ODOR PERCEPTION AND HEALTH EFFECTS[1]

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Abstract

Odor complaints at biosolids management operations are very common. Often the perception of odor by a neighbor to a biosolids operation progresses to a health complaint. Environmental health professionals, especially those in Europe, have been expanding the definition of environmental health to include quality of life issues like odor. This has been reinforced by the confusion between toxicological and physiological irritation induced by odorants. The object of this paper is to present a factual basis for the investigation of health complaints that may be associated with the perception of odor. We present working definitions useful to the practitioner in the field, advance the concept of "sludge victims" as a subset of multiple chemical sensitivity subjects, and develop a working protocol for the investigation of complaints.

Introduction

The most common complaints heard from citizens regarding biosolids management start with the perception of an unpleasant odor. Often, the public feels that the perception of an odor is an indication of the presence of a toxic substance and that their health has or will be impacted. Most environmental and public health agencies regard odor as a nuisance or "quality of life" issue and are likely to give odor complaints a lower priority for action than complaints about adverse health effects. If action is not taken by the generator of the odors or by regulatory authorities and the odor persists, the impacted public may progress to a second stage of complaints characterized by a group of diffuse physical symptoms. The classic environmental health response to this situation has been to make a clear distinction between levels of a chemical that result in odor (odor threshold) and levels causing an adverse effect (toxicological threshold). Environmental health practitioners then intervene to control concentrations of odorants so that they are below toxicological thresholds, although they may still be above odor thresholds. In the mind of the public, however, the persistence of an odor, even after controls, implies the persistence of a health threat and the public perception problem remains unresolved although the environmental health problem may be resolved.

Recently, the previously clear distinction between adverse health effects and quality of life issues has become blurred. This phenomenon appears to originate from two sources. The first is a series of definitions and policies regarding environmental health coming from governmental agencies that include quality of life issues along with classical health issues. The second source is a scientific school of thought that links odors and health

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effects through a variety of mechanisms (Schiffman et al. 2000). The net result has been to reinforce the view, in the mind of the public, that odors and health problems are synonymous, or at least closely linked.

This paper presents an initial exploration of the nature of the link between odor and health effects through analysis of information that has been published in the scientific literature or is available on the Internet. We set the stage for this presentation by looking at some of the current definitions of environmental health and how quality of life issues are treated in these definitions. We then discuss the odorants that are most responsible for complaints about biosolids. This is followed by a brief review of the physiology of odor necessary for understanding the chemical senses. Following this, we show the difference between irritation as a sensation and irritation as a toxicological effect. This leads us to the topic of multiple chemical sensitivity and related disorders as diagnoses for many of the health complaints related to odors from biosolids. We conclude with a discussion of methods for separating fact from fiction when investigating health complaints.

Definitions of Environmental Health

Environmental health has traditionally been considered as a branch of public health that focuses on the prevention of disease through the control of environmental factors and the reduction of potential hazards. Most environmental health practitioners are involved with infectious diseases, chemical toxicity, or physical hazards such as ionizing radiation. This can be defined as the "adverse impact" school of environmental health. The definition of environmental health used by the Agency for Toxic Substances and Disease Registry (ATSDR) is consistent with this approach. According to ATSDR, "Environmental health is the branch of public health that protects against the effects of environmental hazards that can adversely affect health or the ecological balances essential to human health and environmental quality" (USDHHS 1998). The National Environmental Health Association and many state and local health departments use similar definitions.

Recently a trend has emerged that expands the definition of environmental health beyond the traditional adverse impact to include quality of life issues. This expansion probably originally stemmed from the World Health Organization's (WHO) definition of health as a complete state of physical, mental, and social well-being, not just the absence of infirmity or disease. In 1993, the WHO proposed the following definition of environmental health (USDHHS 1998): "Environmental health comprises those aspects of human health, including quality of life, that are determined by physical, biological, social and psychosocial factors in the environment. It also refers to the theory and practice of assessing, correcting, controlling and preventing those factors in the environment that can potentially affect adversely the health of present and future generations."

Although this definition has not been formally adopted by any federal United States agency, it has become widely used throughout the United States. For example, the Wisconsin Department of Health defined environmental health as the "assessment, management, control, and prevention of environmental factors that may adversely affect the health, comfort, safety, or well-being of individuals" (USDHHS 1998). Obviously these newer definitions are intended to encompass quality of life issues such as noise or odor.

Although there seems to be a developing consensus that odor is of interest to the environmental health community, obviously the perception of odor alone cannot be considered to be an adverse environmental health effect. Many odors are indeed pleasurable and a multi-billion dollar fragrance industry is dedicated to the creation and application of pleasant odors. An adverse health effect may be defined as a pathological lesion or a biochemical, metabolic or genetic change that affects the normal function of an organism, impairs its ability to adapt to environmental change, or causes a change in genetic information transmitted to offspring (Hodgson et al. 1999). Thus, an odor would need to interfere with the normal function of an individual or a population before it could be considered to be adverse in the health context.

Schiffman et al. (2000) have advanced the hypothesis that odors associated with animal manures and biosolids can produce health effects[2]. Schiffman et al. report a variety of health complaints putatively associated with low levels of odors emanating from manure including eye, nose, and throat irritation, headache, nausea, diarrhea, hoarseness, sore throat, cough, chest tightness, nasal congestion, palpitations, shortness of breath, stress, drowsiness, and alterations of mood. Many of these conditions would be considered to be classical adverse effects. Schiffman et al. posited three paradigms by which odors could produce health symptoms. The first is one in which the adverse effects are caused by exposure to odorants at levels above the toxicological threshold for the effect. This is consistent with the classical environmental health view. The second paradigm concerns cases where the concentration of the odorant exceeds an odor threshold but not a toxicological threshold and a health effect results. The third paradigm is one in which an odorant is part of a mixture in which a non-odoriferous co-constituent is actually responsible for a health effect.

Odorants Found in Sewage Sludge and Biosolids

Characterization of odor perception or health effects associated with odors, requires knowledge of the chemical constituents responsible for the odors. The chemicals associated with odor emanating from biosolids have been well defined. In general, most biosolid odorants are sulfur compounds, nitrogen compounds, ketones, or volatile fatty acids (Rosenfeld 1999). Examples of each of these categories are shown in Table 1.

[2] It should be noted that the work of Schiffman et al. (2000) is confined to animal wastes and does not actually deal with biosolids from municipal wastewaters.

Table 1. Odorant Categories

Odorant Category	Examples
Sulfur compounds	Hydrogen sulfide, methyl mercaptan, ethyl mercaptan, dimethyl sulfide, dimethyl disulfide
Nitrogen compounds	Ammonia, trimethylamine, skatole, pyridine
Aldehydes and Ketones	Acetone, methyl ethyl ketone, acetaldehyde
Volatile Fatty Acids	Acetic acid, propionic acid, butyric acid

Most of these chemicals have been studied and their physicochemical, toxicological and odor properties are well known. Odor thresholds and toxicological thresholds for irritation abstracted from Ruth (1986) for some of these substances are shown in Table 2.

Table 2. Odor and Toxicological Thresholds for Irritation

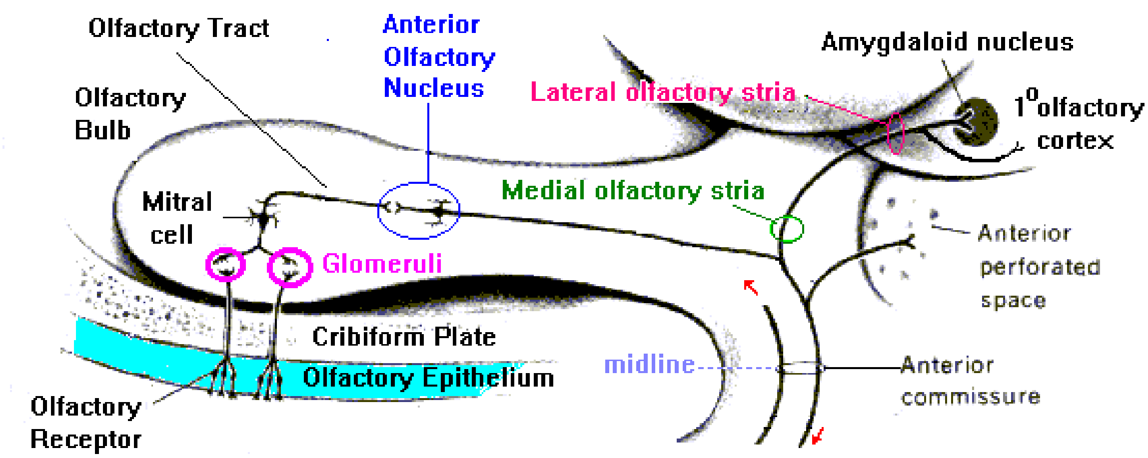
Chemical	Odor Threshold Range (mg/m3)	Irritating Concentration (mg/m3)
Acetic acid	2.5-250	25
Acetone	47-1613	475
Acetaldehyde	0.0002-4.1	90
Ammonia	0.026-40	72
Butyric acid	0.001-9	
Dimethyl disulfide	0.0001-0.35	
Dimethyl sulfide	0.0025-0.05	
Hydrogen sulfide	0.0007-0.014	14
Ethyl mercaptan	3.2E-5-0.092	
Methyl mercaptan	4E-5-0.082	
Propionic acid	0.084-60	
Skatole	4E-7-0.26	
Methyl ethyl ketone	0.74-147	590
Trimethyl amine	0.0008	

The Physiology of the Chemical Senses

Three chemical senses – olfaction, chemesthesis, and taste are known to science. A brief explanation of the physiology of the first two will be presented to aid in understanding the potential relationship between odor perception and health effects.

Olfaction is the sense of smell. A simplified schematic of the olfactory system is provided in Figure 1. In general, an odorant travels through the nose (orthonasal) or from the back of the mouth (retronasal) and contacts the olfactory epithelium which contains in excess of 12 million olfactory receptor neurons (Rawson 2000). The signal that is generated in the nasal (olfactory) epithelium travels along the olfactory nerve in the olfactory bulb and reaches cortical areas of the brain where the odor is perceived. In addition to this primary olfactory system, a secondary system involving a structure known as the vomernasal organ is important in some mammals. Although controversial in human beings, the postulated existence of the vomernasal organ may play a role in odor perception and health effects.

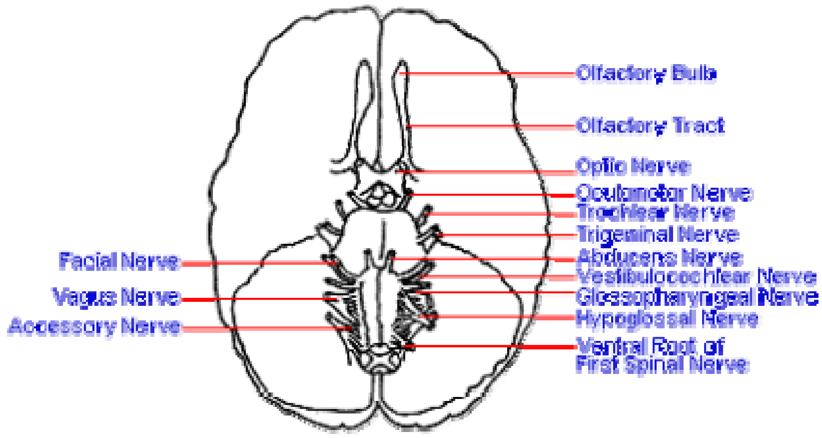
Figure 1. Simplified Diagram of Olfactory System



The perception of odor is highly idiosyncratic. Numerous factors including adaptation, environmental exposures, medications, aging, nutritional status, pregnancy, mental illness and a variety of diseases and disorders can affect odor perception (Rawson 2000). Adaptation, or the process of becoming familiar with an odor is a common phenomenon. Disorders of the olfactory system, common to over 2.7 million Americans, can also have a significant impact on odor perception (Rawson 2000). These disorders include phantosmia or the perception of an odor in the absence of an odorant and parosmia in which the affected person smells something other than the scent which is present. Recent research shows that odors are perceived to be more pleasant when smelled with the right nostril than with the left (Herz et al. 1999). Cognitive factors can also have a significant impact on odor perception. Dalton (2002) notes that numerous factors, including exposure history, expectations, personality, beliefs, social factors, and bias, can influence an individual's perception of odor, irritation, or health effects. Dalton (2002) also notes that anxiety over the consequences of exposure can worsen the perception of odor and/or irritation. Dalton (1996) reported that subjects rated an odor as more intense when they were told it was hazardous compared to those who were told that the same odor was a natural product. In another study, Dalton et al. (1997) found that people given positive information about odors to which they were exposed had less perceived irritation compared to people given negative information.

Figure 2 presents a schematic of some features of the nervous system that are important to the chemical senses. This figure shows that the portions of the nervous system associated with odor (olfactory bulb, olfactory tract) are physically distinct from other sensory nerves. One of these nerves, the trigeminal plays a key role in chemesthesis.

Figure 2. Nervous System Features Important to Senses



Chemesthesis is the chemical pathway used by many organisms to detect irritants, which may not be odoriferous. The most common mechanism of chemesthesis is stimulation of the trigeminal nerve which has branches in the nose, mouth, and eyes. Other nerves, for example the vagus and glossopharyngeal nerves (Figure 2), may also be involved in chemesthesis. Many chemicals that are not odorants are capable of stimulating the trigeminal nerve. For example, carbon dioxide stimulates trigeminal but not olfactory receptors. Some chemicals can simultaneously stimulate the trigeminal and olfactory nerves. Chemesthesis obeys a sigmoid dose-response relationship with thresholds often many orders of magnitude higher than odor thresholds. Frank toxicity (for example clinical inflammation) usually has thresholds substantially higher than chemesthesis thresholds.

Two Views of Irritation

Toxicologists and odor scientists view the concept of irritation differently which has contributed to confusion in the debate about odor perception and health effects. From a toxicological standpoint, irritation is considered to be a classical adverse effect. Hodgson et al. (1999) define an irritant as a non-corrosive substance that produces an inflammatory reaction on normal tissue after prolonged or repeated contact. Stedman's (2000) first definition of irritation is "Extreme incipient inflammatory reaction of the tissues to an injury". Inflammation is a recognized pathology with an associated set of symptoms including redness, heat, swelling, pain, and inhibited or lost function. Irritation is usually further classified by target organ. For example, irritation of specific target organs includes irritation of the skin, upper respiratory system, cornea, etc. Toxicological irritants typically obey a sigmoid dose-response relationship with a threshold under which no irritation reaction occurs. Many toxicological irritants show reversible effects – the inflammation disappears after exposure to the irritant ceases, however, acute exposures to high levels of some irritants can result in irreversible effects. There is general recognition in the environmental health sciences that irritation is an adverse effect which should be prevented if at all possible.

Stedman's second definition of irritation is "The normal response of nerve or muscle to a stimulus". This is close to the working definition used by odor scientists where irritation relates to stimulation of chemesthesis usually through the trigeminal nerve. This sense originally evolved to signal skin and mucosal conditions that are actually or potentially harmful (Bryant and Silver 2000). This warning mechanism has lost some of its relevance in the modern world in which people intentionally seek irritating tastes and odors. The popularity of strong mints, menthol, chilies, and some forms of aromatherapy attests to a hedonistic, rather than solely a warning, function of chemesthesis. Most environmental health professionals would not consider stimulation of chemesthesis to be an adverse effect.

There are several physiological or neurological tests that can be used to discriminate between olfaction and trigeminal irritation. One that has seen recent use in the biosolids context is lateralization testing. The work of Schiffman et al. (2000) has been used to support the use of lateralization testing to determine if odors are irritants. It is based on nasal stimulation in a single nostril by a chemical substance. Irritants are localized—that is, the subject can state which nostril is being irritated. Odorants are not localized – stimulation of one nostril generates a perception of an odor from both nostrils (Wysocki et al. 1992). The use of lateralization has been advocated for the setting of threshold limit values for worker protection (Cometto-Muniz and Cain 1998) based on the assumption that chemesthesis is a warning that precedes frank toxicity. Schiffman et al. (2002) note that a positive lateralization test is a low-level, threshold response to a short term exposure. The extent of the irritation or the degree of involvement of cellular level responses such as histamine secretion is unknown. Thus, the distance between trigeminal stimulation and frank toxicity on the dose-response curve for a particular substance is largely unknown which leads to ambiguity in interpretation of the results. Some additional the drawbacks of the use of lateralization involve the lack of methodological standardization and difficulty in interpretation of methodological differences. The literature reveals a great deal of variability in how the substances are administered, for example, intranasally or in the air adjacent to the nose, factors such as the intervals between testing, and how subjects rate their responses.

Multiple Chemical Sensitivity and "Sludge Victims"

Multiple chemical sensitivity (MCS) is a term referring to chronic illness "acquired in relation to an environmental exposure affecting more than one organ system, with symptoms aggravated by exposures to chemicals at levels orders of magnitude below those that cause illness in the healthy population" (Cullen 1987). Individuals who suffer from MCS often allege that they acquired a sensitized state following a chemical exposure. A typical MCS patient is between 40 and 50 years of age, more likely to be female, and suffers from anxiety, lightheadedness, impaired mentation, poor coordination, breathlessness, tremor, and abdominal discomfort (Tarlo et al. 2002). Often the chemical exposure is to an odorant, which is commonly a fragrance. Shusterman (2002) has identified a range of disorders that are associated with MCS and odor including nonallergic rhinitis, odor-triggered asthma, odor-triggered panic attacks, and chemical-induced olfactory dysfunction. Ross et al. (1999) have proposed several mechanisms whereby odors are associated with MCS through stimulation of either the olfactory system or the trigeminal system. One theory for the etiology of MCS involves neural sensitization (Sorg 1999). In this theory, repeated stimulation of a nerve (olfactory or trigeminal) results in increased neuronal responsiveness. An individual who has been sensitized may exhibit extreme odor intolerance that leads to a variety of symptoms. Sensitization is a learned behavior which could explain the spread of symptoms throughout populations that claim environmental exposure to odorants. Another recent hypothesis of the etiology of MCS concerns the controversial vomeronasal organ (Greene and Kipen 2002). The existence and prevalence of the vomeronasal organ in humans is a matter of heated scientific debate, however, Greene and Kipen have hypothesized that the vomeronasal organ responds to low levels of chemical substances with subsequent alteration in central nervous system activity and resultant changes in behavior, even without direct or conscious awareness of the exposure, i.e., below olfactory or irritation thresholds. This mechanism is responsible for the perception of pheromones in non-humans; however, it is still a matter of conjecture if it has the same function in humans. This hypothesis deserves further investigation. If proven true, it could lead to a simple therapeutic regimen for MCS patients.

The Cornell Waste Management Institute (CWMI) is spearheading an effort to collect self-reported symptoms from people who allege that they have been impacted by biosolids[3]. As part of this effort, CWMI has developed a list of so-called "sludge symptoms" (Table 3). Most of these diseases have not been confirmed by physicians, nor have the allegedly impacted populations been subjected to a formal investigation as discussed subsequently in this paper. Some of the conditions on the list are actually disorders (illnesses) rather than symptoms; for example, asthma is a diagnosable illness rather than a symptom. However, the list has been widely circulated and forms the basis of informal symptom prevalence surveys by anti-biosolids activists throughout the United States. Many of the symptoms on the list are linked to MCS.

Table 3. CWMI List of Symptoms

CWMI "Sludge Symptom"	MCS Citation
Asthma	Ashford and Miller 1998, Baldwin et al. 1999
Dry heaves/coughing	Ashford and Miller 1998
Eye problems	Donnay 1999; Ashford and Miller 1998
Flu-like symptoms	Ashford and Miller 1998
Gastrointestinal problems	Donnay 1999
Headaches	Donnay 1999; Gotts and Pirages 1999
Nausea	Gotts and Pirages 1999; Shusterman 2002
Respiratory problems	Shusterman 2002; Ashford and Miller 1998
Skin rashes	Ashford and Miller 1998
Vomiting	Ashford and Miller 1998
Burning throat	Donnay 1999

[3] http://www.cfe.cornell.edu/wmi/Sludge/Incidents.htm.

Burning nose	Donnay 1999, Sorg 1999.
Fatigue	Donnay 1999; Natelson and Lange 2002

The similarity between MCS and "sludge symptoms" suggests a common origin. Since almost all complaints about biosolids health effects start out with an odor complaint[4] and since MCS is linked to both the olfactory and chemesthesis systems, it is possible that "sludge symptoms" are a reflection of MCS.

If this is the case, it adds several new dimensions to the discussion of odor perception and health effects. First, although many aspects of MCS are vague, there are suggested definitions and diagnostic criteria. The Cullen (1997) criteria include the existence of a documentable environmental exposure, involvement of multiple organ systems, exposures that are demonstrable although low and subjective manifestations of effects. Ashford and Miller (1998) have attempted to remove subjectivity by using an operational definition, that is, if symptoms disappear on removal of the agent and reappear with subsequent challenges then causation may be inferred. Second, there are at least four competing theories of the etiology of MCS — biogenic (biological in origin), psychogenic (psychological in origin), misdiagnosis, and MCS as a belief system (Gad 1999). Obviously psychogenic MCS would be treated differently than biogenic MCS (Mitchell 1996). Gots and Pirages (1999) have concluded that current scientific evidence suggests that behavioral or psychogenic explanations predominate for MCS patients and that behavioral treatments are often indicated. The possible etiology of MCS as a belief system may be an outcome of iatrogenic influence (physician's belief system), or a manifestation of chemophobia. In the case of biosolids, odor-related MCS has been reinforced or even created by activists such as the CWMI and by the identification of "sludge victims".

How to Distinguish Health Effect Fact from Fiction (or Odor from Health Effect)

The first action of an individual who feels they have been impacted by an odor from a biosolids operation should be a visit to their doctor. A report of a disease must be verified by a licensed physician or equivalent health care provider. Diseases should be classified according to International Classification of Diseases—Clinical Modification (ICD-9-CM)[5]. The physician should follow a standard process in establishing an environmental diagnosis (Brooks 1995):

- Establish the clinical characteristics of the medical condition
- Characterize exposure (to the odorant/chemical)
- Demonstrate correlation between exposure and clinical manifestation
- Establish diagnosis of environmental medical condition.

[4] See working papers of David Lewis in Marshall v. Synagro et al.
[5] www.cdc.gov/nchs/about/otheract/icd9/abticd9.htm

The physician should consider clinical toxicology (toxicology as it applies to adverse human health effects) in the case of potential chemical exposure, alternative etiologies, temporal relations, and the effect of removal from exposure.

A wide variety of tests exists for clinical investigation of putative odor impacts (Schiffman et al. 2000). Tests and tools have been investigated to evaluate symptoms including eye irritation, headache, nasal congestion, nasal irritation, throat irritation, hoarseness, palpitations, sensory alterations, shortness of breath, and stress. For example, eye irritation may be investigated using slit lamp examination, blink rate, tear film stability, lissamine green staining of conjunctiva, and corneal carbon dioxide threshold. If MCS is a potential diagnosis, the clinical investigation should be expanded to include immunologic, respiratory, cardiovascular, neurological, psychological and social function tests (Ashford and Miller 1998). The Environmental Exposure and Sensitivity Inventory (EESI) is a clinical instrument developed for evaluating MCS following a well-defined exposure. Use of the EESI can help to make perceptions more objective, especially if administered over time or if the exposure has stopped. Other instruments such as a standardized respiratory health questionnaire and the Chemical Odor Intolerance Index have been discussed by Baldwin et al (1999) in the context of odors and MCS.

The demonstration of exposure is critical to evaluating potential health effects. Exposure must be demonstrated using chemical measurement, mathematical modeling, biomarkers, or combinations of these techniques (Chrostowski 1994). Standard methods should be used for sampling and analysis of environmental media for chemical agents. Sources of methods include: APHA/AWWA/WEF *Standard Methods for the Examination of Water and Wastewater*, EPA's SW-846 for chemicals in soils and biosolids, EPA's TO-series for air, and publications of ASTM. All quality assurance and quality control (QA/QC) guidelines specified in these methods should be adhered to. If a standard method is not available, methods published in the peer reviewed literature may be used with proper QA/QC.

Consideration should also be given to conducting field tests in areas where people claim exposures to odors. EPA's (2000) Guide to Field Storage of Biosolids contains an appendix on odor characterization, assessment and sampling techniques. McGinley and McGinley (2002) reviewed standard odor testing practices. Odors emitted from biosolids may be measured using flux chamber methods (ASTM 2003) or estimated using emission rates (EIIP 2000). Airborne odors may be evaluated using standard ASTM methods (ASTM 1997, 1999) or modeled (Wu 2000). In some cases, lateralization testing may also be warranted, however, the results from lateralization testing should be used with caution until methods and their interpretation have been standardized.

Conclusions

Based on the scientific literature, there is little evidence to support the contention that odor itself is a health effect in the traditional context of environmental health. Trigeminal stimulation, which occurs at higher chemical concentrations than olfaction, may be considered to be an absolute threshold for irritation, however, the mere presence of trigeminal stimulation is not sufficient for adverse effects that negatively affect function to occur. There is a possible link between "sludge victims" syndrome and MCS evidenced by a commonality of symptoms and perception of odors in both cases. The ambiguity associated with MCS requires rigorous investigation of etiology in any given case or population. Because MCS may be psychologically or sociologically influenced, it is possible that the work of anti-biosolids activists may exacerbate the perception of health effects associated with land application sites. Any health claim related to biosolids should be formally investigated using tools of medicine, physiology, chemistry, and psychology to gain a true understanding of causes and the potential for therapeutic or public health intervention.

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