds and air drainage patterns minimize nuisances for neighbors and local public use areas. Prevailing winds from an operation should blow away from neighbors. Remember that when wind velocity is low, air movement follows the same general path as water running off of the site. Hence, locating a facility topographically up gradient of a nearby sensitive area is a prescription for trouble. Orienting facilities so the narrow dimension faces the wind direction of most concern helps to reduce the width of the odor plume blowing downwind (University of Georgia, 1999).

One particularly helpful tool is the ***wind rose***. As illustrated in Figure 7.1, a wind rose graphically portrays the frequency of wind direction on a 16-point compass, over a specified period of time. Rays are drawn out from the center of the rose depicting the direction from which wind is blowing (on average). Concentric rings on the rose indicate the relative frequency of winds. Some wind roses further show the relative wind speed (typically expressed in knots) by superimposing a color or line code over the directional rays.

Figure 7.1 shows a wind rose for Lancaster, Pennsylvania based on weather data spanning April 1 through October 31 (1988-1992) during the period of 7:00 AM to 6:00 PM. This sampling period spans the typical growing season in Pennsylvania, covering weather conditions most conducive to odor emission and nuisance complaints. The period also covers the daylight hours, when most farm work is performed and neighbors are *out-and-about*, resulting in the highest susceptibility to exposure to malodors. Accordingly, this wind rose provides some valuable insights for facility siting.

It is important to keep in mind that wind rose information is specific to the location where measurements are taken. As noted previously, air movement at a particular site may differ from that reported by an off-site weather station due to variations in topography.



http://home.pes.com/windroses/wrgifs/_4000.GIF

Figure 7.1 Wind Rose for Lancaster, PA Area

Figure 7.1 shows that calm conditions predominate approximately 14% of the time. In all, over 61% of winds come from westerly compass positions. About 15% of the time winds come from due west. Due west winds are further identified by wind speed, with about 40% at 4-6 knots. Another 40% of due west winds fall into the 7-10 knot category, and 11-16 knot winds occurs approximately 15% of the time.

Based on Figure 7.1, potentially odorous activities should be located a far as possible to the west of sensitive areas. It is also important to note that while winds predominantly came from the west, there are periods when wind comes from easterly compass positions. Hence, neighbors located nearby to the west could also be expected to experience periodic malodors. Further, substantial periods of calm conditions suggest that adjacent low-lying areas may expect malodors during times when air is cooling at the ground surface.

Wind rose information like that presented in Figure 7.1 can be accessed at the following web site:

http://home.pes.com/windroses/

These wind roses, although originally developed for EPA air pollution assessment, are well suited for odor management / preliminary siting studies. Currently available wind roses from this Web site for Pennsylvania locations include Allentown area, Altoona area, Bradford, Clearfield County, Erie area, Harrisburg, Harrisburg area, Johnstown, Lancaster area, Philadelphia, Pittsburgh, Scranton area, State College, Williamsport, and Wilkes-Barre (See Appendix D for wind roses).

7.4 Topography and Barriers

Local topography and landscape largely determine site-specific air movements, since these factors are essential to dispersion and dilution rates. For example, neighbors who live down gradient from a facility on steeper slopes are especially vulnerable during nighttime.

Ideally, a site should be level or gently sloping so that buildings can be properly located and constructed to the desired grade without excessive cuts and fills (Hoehne, 1996). Gentle slopes facilitate movement of equipment, animals, and workers. They also facilitate transport of manure effluent from livestock buildings to treatment and/or storage facilities. The landscape should be graded and maintained to insure effective drainage of rainfall runoff. Accumulations of standing water should be avoided, which can create anaerobic conditions and malodors.

Dense stands of trees and bushes should be established and maintained as vegetative buffers around lagoons, fields, and production facilities. Such buffers can beneficially reduce or modify wind patterns and help to contain or disperse odors (SOTF, 1995). An added benefit of trees is that they act as natural air filters by collecting particles on needles and leaves.

Finally, the shelter provided by a vegetated buffer will also improve the appearance of the facility. The visibility of the facilities buildings or waste storage increases the likelihood of odor complaints. Thus it is important to integrate the facility into the landscape.

CHAPTER 8:
ODOR MANAGEMENT PRACTICES

In this chapter we will examine specific strategies and management practices which can have a direct and meaningful impact on limiting odor emissions and reducing odor complaints. Individual practices are generally categorized and briefly described providing a range of potential options for management. Since more than one practice is often needed for effective control, the chapter concludes with considerations relative to the integration of multiple practices to achieve the desired goal – that of remaining on good terms with our neighbors.

8.1 Fundamental Control Strategy

All effective control practices are fundamentally based on some form of *intervention* in the odor pathway. The odor pathway contains four basic components: (1) odor source, (2) odor release, (3) off-site odor transport, and (4) odor reception (Chapter 3). When all four components are present, the probability of odor complaints is high. If the odor pathway can be interrupted at more than one location, then the chances of nuisance complaints are dramatically reduced.

8.2 Control Practices

Odor management practices have been categorized based on their primary *intervention mechanism* in the odor pathway. Some practices defy categorization since more than one odor pathway component was affected. Given this complexity, management practices have been categorized into the following groups: *(1) Preliminary Considerations, (2) Source Reduction, (3) Treatment, and (4) Emission Suppression and Dispersion*.

The presentation format includes: *(1) practice title and code, (2) short description, (3) conditions where practice applies, (4) design concept (where appropriate), (5) operation and maintenance, and (6) additional resources.*

The *practice code system* allows the user to quickly identify the type of practice being discussed provides for an orderly expansion of the practice lists within each category.

The prefix for all practice codes incorporates the characters *MP#*, which means *management practice number*. The next letters refer to the practice category. For example, the letters *PC* indicate *Preliminary Considerations*. The letters *SR, T, and ESD* refer to *Source Reduction, Treatment, and Emission Suppression and dispersion,* respectively. The last three numerical digits in the management practice number specify the individual practice within the specified category.

Detailed coverage of design, operation, and maintenance are outside the scope of this document. The *additional resources* section included in each practice narrative is provided for those desiring more information on a given practice.

8.2.1 Preliminary Considerations (PC)

Siting Critical Operations (MP#PC001)

Short description
Wise *location* of farm and processing operations can greatly reduce or eliminate problems.

Conditions where practice applies
This practice is appropriate for all odor-generating operations. Proper siting of facilities is most appropriate during planning, when a new site, new process, or expansion is being considered.

Design concept
Since situations vary widely, there are no universally applicable rules. There are, however, many generally valid principles. For example, it is a good idea to site an operation (a manure storage lagoon, for example) where it is less visible to the neighbors. By planting a row of trees, or siting the facility over a hill or far enough away that it cannot be seen by the neighbors, it is less likely that they will complain about the odors. If they can’t see it, they won’t be as likely to smell it.

Maintain as much distance as practical between potential malodor sources and neighbors. The further an odor has to travel, the more dilute and less intense it will be when it reaches the neighbors. If there is *undeveloped* land surrounding a facility, it is wise to try to keep this as a buffer region, rather than selling the land and inviting neighbors closer to the source of odors. If an odor is sufficiently diluted before it reaches the neighbors, no complaints will be registered.

By taking advantage of the *prevailing wind direction*, the transport of odors into sensitive adjacent areas can be dramatically reduced. However, keep in mind that prevailing wind direction is just that—prevailing. Wind blows in all directions at various times, so while the wind may be blowing favorably most of the time, there will be occasions when the wind will carry odors in less desirable pathways. During these times, other odor control measures should be in-place to avoid complaints. Appendix D contains a series of *wind roses* which provide the prevailing wind direction patterns for several locations in Pennsylvania.

Operation and maintenance

Don't allow new or expanded sources or operations to encroach on *buffer zones*. By the same token, remain vigilant for changing neighborhood conditions that include the migration of residential development into downwind corridors. Pay attention to any proposed changes in local zoning, development codes and ordinances, and participate by voicing your opinion regarding changes that place agricultural operations at increased risk to odor complaints.

Timing Critical Operations (MP#PC0002)

Short description

Timing odor producing activities for periods when neighbors are less likely to be exposed will significantly decrease odor complaints.

Conditions where practice applies
This applies to any facility with operational flexibility for activities prone to malodor emissions. For example, there are some times for spreading manure that are better than others. By taking advantage of the *better times*, odor complaints can be reduced.

Operation and maintenance
Spread manure as early in the day as possible. Many people are at work during the day (typically 8:00 AM to 5:00 PM), and by the time they get home in the evening, the odor will have had the chance to dissipate. If spreading is delayed till evening, it also increases the amount of time for the manure to dry out. Remember, the wetter the manure, the more potential for odor problems.

Spreading frequency is just as important. There is a tradeoff between spreading more or less frequently. The more often spreading is performed, the more often odors will be released. However, these odors will be much less intense than odors from stored manure. If manure is stored for several months, spreading will occur less often and odors released less frequently, but they will be more intense and offensive.

Other matters of timing have to do with common courtesy. When possible, try to let neighbors know ahead of time when spreading will occur. Informing them of your plans shows them you are considerate and makes complaints less likely. Avoid manure application on weekends or on holidays when people are more likely to be outdoors. Maintaining good relations with neighbors definitely reduces odor complaints.

8.2.2 Source Reduction (SR)

Sanitation (MP#SR001)

Short description
Maintaining sanitary conditions at farms and processing facilities is a very effective way to control odors before they start.

Conditions where practice applies
This practice is appropriate for any operation, including animal agriculture, composting, food processing, and mushroom production facilities.

Operation and maintenance
Keeping facilities neat and equipment in good working order is inherently a high maintenance activity. However, the benefits generally far outweigh the effort when it comes to odor complaints. The buildup of waste materials promotes anaerobic decomposition, leading to the generation of offensive odors. Regular cleaning lowers the likelihood of this happening and improves air quality in the facility. Areas where animals are kept should be kept as clean and dry as possible. Manure accumulation on the warm bodies of animals creates the perfect breeding ground for bacterial growth and odor.

Keeping equipment clean and well maintained also helps. Machinery in good working order operates more efficiently, reducing delays in spreading manure and other operations. A clean, well-maintained facility generates fewer odors, looks much better, and attracts fewer complaints from neighbors than unsanitary, unkempt operations.

Maintaining Aerobic Conditions (MP#SR002)

Short description
Maintaining aerobic conditions where materials are being accumulated involves keeping air (oxygen) readily available throughout the material to discourage septic (anaerobic) conditions. Anaerobic conditions promote the generation of malodors.

Conditions where practice applies
Ideally, aerobic conditions should be maintained anywhere waste material accumulates or is being stored.

Design concept
There are several ways to achieve adequate oxygen supply in a storage or treatment structure. This can be done mechanically, via aeration, or by simply taking advantage

of a large surface area and shallow storage depth. Oftentimes maintaining an aerobic condition requires large energy inputs for aeration of the structure. This can be accomplished with an air pumping system. The requirements of the system depend on several variables including the type of aeration, the dissolved oxygen requirements, the level of stabilization, the quantity of required aeration, often only the top portion is aerated to save energy costs.

Aerobic conditions can also be promoted by constructing a storage structure with a large surface area to depth ratio. By keeping the surface area large, greater air interface is available for oxygen exchange between the stored material and the surrounding atmosphere. A larger surface area may decrease energy costs for mechanical aeration. However, the savings must be weighed against the loss of acreage for other operations.

An important design consideration is the size of the aeration pump. It should not be undersized in an effort to reduce energy costs. While initially this may seem logical, under-sizing the pump will mean inadequate aeration and potential odors. Much effort may be spent to correct a problem that could have easily been prevented.

Moisture Control and Drainage (MP#SR003)

Definition
Maintaining the proper water content of decomposing material generally lessens odor production and maintenance difficulties.

Conditions where practice applies
This control strategy is appropriate when odorous materials are being stored.

Design concept
Maintaining manure in the proper moisture range makes life easier for the farmer in a number of ways. Reducing water content of manure to less than 70% has been shown to reduce odors generated. Manure with 30-70% moisture content is sticky and hard to handle. It is likely to damage the equipment used to move it. The farmer is better off at

either extreme—either very wet manure (greater than 90% moisture) or very dry manure (less than 70 % moisture).

Operation and maintenance
Using litter or bedding material helps to absorb moisture in manure, lessening odors resulting from anaerobic conditions.

Dust Management (MP#SR004)

Definition
Dust control is an odor suppressing strategy that includes reducing the rate of emission (source control), effective ventilation (ventilation control), and air cleaning (removal control).

Conditions where practice applies
This practice applies to agricultural animal housing situations and outside lots during dry weather.

Design concept
There are several pratical dust control techniques. Feed additives such as oils or fats can be added to the animal feed in an effort to reduce dust. Sprinkling water or oil on the floor of animal storage building reduces respirable and inhalable dust.

Controlling ventilation rate and air distribution provide another dust management technique. Purge ventilation (short period of high ventilation) may be effective in producing a short term decrease in particle concentration. Direction of airflow is also important in reducing dust. In animal housing, upward airflow has been found to be superior to downward airflow.

Dust can also be removed using electrostatic precipitators that impart a charge to dust particles that are then attracted to oppositely-charged collector plates. Studies using electrostatic precipitation have shown removal efficiencies between 18.5 and 96.4% at applied voltages of –10.3 and –12.1 kV, respectively at an airspeed of .76 m/s.

Finally, filtration and wet scrubbing are used in dust management. Filtration occurs through direct interception, inertial deposition, diffusion and electrostatic effects. Fabric filter systems are effective in dust control, but cleaning and filter replacement make them labor intensive and costly.

Additional resources

http://adminsrv.usask.ca/paci/psc_db/dust.html

Manure Additives (MP#SR005)

Definition
Manure additives are chemicals incorporated into excreted manure to reduce offensive odors.

Conditions where practice applies
These chemicals are applicable to any manure accumulation/storage facility where odor control is needed.

Design concept
Manure additives are grouped on the basis of their mode of effectiveness. These include (1) masking agents, deodorants, and perfumes, (2) counteractants, (3) oxidants and bacterial inhibitors, and (4) enzymes.

Masking agents, deodorants, and perfumes are used to cover up malodors with a presumably more pleasant odor. These products have the advantage of predictability, making them the most often-used manure additive. However, these products should be used cautiously because with long-term use neighbors may eventually find their odor more offensive than the odor being covered up.

Counteractants interact with specific odorous compounds, neutralizing the odor. Their effectiveness is limited because of the large array or compounds contributing to agricultural malodors.

Oxidants and bacterial inhibitors oxidize odorous compounds and reduce bacterial populations responsible for generating the malodors. The success of this group of products seems to be limited. In addition, these products can be expensive in the large quantities required.

Enzymes are required in all biochemical reactions, and as such may be used to manipulate odor production. Again, because of the complexity of compounds making up malodors, the effectiveness of enzyme additives is uncertain. Small quantities should be purchased and tested before purchasing for full-scale operations.

Keep in mind that the purpose of these chemicals is to alter the characteristics of off-gasses released from fresh manure. When manure is stored, chemical breakdown is occurring, and new compounds are being released. As decomposition progresses, the effectiveness of chemical additives may be dramatically reduced.

Operation and maintenance
Large amounts of these chemicals are required for odor control, so this can be an expensive practice. Because of the cost, the use of manure additives is typically on a short-term basis. There are many different additives available, so the best way to ensure success is to research what is available (different manufacturers, different applications, etc.) and choose the one best suited to your operation.

Feed Additives (MP#SR006)

Short description
Feed additives reduce odors by manipulating the animal diet.

Conditions where practice applies
The use of feed additives is applicable in agricultural animal operations, where, despite proper management, manure presents a significant odor emission problem.

Design concept
There are several factors involved in manipulating animal diets to reduce odor emissions. The first is to feed essential available nutrients based on the animals' genetic potential and stage of growth, so that the nutrient excretion is minimized. Second is the idea of inhibiting certain bacterial groups in the gastrointestinal tract or altering the fermentation of existing bacteria to control odorous end products. Finally, by changing the diet composition (nitrogen and carbohydrate content), it may be possible to

change physical characteristics of urine and feces that impact odor production.

Previous research has shown that imbalances in the carbon to nitrogen ratio (C:N) in the intestinal systems in pigs, or in digestion, produce increased levels of malodorous compounds and reduced efficiencies of nutrient utilization. Reducing the dietary crude protein level and supplementing with synthetic amino acids reduces nitrogen excretion from pigs. From 25-30% reduction of nitrogen in manure has been reported (see below) and theoretically, a nitrogen reduction of 40-50% is possible (1). Altering the ratio of nitrogen excretion in urine and feces is a potential means for reducing ammonia emissions.

Changing the carbohydrate structure of the diet to increase bacterial utilization of nitrate results in significant reduction of nitrogen excretion. Use of complex carbohydrates and organic acids in diets have also changed microbial populations and concentrations in the intestinal system of animals potentially affecting pH and volatile organic compound production in manures (1).

Reduction in crude protein content of the diet with adjustment to maintain essential amino acid levels also results in a reduction in manure nitrogen content. Reduced manure nitrogen leads to a reduction in the concentration of select odorants (volatile fatty acids, phenols, and indole).

Composting (MP#SR007)

Short description
Composting transforms coarse organic material into a soil-like soil amendment product through the use of aerobic biological degradation and decomposition.

Conditions where practice applies
Composting of waste material is applicable in agricultural and food processing operations where waste organic material is generated. For composting to be successful, careful planning and operation management is crucial. Finally, this system must provide for an end use of the compost produced.

Design concept
Siting compost facilities must consider protection of surface and ground water resources, sensitive land uses, area requirements, soils and topography, and accessibility. Compost facilities should be located in an area that is well drained and has all weather access to roads and work areas. Facility design decisions should be individually evaluated on the basis of their impact on odor generation and transport.

Agricultural composting is regulated at the state level by the Department of Environmental Protection (DEP), and may require a permit in certain situations. Pennsylvania farmers are exempt from water quality permitting requirements provided that they comply with guidelines set by the state. All exemptions are granted on the condition that the activity does not cause pollution of the air, water, or natural resources of the Commonwealth. In addition to state regulations, local-zoning ordinances may also affect on-farm composting operations.

Additional resources
Manure Management Manual, Agriculture Composting Supplement. Agricultural Composting of Manures. PADEP. Pages 19-25.

Alkaline Stabilization (MP#SR008)

Short description
Mixing alkaline materials (e.g. lime) with organic residuals can raise pH outside of the range needed by most microorganisms that are responsible of odor production.

Conditions where practice applies
This practice would most often be used in situations where organic materials are being stored and temporary odor suppression is desired.

Design concept
Because odorous compounds are generated from the microbial breakdown of organic compounds in manures and other materials, chemicals with anti-microbial properties will prevent production of odors. Although the pH range over which microorganisms as a group can thrive is very wide, most microbes responsible for odor

generation tend to operate optimally in near-neutral conditions (pH 6-8). Thus, adding lime to raise pH significantly outside this range will retard microbial growth and the production of hydrogen sulfide (H_2S), ammonia (NH_3) and other odorous compounds which accompany metabolic activity of microbes. Lime has been used to control odors in liquid hog manure (Day, 1966).

The effectiveness of lime treatment depends on the principal odorous compounds being generated. At high pH, the solubility of H_2S increases but the solubility of ammonia (NH_3) decreases. Thus, lime treatment will suppress the release of H_2S, but NH_3 may be more easily released to the atmosphere at high pH. Thus, sometimes lime addition may alter the nature of the odors without necessarily suppressing the quantity of odors being generated.

Lime slurry can be applied as a topical treatment to stockpiled or stored materials, or it can be blended into liquid materials with odor-generating potential. Lime in a powdered or granular form can also be used but it must be mixed thoroughly for effective treatment of the entire quantity of odor-producing material. Topical application to stockpiled or stored materials also tends to form a crust that seals in odors. Crust formation also promotes anaerobic conditions so the potential for odor generation inside the pile is high. When the material is agitated or unloaded and the surface crust is broken, odors may be very intense and offensive.

Lime addition often does not permanently suppress odors. As regrowth of microorganisms occurs with the production of organic acids, pH will begin to drop and odor production will begin. Thus, long-term storage of potentially odorous materials will require periodic application of lime to prevent odors.

Additional resources

Day, D.L. 1966. Liquid hog manure can be deodorized by treatment with chlorine and lime. Illinois Research 127:16

8.2.3 Treatment (T)

Bio-filtration (MP#T001)

Definition
Bio-filtration is an odor treatment process where contaminants and odor causing agents are adsorbed and filtered through a biologically active media that may consist of compost, activated carbon, bulking agents, buffering agents, or inorganic additives (1).

Conditions where practice applies
Bio-filtration is applicable in agricultural, food processing, and solid waste treatment.

Design concept
The success of bio-filtration systems to control odors is related to two processes: sorption and regeneration. Sorption processes employed in bio-filtration include absorption or dissolving in moisture on the media surface, chemisorption, catalytic contact on the soil particle surface, and ion exchange on the particle surface. For example, hydrogen sulfide is precipitated onto the soil particles as iron or other metal sulfides. Hydrogen sulfide is first dissociated into HS^- and H^+ and then precipitated out as a metal sulfide.

Bio-filtration systems consist of four major components. The ventilation or *air collection system* collects odorous gas from the operation facility. *Blowers* direct collected gasses to the distribution system beneath the biofilter. The *distribution system* delivers the gas uniformly to the base of the filter bed. The *biofilter bed* sorbs and degrades the odors, producing a relatively odor-free exhaust at the bed surface into the atmosphere.

Odorous gases are transported to the biofilter bed and distributed evenly throughout the filter by a perforated pipe system surrounded by gravel or wood chips. Other types of air distribution systems include a plenum or pressure chamber, or a sinter block system. Numerous biofilter media materials have been used including soils, composts, fibrous peat, shredded brush, shredded bark, volcanic ash, sand, or mixtures of such materials. The choice of media is site specific, and is dictated by the loading rate of the odorous gas applied, the desired pressure drop across the filter bed, and the chemical composition of the gaseous components.

The depth and area of the filter bed depend on the chemical constituent loading and airflow volume applied to the bed. While horizontal beds are most common in recent years, biotowers (vertical adaptations of the biofilter) have also been used where area limitations exist. The shallow biofilter, typically three feet thick, however, is less complex, less expensive, and can more efficiently remove odors from most waste gases.

The sorption capacity of all filter materials is limited, and regeneration of the material is achieved by chemical and microbial oxidation of the odorous compounds. Regeneration of sorbed chemicals is moderated principally by microbial biodegradation. For example, hydrogen sulfide and HS^- are oxidized by *Thiobacillus* bacteria to non-odorous hydrogen and sulfate ions.

Operation and maintenance

The capacity of a filter material to remove odorous compounds depends on the simultaneous operation of both the sorption and regeneration processes. Excessive airflow rates can saturate the sites where odors are retained on the filter media and diminish the odor removal of the system. A second limiting factor is the microbial regeneration rate of the sorbed chemical. This must equal or exceed the sorption rate. In most cases of biofilter failure, the limiting factor is overloading of the filter rather than microbiological processes because of the great diversity and numbers of soil bacteria (2).

Biofilter maintenance focuses on media moisture and pH management. Keeping the media free of vegetation (weeds or other volunteer plants) is also required for good performance.

Advantages of biofilters include an odor reduction of 60-80%, relative low cost, ease of installation, and limited space requirements. There is no requirement for the addition of chemicals, and disposal of spent media is generally not a problem for most agricultural applications.

Biofilters have low energy requirements and can simultaneously remove a wide variety of dissimilar odorous compounds effectively. However, the useful life of a biofilter may vary from as little as two years as much as five years, at which time the filter media must be replaced to restore performance.

Additional resources

(1) Matrix Environmental Technologies. http://www.matrixbiotech.com/html/biofilter.html

(2) Naylor, L.M. and G.A. Kuter. 1990. Odor Control with Biofilters. From: National Poultry Waste Management Symposium. Edited by J.P. Blake and R.M. Hulet.

(3) Hog Manure Treatment Technologies. http://www.cetac-west.ca/hmm/tech/matrix/matrix.html

Scrubbers (MP#T003)

Definition

Scrubbers are collection devices that wet particles in order to remove them from the gas stream.

Conditions where practice applies

This practice applies in agricultural, food processing, and mushroom facilities where odor emissions can be captured for treatment.

Design concept

Six categories of scrubbers are defined. These include preformed spray, packed-bed, plate, venturi, orifice, and mechanical scrubbers.

The principle features of preformed spray scrubbers are their low energy requirements and their low efficiency for removing particles less than 5 µm in diameter. Two types of preformed spray scrubbers include the spray tower and cyclone scrubbers.

The characteristics of packed bed scrubbers include introduction of liquid near the top of the unit followed by a trickling down of the liquid to the packed bed. The liquid and gas flows may be co-current, crosscurrent, or counter-current. Collection efficiency depends upon the contact time of the gas stream on the packed bed. Packing includes coke, crushed rock, and synthetic rings or saddle-shaped materials. Co-current packed bed scrubbers are usually the most efficient type for smaller particles, but they tend to have higher pressure drops. The crosscurrent scrubber requires less liquid flow, usually has a lower pressure drop, and tends not to clog. The countercurrent type requires the most liquid flow and is best suited for higher loadings.

A plate (tray) scrubber consists of a tower containing one or more perforated plates; flow is countercurrent with the gas entering near the bottom of the tower. Generally, the plates have impingement baffles over the perforation to force the rising gas to turn into the liquid level on the plates. These devices are useful for collection of particles over 1 μm in diameter.

One of the most common particulate removal devices is the venturi scrubber because of its simplicity and relatively high collection efficiency of particles in the 0.5 to 5 μm range. This system is unique in that it collects fine particles and absorbs some gas phase emissions. In this system, liquid (usually water) is atomized and collects particles impacting the liquid as a result of differing velocities for the gas stream and atomized droplets. Downstream in the diverging section, the mixture decelerates, and further impacts occur, causing the droplets to agglomerate. Once the particles have been captured by the liquid, a separator is used to remove the particle or liquid from the gas stream.

In an orifice scrubber (also known as an entrainment or self-induced spray scrubber), the gas stream passes over a pool of liquid at a high velocity before entering an orifice. The high velocity results in centrifugal forces, impingement and turbulence, which cause wetting of the particles for their separation and collection from the gas stream.

Mechanical scrubbers are devices that use a rotating element, such as a drum, disk, or fan, to distribute the liquid spray. This approach produces very finely divided droplets that results in effective capture of fine particles at the expense of higher energy costs.

Operation and maintenance
Operation and maintenance procedures for wet scrubbers must simultaneously consider also air quality control, employee health, and general safety. Most wet scrubber component failures (such as clogged spray nozzles) result from abrasion, corrosion, chemical scaling, sedimentation, and wearing of moving parts (2).

Other considerations
Wet scrubbers typically use water as the cleaning liquid. Water usage and wastewater disposal requirements are important factors in evaluation of the scrubber alternative.

Advantages of scrubbers include their compact size and versatility for a variety of emissions. They are efficient over a wide loading range, and they have low capital and operations and maintenance costs. They are insensitive to moisture content of the air being treated, and re-entrainment is rare. On the other hand, there are several disadvantages. They are inefficient with high temperature gases, and they require a high power input. Corrosion is a potential problem and the waste scrubber liquid may involve special disposal requirements.

Additional resources
(1) Corbitt, R.A. 1990. Handbook of Environmental Engineering. McGraw-Hill, Inc. Editors Harold B. Crawford and Dennis Gleason.

(2) Control Techniques for Particulate Emissions from Stationary Sources, Volume 1. U.S. Environmental Protection Agency, EPA 450/3-81/005a. Research Triangle Park, N.C. 1982.

Adsorption (MP#T004)

Short description
Adsorption is the process by which odorous air is passed through an adsorbent and odorous constituents are removed. In contrast to bio-filtration, adsorption typically involves sophisticated and costly equipment, process control, and operational know-how.

Conditions where practice applies
Adsorption is applicable to odor control in any type of agricultural operation. However, due to the relatively high cost, it may be most practical in applications such as removal of food processing odors, rather than odors from farming operations.

Design concept
In the adsorption process, odorous air is passed into an odor adsorption chamber, where it flows through a section containing the adsorbent material. The media can be either in thin panels, as shown in the diagram, or in thick sections, known as deep bed filters. Several types of media are available. Various carbons, including activated carbon, are the most common, in addition to activated alumina, activated bauxite, aluminosilicate, iron oxide, and silica gel. The key to an adsorbent is that it has a high surface area to volume ratio, so that there is a lot of surface area for the odorous gas to contact.

The main design considerations for odor control by adsorption are:

- Selecting the proper air flow
- Maximizing efficiency based on odor removal and adsorbent utilization
- Minimizing power requirements
- Estimating adsorbent usage

Advantages and disadvantages
Adsorption is a very reliable method of organic and inorganic odorous substance removal. 80-100% odor removal can be achieved with no chemicals or water required. However, the systems are costly, and there exists the potential for fouling or unexpected reactions resulting in the formation of toxic substances. Careful monitoring of the efficiency of the media is essential.

Additional resources
Lue-Hing, C., D.R. Zenz, P. Tata, R. Kuchenrither, J.F. Malina, Jr., and B. Sawyer. 1998. Municipal Sewage Sludge Management: A Reference Text on Processing, Utilization, and Disposal. Technomic Publishing Company, Inc., Lancaster, PA.

Effective Odor Control with Calgon® Carbon Granular Activated Carbon Systems. Calgon Carbon Corporation, 1991.

Incineration (MP#T005)

Short description
Incineration involves the burning of odorous compounds using direct or catalytic incineration to convert combustible (volatile) gases, vapors, and/or particulates to carbon dioxide, water, and ash.

Conditions where practice applies
Incineration is applicable in food processing operations and is especially applicable where there are small quantities of highly intensive odors and where boilers or incinerators are already available.

Design concept
Thermal (direct fired) incineration is a traditional system that provides excellent removal of odors. The technology is based on raising the temperature of the gas stream to 650-800 ^{o}C for a reaction time of less than one second. Incinerators include a fuel feed system, open flame burners, combustion zone, and exhaust system. Natural gas and, to a lesser extent, propane, butane, or other fuels are used. It is important that complete combustion occur since partially oxidized compounds may be created, which are more odorous than the original source.

Catalytic incineration operates by passing a preheated gas stream through a catalyst bed to oxidize the combustible emissions. The catalyst is used to initiate and promote combustion at much lower temperatures than those required for thermal incineration do. The catalytic incinerator operates in the 250-500 ^{o}C range with an associated smaller fuel demand. The system has limited application when the gas stream is carrying metals, other solids, liquids, or compounds that react with the catalyst.

In both cases, the process requires supplemental fuel since the gas stream volatiles are almost always below concentrations required to sustain combustion.

Other considerations
Gas and equipment characteristics must be examined closely before selection of a catalytic incineration system.

Due to operating problems, catalytic incinerators are severely limited in applications with a very high concentration of particulates.

Suggested values and limits for design variables are available in the Handbook of Environmental Engineering (Corbitt, 1990).

Additional resources
Corbitt, R.A. 1990. Handbook of Environmental Engineering. McGraw-Hill, Inc. Editors Harold B. Crawford and Dennis Gleason.

8.2.4 Emission Suppression and Dispersion (ESD)

Soil Injection/Incorporation (MP#ESD001)

Definition
Direct injection or immediately *turning-under* manures and residual materials into the soil is a very effective means of limiting odor emissions form land application sites.

Conditions where practice applies
Injection of materials is applicable in agriculture and may utilize high nutrient material generated in livestock agriculture, food processing, and municipal solid waste treatment.

Design concept
A variety of equipment types and manure injection/application configurations have been utilized with variable success. This section will discuss a few important procedures that apply in land application of manure when odor reduction is desired.

Prompt incorporation of the spread manure into cropland will help dramatically in avoiding odors. It has been found that injecting swine manure reduces odors by 90% compared to spreading the manure. Plowing the manure into the soil reduces odors 70%-90% (Miner 1997).

Incorporation or injection is also beneficial in decreasing nitrogen loss due to volatilization and nutrient loss in runoff (PA DER Dairy Manure Mgmt. 1986).

Operation and maintenance
Injection or incorporation of the manure requires more time and machinery to get the job done. It becomes a trade-off. The more time you spend, the better odor control you get. It is a question of how important the odor control is at your facility. If you are located right next to a residential area, it may be necessary to go with the stricter odor control to prevent constant odor complaints. If your farm is secluded, you may not be as likely to receive odor complaints, and practices such as injection or incorporation may not be necessary.

Covers (MP#ESD002)

Definition
Covering a structure where odorous materials are stored is one effective way of reducing the quantity of odors leaving the facility.

Conditions where practice applies
This type of odor control measure is applicable to any type of agricultural operation where potentially odorous material is being stored. The structure could be a formal manure storage structure, or something less formal, such as a waste storage lagoon.

Design concept
There are many types of covers in use to prevent the release of odors from storage facilities. Some covers consist of floating organic material, such as chopped straw. Others are made of plastic, or similar manufactured polymers.

Barriers (MP#ESD003)

Definition
A wind barrier consists of herbaceous vegetation in rows or narrow strips across the prevailing wind direction.

Conditions where practice applies
This practice applies to agricultural cropland or other land where land application of manure is utilized.

Design concept
Barriers may consist of perennial or annual plants. Additional criteria in selecting specific plants should include adaptation to the site, non-spreading growth habit, good leaf retention, and minimum competition with adjacent crops.

Where two or more rows are needed to achieve the required density, rows should be spaced so that no significant gaps exist. Selection of plants for use in barriers should favor species or varieties tolerant to herbicides used on nearby crops.

Operation and maintenance
Periodic trimming or care of the vegetation overgrowth into adjacent crops will avoid potential plowing or harvesting problems.

Strengths
Barriers are an effective control method that work by redirecting the wind away from neighbors. The vegetation

absorbs CO_2. They are inexpensive. They reduce wind erosion of the soil and protect crops from damage by wind borne particles. They provide food and cover for wildlife. They are often more suitable to field windbreaks due to height considerations.

Weaknesses
The benefits of herbaceous wind barriers will not be observed for some time while the vegetation establishes itself.

Additional resources
PAMI (Prairie Agriculture Machinery Institute)
http://aceis.agr.ca/pfra/pfintroe.htm

Natural Resources Conservation Service. Conservation Practice Standard. Herbaceous Wind Barriers. Code 422A. February 1999.

Anaerobic Digestion & Biogas Recovery (MP#ESD004)

Definition
Anaerobic digestion is controlled method for accelerating the natural biological decay process in order to create a low-odor, biologically stable manure.

Conditions where practice applies
Anaerobic digestion is typically used to treat manure and other organic matter. The practice is also commonly used as a unit operation in municipal wastewater treatment systems.

Design concept
Recall that maintaining aerobic conditions is an effective way of controlling odors. Anaerobic digestion is not a contradiction, but rather a different application. By maintaining anaerobic conditions at elevated temperatures in a controlled environment, this digestion can actually achieve more complete decomposition than in an aerobic environment. The odorous compounds are still created, but they are then converted into odorless *biogas*–a combination of carbon dioxide and methane. What is left is a manure with considerable less odor, and the biogas, which can be used as a fuel source to generate electricity or heat.

Digested manure is not odor free, but the odor is less intense and tends to dissipate quickly when spread on the field. Also, the manure still has most of its nutrients, so the fertilizer value of the manure is retained.

The anaerobic conditions can be maintained in either a specifically designed structure or an anaerobic lagoon. The structure is more ideal because it can be constructed specifically for the application, but it is also more expensive. The anaerobic lagoon is less expensive, but the breakdown occurs at ambient temperature, so it is a slower process. This requires a larger capacity to treat the same amount of manure. In Pennsylvania, anaerobic lagoons aren’t very popular because of the large land area required and the cool winter temperatures, leading to seasonal treatment (PSU Coop Extension 1995). Also odors occur when the lagoon contents are disturbed.

Operation and maintenance
Maintaining the right conditions in the digester is the most important operational aspect of anaerobic treatment. They require very dilute manure, on the order of 1-2% solids. The temperature must be elevated, and the correct mix of bacteria must be present. A common problem associated with anaerobic digesters is known as “a sour digester.” This happens when the digester becomes too acidic. The acid-forming bacteria work harder than the methane-forming bacteria, souring the digester. In order to fix this problem, it is necessary to add lime or other alkaline material to neutralize the acid (NFEC 1999).

CHAPTER 9:
EMERGING ODOR MANAGEMENT STRATEGIES AND ASSESSMENT TOOLS

Many traditional odor control practices, such as keeping manure as dry as possible and keeping the agricultural operations well maintained, have been discussed. In addition to these tested odor management techniques, there are many emerging odor management strategies (or ‘new twists on old favorites’). While many are still under development, they hold potential for detecting and reducing odors associated with agricultural operations.

9.1 Diet Manipulation

The use of diet manipulation to modify manure characteristics is one way of controlling odors at their source. The idea is that by changing what you put in (the animal feed), you can change what you get out (the manure). For example, a study was conducted at the University of Minnesota in which pigs were fed either a reduced sulfur diet or a normal diet. The purpose of the study was to see if altering the amount of sulfur in the pigs’ diet caused them to produce less (hydrogen sulfide) H_2S gas, a common odor producing compound. The researchers found that a reduced sulfur diet led to decreases in H_2S gas by around 30%. The diets used were identical except for the amount of sulfur, and all other nutritional needs were met, with no compromise in energy, nitrogen digestibility, or pig performance (Shurston et al., 1999). By lowering the levels of odor causing compounds in manure, it is possible to reduce its intensity.

9.2 Feed Additives

A similar attempt to alter the characteristics of animal excretions is by the use of feed additives. Research is being conducted to see if adding certain compounds to animal feed will decrease the amount of odor-causing products in the waste material. For example, fructooligosaccharide (FOS) is a source of soluble dietary fiber that affects digestion by reducing production of ammonia, one of the odor causing compounds in animal feces. Adding FOS to pig feed decreases odor-causing compounds in the feces by about three-fold (Bunce et al., 1995).

Urease inhibitors, produced under various brand names, can also be added to feed to reduce odors. For example, Diversified Nutri-Agri Technologies, Inc. produces a urease inhibitor called Dinase®. This product inhibits intestinal activity of urease, the enzyme that converts urea into ammonia. Again, by reducing the amount of ammonia gas produced, the odor in the waste material is also reduced. The urease inhibitor can be used as a feed additive, but it has also been added directly to the manure. Results showed that addition to manure prevented the breakdown of urea into ammonia for around four days, compared to complete conversion in one day in the untreated manure (Hardin, 1998).

Addition of synthetic amino acids has been reported to reduce amounts of nitrogen in the animal feces and urine through enhanced nutrient utilization. This is still in the early stages of research, but it could offer another alternative in reducing odor-causing compounds in animal waste (Miner, 1995).

While a reduction in specific odor-causing compounds has been shown, whether FOS or urease inhibitors will affect the *perceived* odor has not been proven. Research in this area continues, and the outlook is promising.

9.3 Electromagnetic Energy Applications

Subjecting the manure to doses of electromagnetic energy is also being explored for odor control. This method is expected be more economical than chemical treatments or mechanical aeration. The target of the electromagnetic energy is the microorganism population that degrades the manure while in storage. In trial experiments, this technique successfully inactivated the target microorganisms, showing a significant decrease in numbers compared to the untreated samples. By making the odor causing bacteria inactive, odor production should be reduced. This method is unique because it attempts to inactivate only those microbes responsible for odor production.

9.4 Electronic Nose

Researchers are working on developing an Electronic Nose that simulates the human olfactory system. The benefit of using this technology is that it eliminates the subjectivity associated with an odor panel. Results from some kind of electrical, mechanical, or chemical "instrument" are often considered more reliable, or at least more scientifically satisfying, than a subjective opinion. This technology can be applied in many disciplines other than agriculture, such as the medical field and industrial applications.

To use the electronic nose, a chemical vapor or odor is blown over the sensors. The sensor signals are digitized and fed into the computer and the chemical is identified. Potential future benefits of this technology include compactness, portability, real-time analysis, and automation. Use of electronic nose field measurements for quantitative odor evaluation will undoubtedly be useful in setting better defined odor levels for implementation of regulatory standards.

9.5 Olfactometers

Unlike the electronic nose, which is completely automated and objective, the olfactometer relies on the human sense of smell, and is therefore subjective. However, there are advantages to this device. The human nose can smell an odor at concentrations below those registered by the best existing analytical instruments

While improved olfactometer designs vary, all are based on a *dynamic dilution* capability. This means that the machine can continually dilute the odor concentration to a desired level for presentation to a panel of *sniffers* who are each presented with the same odor concentration. Odor detection thresholds are determined through analysis of panel response data.

9.6 Wetland Treatment

Wetlands have been referred to as nature's kidneys because they have the ability to clean out contaminants that enter them. They have been used to treat municipal and private wastewaters, discharges from industrial or agricultural operations, and acid mine drainage. Their use has recently been investigated as a method of removing contaminants from livestock wastewater. It has been shown that odors from wetlands are of very low intensity or are non-existent.

As with any method, wetlands have their advantages and disadvantages. On the good side, they provide a very high level of treatment of livestock wastewater. However, they do remove some crop nutrients. Depending on the land, they can be either very expensive or very inexpensive to construct. They require little or no energy use or equipment to operate, unless pumps are required to move the water through the system. They are able to handle variable pollutant loadings, but they do require a continuous supply of water. Additional water must be supplied during periods of low wastewater flow. The wetland habitat is usually aesthetically pleasing and attracts a variety of wildlife. They reduce the land area required for application of the treated wastewater, but their treatment is limited by seasonal weather conditions. You can see that using wetlands to treat wastewater has many benefits and some disadvantages that must be considered.

Keep in mind that wetlands are able to treat waste*water*, not *solid* wastes. Having a settling pond upstream of the wetland greatly increases the efficiency of the wetland by reducing the solids load into the wetland. It is also a good idea to construct two parallel wetlands so that one can be taken offline to rest or be maintained while the other is still available to provide treatment. Effluent resulting from wetlands treatment typically must be land applied due to receiving stream water quality discharge considerations.

For the right topography, farm size, and management methods, constructing wetlands can be a viable option for odor and nutrient removal.

9.7 Biofiltration

Biofilters sorb odorous compounds from an air stream onto porous media in beds where microorganisms degrade the compounds. The biofilter also contains an air distribution system and watering systems to maintain adequate filter media moisture levels. Odorous air is passed through the media, where it is treated by the microorganisms and released to the atmosphere.

The media usually consists of equal parts of wood chips and compost. The wood chips increase the porosity of the bed, making it easier for air to flow through. The compost is added as the source of microorganisms and nutrients. The microorganisms use the odorous compounds as a source of food, breaking them down, and neutralizing the odors. The main by-products of the breakdown are water and carbon dioxide.

Biofilters are extremely effective when they are well managed, and can reduce odor emissions by 90%, hydrogen sulfide by 85% and ammonia by around 50%. Biofilter media composition, moisture content, and the time required for the air to pass through the biofilter media (the residence time) are key factors that affect odor reduction.

Biofilter maintenance includes weed control, a good rodent control program, and regular tilling to maintain the porosity of the bed (Janni, 2001).

9.8 Windbreak Walls

Windbreaks are used widely to control snow deposition and direct ground-level winds. These structures have been tested for their effectiveness in reducing emissions of dust and odors. Because odor-causing compounds are carried by dust particles, reducing their transport from a facility lessens the spread of odors.

At the North Carolina State University small prototype structures and full-scale models were constructed to evaluate the effectiveness of wall (windbreak) designs and to observe air flow patterns around the walls. The full-scale walls were made of 3m x 3m pipe frames with tarps tied to the frames. These walls were placed 3m or 6m away from the exhaust fans on the buildings. Airflow patterns were observed using smoke candles, and odor strength was determined by using an odor panel's observations. Dust particles were counted by a laser particle analyzer. Results of the experiments showed that both dust concentrations and odor concentrations were lower downwind of the fans with the windbreak walls than they were with fans without the windbreak walls. This is because the walls deflect the plume of air upward past the walls under low wind conditions.

Much remains to be done in evaluating the effectiveness of this type of odor control structure; however, this option could prove to be a relatively inexpensive structure with little maintenance that can be added to existing ventilation systems. Future research could explore the use of vegetated windbreaks to further enhance odor control (Bottcher et al., 1999).

9.9 Odor Modeling

Not all odor control structures are suited for all farming operations. In order to apply odor control structures most effectively, it is helpful to be able to predict where the odor will be distributed from the source and how the odor concentration will vary. Models are being developed to make these predictions.

Researchers at Penn State have developed two types of models for odor generation and dispersion from mushroom composting facilities. One model, *the source model,* is used to determine the odor emission rate from a composting facility. This simulation is based on the odor source characteristics, including source size, number of sources, and odor emission rate, as well as the prevailing wind direction. This model determines the strength of the odor source, which is then used in an *odor dispersion model* to predict the movement of the odor plume. The odor dispersion model uses a series of equations to predict the odor concentrations in the plume downwind of the source in three dimensions. The investigators verified these models, finding that emission, transport, and dispersion of odors were predicted under differing atmospheric conditions (Heinemann and Wahanik, 1998).

Models such as these still have room for improvement. The odor dispersion model relies on methods that don't account for some variations, such as complex terrain effects. This model could be made more accurate by incorporating the topographic effects. It should be noted that while these models were developed on mushroom composting facilities, they also apply to other types of odor-producing agricultural facilities, such as animal production and feedlot facilities.

9.10 Covers

Covering odor sources is a common method for containing odors and reducing emissions. An interesting variation of this technique uses covers made out of a microporous membrane material. The microporous material is semi-permeable, meaning that some materials can pass through it, and some can't because of the small pore size. The pores are sized so that small gaseous chemicals, such as water vapor, carbon dioxide, and oxygen, can pass through. Odor producing chemicals tend to be larger than the pore size of the fabric, so they get trapped underneath the cover, and emission to the atmosphere is reduced.

Because oxygen can be freely exchanged above and below the cover, aerobic conditions under the cover can be maintained, and anaerobic conditions avoided. Also, since the odor producing compounds are kept under the cover for a longer period of time, they have the opportunity to break down into non-odorous compounds. This was confirmed when fewer odors were released as the covers placed over mushroom substrate windrows were removed to turn the piles (Labance et al. 1999). Microporous covers have an advantage of being simpler and less expensive than some other types of odor control structures.

Another twist on the use of covers is that of an inflatable cover. This type of cover was tested in Canada on manure storage lagoons. The cover is attached to the perimeter of the storage and inflated with a low-pressure blower. This keeps the odor under the cover, and odor reductions of greater than 95% were measured. The weather was a major concern with this type of cover. Provisions were made for rain and snow. By keeping the pressure under the cover high enough, the cover will stay inflated, and snow will not collapse it. In order to keep rain from accumulating in the center of the cover, a series of holes with anti backdraft flaps were included. This allows the water to enter the lagoon through these holes without air escaping from under the cover. One major advantage of this type of cover is cost. The cost is estimated at $10,000, or about one fifth the cost of a solid cover. This price could be expected to decrease as the cover is commercially manufactured.

A third variation is to cover open-topped storage facilities with a layer of straw. Various straw covers and flotation systems were tested by researchers in Canada. The performance of various materials, including good quality barley straw, oat straw, flax, and durum straw, and poor quality oat and barley straw was evaluated. They also tested one-inch thick polystyrene sheets and plastic engine oil bottles as two types of flotation devices, as well as no flotation device at all. They found that good quality barley straw was the best option when no flotation device was used.

Polystyrene floats seemed to be effective during the entire season and helped to achieve excellent odor control. The oil bottles also worked well, with the exception of the few whose caps were not screwed on tightly. These filled up, sunk to the bottom, and caused problems when the lagoon needed to be pumped out. Also, with the use of floating supports, a lower quality of straw can still prove to be effective. Overall, the use of straw covers seemed to be a viable option for controlling manure lagoon odor, as long as the right materials are used and the cover is maintained by adding more straw if it begins to sink in some areas (PAMI, 1993).

9.11 Anaerobic Digestion

Anaerobic digestion is not a new technology; however, there are new things being done with the process. Anaerobic digestion is a method of treating organic waste in which microorganisms break down the raw waste in an oxygen-free environment, releasing methane and carbon dioxide gases in the process. These byproducts, collectively known as *biogas*, can be captured and used as a fuel source. This technique isn't efficient in every situation because of optimum size requirements, but it presents a beneficial alternative for odor control when the size is right.

In a typical system, manure is collected in a mixing tank and heated to the optimum temperature for digestion. The manure is then placed in the digester where an oxygen free environment is maintained by keeping the structure covered. From the digester, the waste products can be land applied as a nutrient source.

Biogas can be used in a number of ways. The gas can simply be ignited (in a controlled way, of course), known as flaring off the gas. This is appropriate when biogas collection is a new process in the operation, or if the facility isn't producing enough gas to make electricity generation cost effective. Also, flaring off the gas serves as a visual check to be sure that the system is working properly. If the digester isn't generating enough gas to maintain a flame, the farmer knows there is something wrong with his digester.

Biogas can also be used as a heat source. The gas can be contained and used as fuel for a boiler, space heater, or refrigeration equipment. It could also be directly combusted and used as a cooking or lighting fuel.

Finally, the biogas can be used to generate electricity, either on site or at a nearby electric utility. This option requires expensive equipment, but is cost effective in the long run if the size of the operation is large enough. When the biogas is sold to an electric utility, both the farmer and the utility benefit. The farmer has a way of disposing of the material, and the utility maintains a good relationship with its farm customers. The utility also has the opportunity to provide "green power" to sell to its customers as a source of renewable energy.

Information for this section came from the National Food and Energy Council webpage, www.nfec.org/methanerecovery.htm.

9.12 Non-Thermal Plasma

The use of non-thermal plasma systems for odor control is being investigated. Non-thermal plasmas are highly reactive free radicals and energetic electrons, which can react with odorous and toxic gases emitted from agricultural operations. The plasmas deactivate these gases and their odorous or toxic characteristics are changed. One advantage of this strategy is that it is more effective than other types of odor control, and it usually does not cause secondary types of air pollution. A non-thermal plasma odor control system was developed and tested at the University of Minnesota, where decomposition of hydrogen sulfide and ammonia from livestock facilities was achieved. As a result, odor intensity in the air surrounding the facilities was greatly reduced (Ruan, 2000).

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Facility Name: ____

Owner: ____

Operator: ____

Date: ____

Activity: ____

Part I. Production Practices

A. Site Information

	Yes	No	N/A	
1.	❑	❑	❑	Are the production buildings, treatment, and storage facilities located ½-mile from neighboring residences or one-mile from public facilities?
2.	❑	❑	❑	Do prevailing winds blow odors away from the nearest neighbors and public facilities?
3.	❑	❑	❑	Are there any windbreaks (shrubs, bushes, trees, hills, etc.) that may intercept odors and promote air dispersion between your farm and neighbors?

B. Production Unit Conditions

	Yes	No	N/A	***Animal Housing***
1.	❑	❑	❑	Are buildings well maintained and cleaned on a regular cycle?
2.	❑	❑	❑	Do you minimize dust accumulation in buildings?
3.	❑	❑	❑	Are fans and shutters frequently washed to remove dust accumulations?
4.	❑	❑	❑	Are the animals kept clean?
5.	❑	❑	❑	Do you use systems that separate animals from manure such as frequent gutter- cleaning, slat floors or manure flush systems?
				Feedlot
6.	❑	❑	❑	Are feedlots well ventilated in areas receiving direct sunlight to promote rapid drying?
7.	❑	❑	❑	Is surface water managed to prevent run-on, on-site puddling, and off-site runoff pollution?
8.	❑	❑	❑	Do you remove manure from feedlots on a regular cycle?
				Manure Storage
9.	❑	❑	❑	Do you use bottom loading, ventilation, pH control, covers, or drying in manure storage and treatment areas?
10.	❑	❑	❑	Do you remove manure from storage on a regular cycle?

	Yes	No	N/A	*Manure Treatment*
11.	❑	❑	❑	Are aerobic treatment, anaerobic treatment, or composting areas a appropriately located to reduce odor conflicts?
12.	❑	❑	❑	Do you maintain aerobic conditions in compost piles through frequent turning?
13.	❑	❑	❑	Do you maintain low nitrogen content in compost piles?
				Other Potential Odor Sources
14.	❑	❑	❑	Are dead animal carcasses disposed of in a timely manner?
15.	❑	❑	❑	Do you follow recommended cleanup, disposal, and water pollution control strategies for milk house waste disposal?
16.	❑	❑	❑	Do you follow recommended cleanup, disposal, and water pollution control strategies for feed odors (e.g. silage juice)?
17.	❑	❑	❑	Do you regularly police your manure storage loading/unloading areas to keep them free of debris that may create odors, or give the mistaken impression that your operation is poorly managed?

C. Land Application

Refer to the Land Application Odor Assessment form to complete this section.

NOTE: A negative response to any of the above questions may indicate an area where management changes could lower the potential for odor complaints. Refer to Chapter 8 for suggested control practices.

(Source: Questions adapted from Barth and Melvin, 1984)

Part II. Odor Offensiveness Rating

A. Description

In this assessment, *offensiveness* is defined as a disagreeable odor that causes unpleasant sensations to the average person upon exposure. Offensive odor is rated according to the following scale adapted from Williams (1984):

Rating	Description	Probability For Odor Complaints
0	Non-Detectable	Low
1	Inoffensive Odor	Low
2	Very Faintly Offensive Odor	Low
3		
4	Faintly Offensive Odor	Moderate
5		
6	Definitely Offensive Odor	Moderate
7		
8	Strongly Offensive Odor	High
9		
10	Very Strongly Offensive Odor	High

B. Odor Source Survey

This survey will identify sources of potential odor problems. The survey is conducted by visiting each of the areas identified in the below table (also see legend on following page) and making a circuit of the site at a distance of approximately 25 feet. Identify the most offensive odor, determine the *numerical odor offensiveness rating* according to the above chart, and enter the rating in the table below. The most offensive rating encountered during a circuit around a source is the rating for that entire source. Allow a one-minute recovery time between ratings to prevent adaptation to the odorant (Bulley and Phillips, 1980). Land application fields referenced in this assessment are limited to those fields that are immediately adjacent to the production facility. Remote application fields are evaluated using the separate *Land Application Odor Assessment* form.

Area	Rating
Animal Housing	
Manure Storage	
Manure Treatment	
Feedlot	
Application Fields	
Other	

C. Site Perimeter Survey

The perimeter survey identifies fugitive odor locations where odor complaints are likely. Begin the perimeter survey by sketching the general shape of your production facility and adjacent parcels (under your control) on the compass axis provided on the next page. (Distant land application sites should be assessed separately using the *land application odor assessment* form.) Place your production units in their appropriate locations on the sketch using the symbols provided in the legend below. Label the odor offensiveness rating for each unit determined in section B near the corresponding symbol on your diagram(s). Draw in the nearest occupied dwellings and/or public facilities, the predominant wind direction, and areas of previous odor complaints on your diagram using the symbols in the legend. Indicate the approximate distance from your property boundary to these nearest neighbors next to the appropriate symbol.

Take as many odor offensiveness ratings as desired around the perimeter, however, make sure a rating is taken on each side of the production facility at points where you feel the strongest odors exist. It is also useful to take ratings at suspected odor problem areas. Locate each assessment point on your sketch and indicate the observed offensiveness rating. Label each diagram with the site name, date of survey, odor generating activity, time, and temperature. Odor generating activities might include land application, manure storage agitation, etc.

Legend

Odor source and site perimeter survey diagram:

Odor source and site perimeter survey diagram:

Facility Name: ______________________________

Owner: ______________________________

Operator: ______________________________

Date: ______________________________

Activity: ______________________________

Part I. Production Practices

Experience has shown that inappropriate management of food processing residuals (FPRs) is often the primary source of malodors at food plants. FPRs are defined as incidental organic materials generated by processing agricultural commodities for human or animal consumption. The term includes food residuals, food coproducts, food processing wastes, food processing sludges, or any other incidental material derived from processing agricultural products. Examples include: process wastewater from cleaning slaughter areas, rinsing carcasses, or conveying food materials; process wastewater treatment sludges; blood; bone; fruit and vegetable peels; seeds; shells; pits; cheese whey; off-specification food products; hides; hair; and feathers (Brandt and Martin, 1994).

A. Site Information

	Yes	No	N/A	
1.	❑	❑	❑	Are the production buildings, treatment, and storage facilities located ½-mile from neighboring residences or one-mile from public facilities?
2.	❑	❑	❑	Do prevailing winds blow odors away from the nearest neighbors and public facilities?
3.	❑	❑	❑	Are there any windbreaks (shrubs, bushes, trees, hills, etc.) to intercept odors and promote air dispersion between your facility and neighbors?

B. Production Unit Conditions

	Yes	No	N/A	***Processing Facilities***
1.	❑	❑	❑	Are buildings well maintained and cleaned on a regular cycle?
2.	❑	❑	❑	Do you minimize dust accumulation in buildings?
3.	❑	❑	❑	Are fans and shutters frequently washed to remove dust accumulations?
				Food Processing Residuals
4.	❑	❑	❑	Do you use recognized best management practices to treat wastewater?
5.	❑	❑	❑	Do you clean machinery used to handle, process, and transport FPRs on a daily basis?
6.	❑	❑	❑	Are FPRs stored in a manner that minimizes malodor generation and release?

7. ❑ ❑ ❑ Are all FPRs collected and stored (or disposed) on a daily basis?

Yes No N/A ***Temporary Animal Housing***

8. ❑ ❑ ❑ Are animals kept clean?
9. ❑ ❑ ❑ Do you remove manure on a regular cycle?

Manure Storage

10. ❑ ❑ ❑ Do you use bottom loading, ventilation, pH control, covers, or drying in manure storage and treatment areas?
11. ❑ ❑ ❑ Do you remove manure from storage on a regular cycle?

Wastewater Treatment

12. ❑ ❑ ❑ Does your wastewater treatment operation appropriately account for and treat the actual organic-strength (BOD), sulfate content, and solids content of the wastestream?
13. ❑ ❑ ❑ Are putrescible organics cleaned out of lift stations, metering stations, and pretreatment screening devices on a regular and adequate cycle?
14. ❑ ❑ ❑ Do you minimize wastewater turbulence?
15. ❑ ❑ ❑ Is the fat, oil, and grease (FOG) content in the wastewater minimized?
16. ❑ ❑ ❑ Do you monitor and maintain appropriate wastewater pH?
17. ❑ ❑ ❑ Are aerobic conditions maintained in treatment lagoons?

Other

18. ❑ ❑ ❑ Are spills promptly cleaned up?
19. ❑ ❑ ❑ Are transport vehicles well maintained and thoroughly cleaned on a regular cycle (this includes raw commodities used in your processing operation)?
20. ❑ ❑ ❑ Do you maintain site access roads in a condition that promotes the impression of a well manage operation?
21. ❑ ❑ ❑ Do you regularly police your loading/unloading areas to keep them free of debris that may create odors, or give the mistaken impression that your operation is poorly managed?

C. Land Application

Refer to the Land Application Odor Assessment form to complete this section.

NOTE: A negative response to any of the above questions may indicate an area where management changes could lower the potential for odor complaints. Refer to Chapter 8 for suggested control practices.

(Source: Questions adapted from Barth and Melvin, 1984)

Part II. Odor Offensiveness Rating

A. Description

In this assessment, *offensiveness* is defined as a disagreeable odor that causes unpleasant sensations to the average person upon exposure. Offensive odor is rated according to the following scale adapted from Williams (1984):

Rating	Description	Probability For Odor Complaints
0	Non-Detectable	Low
1	Inoffensive Odor	Low
2	Very Faintly Offensive Odor	Low
3		
4	Faintly Offensive Odor	Moderate
5		
6	Definitely Offensive Odor	Moderate
7		
8	Strongly Offensive Odor	High
9		
10	Very Strongly Offensive Odor	High

B. Odor Source Survey

This survey will identify sources of potential odor problems. The survey is conducted by visiting each of the areas identified in the below table (also see legend on following page) and making a circuit of the site at a distance of approximately 25 feet. Identify the most offensive odor, determine the *numerical odor offensiveness rating* according to the above chart, and enter the rating in the table below. The highest rating recorded during the survey is the rating for that entire source. Allow a one-minute recovery time between ratings to prevent adaptation to the odorant (Bulley and Phillips, 1980). Land application fields referenced in this assessment are limited to those fields that are immediately adjacent to the production facility. Remote application fields are evaluated using the separate *Land Application Odor Assessment* form.

Area	Rating
Animal Holding	
Processing Facilities	
FPR Handling and Storage	
Manure Storage	
Application Fields	
Wastewater Treatment	
Other	

C. Site Perimeter Survey

The perimeter survey identifies fugitive odor locations where odor complaints are likely. Begin the perimeter survey by sketching the general shape of your production facility and adjacent parcels (under your control) on the compass axis on the next page. (Distant land application sites should be assessed separately using the *land application odor assessment* form.) Place your production units in their appropriate locations on the sketch using the symbols provided in the legend below. Label the odor offensiveness rating for each unit determined in section B near the corresponding symbol on your diagram(s). Draw in the nearest occupied dwellings and/or public facilities, the predominant wind direction, and areas of previous odor complaints on your diagram using the symbols in the legend. Indicate the approximate distance from your property boundary to these nearest neighbors next to the appropriate symbol.

Record as many odor ratings as desired around the perimeter, however, make sure a rating is taken on each side of the production facility where you feel the strongest odors exist. It is also useful to take ratings at suspected odor problem areas. Locate each assessment point on your sketch along with the corresponding rating. Label each diagram with the site name, date of survey, odor generating activity, time, and temperature. Odor generating activities might include land application, storage, FPR and manure storage cleanout, etc.

Legend

Odor source and site perimeter survey diagram:

Odor source and site perimeter survey diagram:

Appendix C3. Mushroom Production Odor Assessment

Facility Name: ____

Owner: ____

Operator: ____

Date: ____

Activity: ____

Part I. Production Practices

A. Site Information

	Yes	No	N/A	
1.	❑	❑	❑	Are the production buildings, treatment, and storage facilities located ½-mile from neighboring residences or one-mile from public facilities?
2.	❑	❑	❑	Do prevailing winds blow odors away from the nearest neighbors and public facilities?
3.	❑	❑	❑	Are there any windbreaks (shrubs, bushes, trees, hills, etc.) that may intercept odors and promote air dispersion between your facility and neighbors?

B. Production Unit Conditions

	Yes	No	N/A	*Mushroom Buildings*
1.	❑	❑	❑	Are buildings well maintained and cleaned on a regular cycle?
2.	❑	❑	❑	Do you minimize dust accumulation and release from buildings?
				Mushroom Substrate Preparation
3.	❑	❑	❑	Do you limit substrate pile size to promote aerobic conditions?
4.	❑	❑	❑	Do you place covers over substrate piles to limit odor emission?
5.	❑	❑	❑	Is appropriate surface water drainage provided?
6.	❑	❑	❑	Are substrate piles turned frequently during wetting?
7.	❑	❑	❑	Is pile turning *timed* to minimize nuisance complaints?
8.	❑	❑	❑	Is pile turning *coordinated* with weather conditions to minimize nuisance complaints?
9.	❑	❑	❑	Do you mechanically aerate substrate piles and lagoons?
10.	❑	❑	❑	Do you apply chemical odor reducing agents?
11.	❑	❑	❑	Do you clean machinery (turner, tractor-loader, etc.) on a regular cycle?
12.	❑	❑	❑	Do you manage substrate ingredient handling and storage to minimize mal-odors?

	Yes	No	N/A	*Spent Mushroom Substrate*
13.	❑	❑	❑	Is spent substrate stored in a manner that minimizes run-on, run-off, and odor release?
				Transport
14.	❑	❑	❑	Are spills in receiving and filling areas promptly cleaned-up?
15.	❑	❑	❑	Do you use enclosed vehicles and/or covers during transport?
16.	❑	❑	❑	Do you inspect transport vehicles to ensure that they are not leaking fluids or tracking odorous materials off site?
17.	❑	❑	❑	Do you clean transport vehicles on a regular cycle?

C. Land Application

Refer to the Land Application Odor Assessment form to complete this section.

NOTE: A negative response to any of the above questions may indicate an area where management changes could lower the potential for odor complaints. Refer to Chapter 8 for suggested control practices.

(Source: Questions adapted from Barth and Melvin, 1984)

Part II. Odor Offensiveness Rating

A. Description

In this assessment, *offensiveness* is defined as a disagreeable odor that causes unpleasant sensations to the average person upon exposure. Offensive odor is rated according to the following scale adapted from Williams (1984):

Rating	Description	Probability For Odor Complaints
0	Non-Detectable	Low
1	Inoffensive Odor	Low
2	Very Faintly Offensive Odor	Low
3		
4	Faintly Offensive Odor	Moderate
5		
6	Definitely Offensive Odor	Moderate
7		
8	Strongly Offensive Odor	High
9		
10	Very Strongly Offensive Odor	High

B. Odor Source Survey

This survey will identify sources of potential odor problems. The survey is conducted by visiting each of the areas identified in the below table (also see legend on following page) and making a circuit of the site at a distance of approximately 25 feet. Identify the most offensive odor, determine the *numerical odor offensiveness rating* according to the above chart, and enter the rating in the table below. The most offensive rating encountered during a circuit around a source is the rating for that entire source. Allow a one-minute recovery time between ratings to prevent adaptation to the odorant (Bulley and Phillips, 1980). Land application fields referenced in this assessment are limited to those fields that are immediately adjacent to the production facility. Remote application fields are evaluated using the separate *Land Application Odor Assessment* form.

Area	Rating
Mushroom Buildings	
Mushroom Substrate Preparation	
Spent Substrate Storage	
Application Fields	
Other	

C. Site Perimeter Survey

The perimeter survey identifies fugitive odor locations where odor complaints are likely. Begin the perimeter survey by sketching the general shape of your production facility and adjacent parcels (under your control) on the compass axis provided on the next page. (Distant land application sites should be assessed separately using the *land application odor assessment* form.) Place your production units in their appropriate locations on the sketch using the symbols provided in the legend below. Label the odor offensiveness rating for each unit determined in section B near the corresponding symbol on your diagram(s). Draw in the nearest occupied dwellings and/or public facilities, the predominant wind direction, and areas of previous odor complaints on your diagram using the symbols in the legend. Indicate the approximate distance from your property boundary to these nearest neighbors next to the appropriate symbol.

Take as many odor offensiveness ratings as desired around the perimeter, however, make sure a rating is taken on each side of the production facility at points where you feel the strongest odors exist. It is also useful to take ratings at suspected odor problem areas. Locate each assessment point on your sketch and indicate the observed offensiveness rating. Label each diagram with the site name, date of survey, odor generating activity, time, and temperature. Odor generating activities might include substrate mixing and turning, etc.

Legend

Odor source and site perimeter survey diagram:

Odor source and site perimeter survey diagram:

Facility Name: ____

Owner: ____

Operator: ____

Date: ____

Activity: ____

Part I. Production Practices

A. Site Information

	Yes	No	N/A	
1.	❑	❑	❑	Are the staging/storage and land application areas located ½-mile from neighboring residences and one-mile from public facilities?
2.	❑	❑	❑	Do prevailing winds blow odors away from the nearest neighbors and public facilities?
3.	❑	❑	❑	Are there any windbreaks (shrubs, bushes, trees, hills, etc.) that may intercept odors and promote air dispersion between your facility and neighbors?

B. Production Unit Conditions

(Note: Residuals may include biosolids, FPRs, crop waste, manure, or other non-hazardous organic waste material.)

	Yes	No	N/A	***Residual Staging and Storage Areas***
1.	❑	❑	❑	Do you use aeration, pH control, temperature control, or drying in staging/storage areas?
2.	❑	❑	❑	Do you completely remove residuals from staging/storage areas during cleanout?
3.	❑	❑	❑	Are staging/storage areas well maintained and *dressed-up* on a regular cycle?
4.	❑	❑	❑	Are residual piles kept small to promote aerobic conditions in storage areas?
5.	❑	❑	❑	Do you prevent excessive water contact (run-on) with residual piles in all staging/storage areas?
6.	❑	❑	❑	Do you minimize runoff from staging/storage areas and appropriately dispose of *contact* water onto adjacent suitable land areas?
				Transport
7.	❑	❑	❑	Do you use appropriate vehicles for transporting residuals, i.e. watertight truck beds and covers for *soupy* and/or malodorous residuals?
8.	❑	❑	❑	Are vehicles regularly cleaned and well maintained?
9.	❑	❑	❑	Do you avoid tracking of mud/residuals onto hardtop roads?

C. Field Application

	Yes	No	N/A	
1.	❑	❑	❑	Do you use daily weather reports to determine when to best spread residuals?
2.	❑	❑	❑	Do you typically spread during cool, windy weather conditions?
3.	❑	❑	❑	Do you select a spreading time when winds blow away from populated areas?
4.	❑	❑	❑	Do you spread residuals early in the morning for better odor dispersal?
5.	❑	❑	❑	Do you avoid spreading near highways, residences, or other public facilities?
6.	❑	❑	❑	Do you directly inject or promptly incorporate residuals into the soil by plowing or disking as soon as possible after spreading?
7.	❑	❑	❑	Do you use a moderate or low application rate to reduce odor intensity?
8.	❑	❑	❑	Do you apply residuals in thin uniform layers to promote quick drying?
9.	❑	❑	❑	Is your spreading equipment regularly cleaned and well maintained?
10.	❑	❑	❑	Do you call your neighbors before spreading residuals on fields?
11.	❑	❑	❑	Do you avoid spreading before or during holiday weekends?

NOTE: A negative response to any of the above questions may indicate an activity where management changes could lower the potential for odor complaints. Refer to Chapters 5 and 8 for additional information on odor sources and suggested management practices.

(Source: Questions adapted from Barth and Melvin, 1984)

Part II. Odor Offensiveness Rating

A. Description

In this assessment, *offensiveness* is defined as a disagreeable odor that causes unpleasant sensations to the average person upon exposure. Offensive odor is rated according to the following scale adapted from Williams (1984):

Rating	Description	Probability For Odor Complaints
0	Non-Detectable	Low
1	Inoffensive Odor	Low
2	Very Faintly Offensive Odor	Low
3		
4	Faintly Offensive Odor	Moderate
5		
6	Definitely Offensive Odor	Moderate
7		
8	Strongly Offensive Odor	High
9		
10	Very Strongly Offensive Odor	High

B. Odor Source Survey

This survey will identify sources of potential odor problems. The survey is conducted by visiting each of the areas identified in the below table (also see legend on following page) and making a circuit of the site at a distance of approximately 25 feet. Identify the most offensive odor, determine the *numerical odor offensiveness rating* according to the above chart, and enter the rating in the table below. The most offensive rating encountered during a circuit around a source is the rating for that entire source. Allow a one-minute recovery time between ratings to prevent adaptation to the odorant (Bulley and Phillips, 1980).

Area	Rating
Residual Storage Area	
Residual Storage Area	
Field Spreading Equipment	
Application Fields	
Other	

C. Site Perimeter Survey

The perimeter survey identifies fugitive odor locations where odor complaints are likely. Begin the perimeter survey by sketching the general shape of your application fields and adjacent parcels (under your control) on the compass axis provided on the next page. Place odor source units in their appropriate locations on the sketch using the symbols provided in the legend below. Label the odor offensiveness rating for each unit determined in section B near the corresponding symbol on your diagram(s). Draw in the nearest occupied dwellings and/or public facilities, the predominant wind direction, and areas of previous odor complaints on your diagram using the symbols in the legend. Indicate the approximate distance from your property boundary to these nearest neighbors next to the appropriate symbol.

Take as many odor offensiveness ratings as desired around the perimeter, however, make sure a rating is taken on each side of the facility at points where you feel the strongest odors exist. It is also useful to take ratings at suspected odor problem areas. Locate each assessment point on your sketch and indicate the observed offensiveness rating. Label each diagram with the site name, date of survey, odor generating activity, time, and temperature.

Legend

Odor source and site perimeter survey diagram:

Odor source and site perimeter survey diagram:

Appendix D Wind Roses For Select Pennsylvania Locations

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