

DRAFT

Appendices to Accompany the Report of the CFO Effects Subgroup

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Appendix B-1: Nitrogen Cycle and Nitrogen Cascade

The nitrogen cycle and nitrogen cascade are presented in figures 1 and 2. An important characteristic of the cascade is that once a N atom enters the cascade, its source (e.g., fossil fuel combustion, agriculture, fertilizer production) is irrelevant - except for different types of control strategies that may be employed (NRC 2003).

Ammonia from agricultural sources can be transferred to soils, water and air in various forms including NH_3 or in the converted forms of NH_4^+ , NH_4 sulfates, NH_4 nitrates, nitrates, nitrites and nitric oxides. The extent of airborne NH_3 emissions will depend on how much of the ammonia-nitrogen in solution reacts to form NH_3 versus ionized ammonium (NH_4^+), which is nonvolatile. The pH of solid manures ranges from 7.5 to 8.5, which promotes NH_3 volatilization. Volatilization of NH_3 increases with manure drying. Liquid and semi-solid manures have lower pH and at $\text{pH} < 7$, NH_4^+ is predominant and NH_3 volatilization is slower (but still occurring). However, NH_3 loss due to volatilization under acidic conditions in liquids is rapidly replaced because of the equilibrium between NH_4^+ and NH_3 . There may be little difference in total NH_3 emissions between solid and liquid manures if liquid manures are stored for prolonged periods of time prior to land application (EPA 2001).

The formation of nitrous oxide from microbial decomposition of manure is limited and requires specific conditions. The manure must first be handled aerobically (i.e., dry) and then anaerobically (i.e., wet). Aerobic conditions promote the microbial nitrification, the oxidation of NH_3 to nitrites and nitrates. Anaerobic conditions promote the microbial denitrification of nitrites and nitrates to nitrogen gas (N_2) with the formation of small amounts of nitric oxide (N_2O). Nitric oxide emissions are most likely to occur from unpaved dry lots for dairy and beef cattle and at land application sites where conditions for both nitrification and denitrification are likely to be present. At these sites, the ammonia-nitrogen that is not lost by volatilization will be adsorbed on soil particles and subsequently oxidized to nitrite and nitrate nitrogen (EPA 2001).

Nitrogen deposition in terrestrial ecosystems through soil, water or air pathways and in its various forms, can increase soil acidity, decrease biodiversity, and increase or decrease ecosystem productivity. Discharged in to aquatic ecosystems, it can increase surface water acidity and lead to eutrophication. In the form of N_2O , it can first increase greenhouse warming and then facilitate stratospheric ozone depletion (EPA 2001).

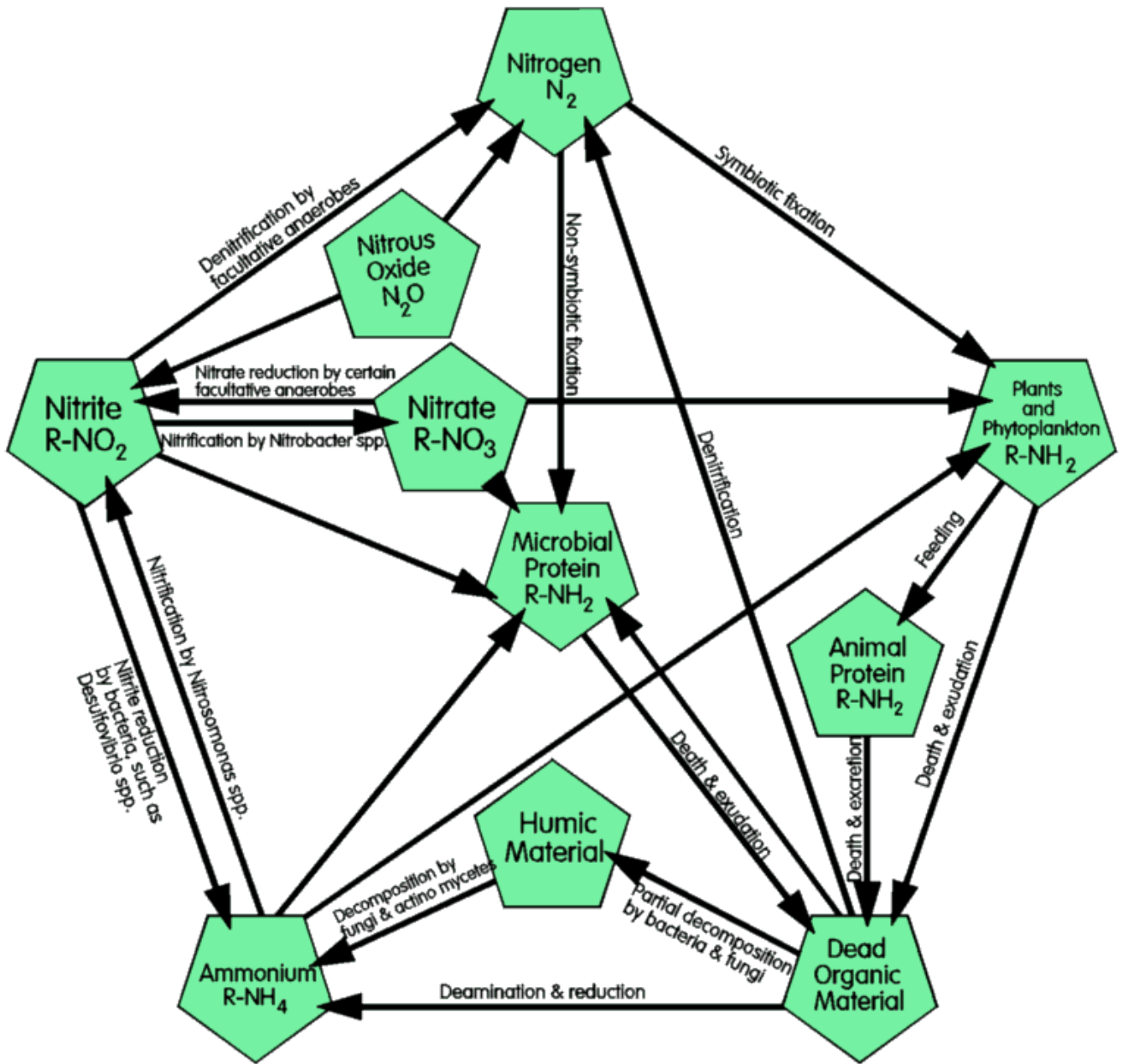


Figure 1: Diagram of the Nitrogen Cycle

Source: <http://www.alken-murray.com/Nitrogen.html>. Alken Murray Corporation. Accessed March 13, 2007

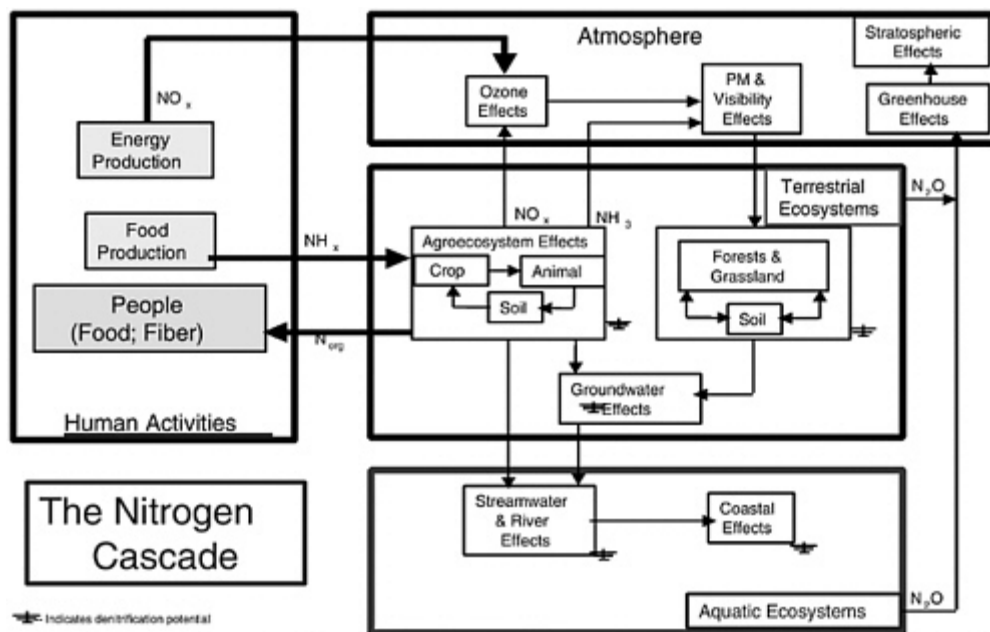


FIGURE 2 Nitrogen cascade.

SOURCE: Galloway and Cowling (2002).

Reference: NRC 2003

Appendix C-1: Effects of Reduced Sulphur Compounds on Vegetation

1.1.1.1 Horticultural Species

From the literature available, the lowest exposure concentration that produced a measurable effect (growth stimulation) in this group (horticultural species) was 30 ppb H₂S over 77 days. The lowest exposure concentration to produce a negative effect was 100 ppb H₂S for 145 days, which caused a decrease in cane dry weight in grapes (Thompson and Kats, 1978). However, this observation was based on the measurement of only five plants. Negative effects on growth, yield and physiological parameters were noted in spinach, lettuce, grapes, kale, tomato, rocket and/or radish at 250, 300, 15,000, 25,000, 50,000, and/or 100,000 ppb H₂S at exposure durations ranging from 4 hours to 177 days.

1.1.1.2 Agricultural Species

The effects of exposure of agricultural plant species to H₂S are summarized in Table 19. de Kok *et al.* (1989) reported no significant effect on shoot fresh weight in maize (*Zea mays*) exposed to 750 ppb H₂S for 12 days. Beans (*Phaseolus vulgaris*) exposed to 250 ppb H₂S for 14 days showed a significant increase in yield (Maas *et al.*, 1987b). Coyne and Bingham (1978) exposed field grown bean plants to 740 ppb H₂S for four hours per day for 18 days, and found a significant increase in stomatal conductance (reduced stomatal resistance) compared with control plants. No effect was observed on soybean yield of plants exposed to 250 ppb H₂S for 14 days (Maas *et al.*, 1987b).

Field grown snap bean subjected to varying concentrations (300 to 700 ppb) of H₂S for 4 hours per day for 40 days showed a decrease in a wide variety of growth and yield measurements compared with control plants (Bennett *et al.*, 1980). Coyne and Bingham (1978) exposed field grown snap bean to 3,250 ppb H₂S for four hours per day for 18 days and found a significant decrease in stomatal conductance and photosynthesis. It is unknown whether these decreases were accompanied by decreases in growth and yield. Taylor and Sevidge (1984) exposed bush beans to concentrations of H₂S ranging from 6,100 to 81,800 ppb and found that photosynthesis was impaired at all concentrations. The degree of impairment increased with increasing H₂S concentration; however, it is unknown how the impairment impacted growth and yield of the plants.

Impairment to the growth and yield of sugar beets was not observed in plants exposed to 30 or 100 ppb H₂S for 131 or 134 days (Thompson and Kats, 1978; Thompson *et al.*, 1979; de Kok *et al.*, 1983b). Sugar beet exposed to 300 ppb H₂S showed a decrease in fresh weight per shoot after 28 days (de Kok *et al.*, 1983b) and a decrease in leaf dry weight and percent sugar content of the root after 134 days (Thompson and Kats, 1978).

Clover (*Trifolium pratense*) exposed to 250 ppb H₂S for 14 days showed a significant decrease in yield compared with control plants. Thompson and Kats (1978) exposed alfalfa to 300 ppb H₂S for 28 to 35 days and found a significant decrease in average dry weight per pot after each of two cuttings.

From these studies it appears that concentrations as low as 50 ppb H₂S for four or five weeks will induce some biochemical responses in different crop species. However, exposure to 250 ppb H₂S for 14 days is the lowest exposure concentration causing reduced plant growth or crop yield for clover,

while exposure to 300 ppb H₂S for 134 and 35 days reduced growth or yield for sugar beets and alfalfa, respectively.

1.1.1.3 Forest Species

Only one study reviewed examined the effect of H₂S on forest species. Douglas fir seedlings were exposed to 30, 100 and 300 ppb H₂S for 246 days in a greenhouse. Although a slight burn on the needles was observed in plants exposed to 100 ppb H₂S, there was no observed effect on growth and dry weight accumulation. Extensive foliar injury was observed in plants exposed to 300 ppb H₂S, which was accompanied by a significant reduction in growth and dry weight.

Ponderosa pine seedlings were exposed to continuous fumigation of H₂S concentrations of 30, 300 and 3,000 ppb H₂S for 76 days (Thompson and Kats, 1978). Tip burn was observed at 300 ppb H₂S, and both tip burn and defoliation were observed at 3,000 ppb H₂S. No observed effects occurred in plants exposed to 30 ppb H₂S.

Only two forest species were examined in this study. The lack of available data for review within the paper make it difficult to identify the potential H₂S effects level for forest species.

1.1.2 Dimethyl Sulphide

No information on the response of plants to dimethyl sulphide could be located in the literature.

1.1.2.1 Horticultural Species

Chen and Paull (1998) fumigated banana with 10,000 to 60,000 ppm carbonyl sulphide and exposed avocado, mango, papaya, and red ginger to 10,000 and 20,000 ppm carbonyl sulphide for 24 hours. While exposure slowed coloration and flesh softening in papaya, the fumigations increased softening in bananas, mangoes and avocados. The authors note that red ginger inflorescences were less tolerant to carbonyl sulphide than fruit, being able to withstand 20,000 ppm carbonyl sulphide for only 0.75 hours. Lemons fumigated with 70 ppm carbonyl sulphide for 20 hours showed a slight amount of peel injury after 12 hours, but increased in offensive juice odours and rind injury with increasing exposure duration (Obenland *et al.*, 1998).

1.1.2.2 Agricultural Species

Ren *et al.* (1996) exposed wheat to 24, 50, 100, 250, and 500 ppm carbonyl sulphide for 24 to 96 hours and observed reduced germination rates at longer exposures and lower moisture conditions, but noted no effect on the plumule length of the plants.

1.2 Effects Levels for RSC Effects on Vegetation

The phytotoxicity of RSC compounds is dependent upon the compound, its concentration and the duration of exposure. The degree of plant response is dependent upon species, cultivar and genotype as well as on a variety of environmental factors such as light, temperature, humidity, water availability, CO₂ concentration and nutrient availability. The review of the literature revealed a general lack of dose-response models for RSC compounds for a variety of species under a variety of

environmental conditions. There was a limited amount of information available for RSC compounds other than H₂S.

1.2.1 Hydrogen Sulphide

The National Research Council of Canada (NRCC, 1981) completed a review of the scientific literature and concluded that vegetation was relatively insensitive to short-term exposure to high concentrations of H₂S. Studies published since 1981 have not examined the effect of acute exposures of H₂S on vegetation. NRCC (1981) suggested that long-term exposures of concentrations less than 280 ppb (392 µg/m³) generally stimulated plant growth whereas long-term exposures of concentrations greater than 280 ppb (392 µg/m³) H₂S were more likely to inhibit growth and cause visible injury.

This review of the literature suggests that impairment to plant growth and physiological processes generally begins at 250 ppb (350 µg/m³) but at higher concentrations of H₂S for several plant species as indicated. Long-term exposures to concentrations up to 100 ppb (140 µg/m³) did not result in detectable impacts for a variety of plant species. One exception was the reduced dry weight accumulation noted in grapes exposed to 100 ppb (140 µg/m³) for 145 days by Thompson and Kats (1978). However, the limited sample size (5 plants) exposed to this concentration raises concerns about the validity of these data.

The lowest observable effect concentration (LOEC) for H₂S is 250 ppb (350 µg/m³) for 3 days. The no observable effect concentration (NOEC) is 100 ppb (140 µg/m³) for a variety of long-term exposure periods. From this review, the highest level without demonstrated or observed effects for H₂S is 100 ppb (140 µg/m³).

1.2.2 Carbonyl Sulphide

Banana, avocado and mango exposed to carbonyl sulphide concentrations ranging from 10,000 to 60,000 ppm for 24 hours resulted in an increase in flesh softening and some skin injury while fumigation of papaya showed skin injury and flesh softening. Red ginger was observed to be the least tolerant of the species studied, withstanding 20,000 ppm carbonyl sulphide for only 0.75 hours. Lemons fumigated with 70 ppm carbonyl sulphide for 20 hours showed a slight amount of peel injury after 12 hours, but increased in offensive juice odours and rind injury with increasing exposure duration. Wheat exposed to 24, 50, 100, 250, and 500 ppm carbonyl sulphide for 24 to 96 hours had reduced germination rates at longer exposures and lower moisture conditions, but was not affected in plumule length (Ren *et al.*, 1996). A lack of further dose-response information prevents the identification of a vegetation effects level for carbonyl sulphide.

1.2.3 Methyl Mercaptan

Methyl mercaptan was the only mercaptan or thiol compound for which there was information on the response of plants (Taylor and Selvidge, 1984). Bush beans were exposed for six hours to methyl mercaptan concentrations ranging from 6,100 ppb (8,540 µg/m³) to 81,800 ppb (11,340 µg/m³) and no impairment to the rate of photosynthesis was detected at any of the concentrations. The lack of further dose-response information prevents the identification of an effect level for methyl mercaptan.

References *All references need to be added.*

Appendix D-1: Management Mechanisms to Reduce Odourous VOCs

Note: The Odour section of this report discusses VOCs and VFAs in Appendix F-2.

Inhibition of methanogenic bacteria is caused by low temperatures or excessive solids loading rates into liquid storage facilities. Both these conditions can create an imbalance in the microbial population that favours VOC generation. VOC emissions will be minimal from properly designed and operated facilities and manure stabilization processes (e.g., anaerobic lagoons), including manure land application sites. VOC emissions will be higher from storage tanks, ponds, overloaded anaerobic lagoons and, subsequently, from associated land application sites (EPA 2001, Michigan 2006).

Most of the odorous compounds are produced from anaerobic processes. Operations with a high odour potential and include liquid manure handling including storage pits, ponds, and associated land application. Properly designed and operated anaerobic lagoons should have a low odour potential except in the spring and fall where the temperature change can upset the microbial balance or if the lagoon is overloaded with solids. Emissions from anaerobic lagoons for swine, laying hen, and dairy cattle manures are thus more problematic in colder climates (Michigan 2006), such as in Alberta. Dry lots can produce odour during combined warm and wet conditions, which promote the development of anaerobic conditions (EPA 2001). Decaying animal carcasses can also be a source of odourous VOCs if stored for a prolonged time.

Well aerated manure stabilization systems would completely eliminate odour issues. However, aerobic treatment is not considered economically justifiable. Lower rates of aeration are generally sufficient to reduce the release of odourous VOCs, gases and compounds by allowing some oxidation to less odorous compounds (Cole 2000).

Some estimates of VOC emission rates have used mass transfer models, in the following two tables, one for swine and one for dairy, which introduces considerable uncertainty (Minnesota 2001).

Table 1: Average Annual VOC Emission Rate Estimates for Swine Facilities

Compound	Swine Deep-Pitted Barn (g/m²/day)	Swine Outdoor Manure Basin (g/m²/day)
Volatile Fatty Acids		
Acetic acid	2.65E-04	1.17E-02
n-Propanoic acid	1.36E-04	5.44E-03
iso-Butyric acid	8.89E-05	3.21E-03
n-Butyric acid	2.54E-04	9.41E-03
iso-Valeric acid	7.39E-05	2.50E-03
n-Valeric acid	1.25E-04	4.30E-03
iso-Caproic acid	8.44E-06	2.62E-04
n-Caproic acid	3.63E-05	1.13E-03
n-Heptanoic acid	8.96E-06	2.65E-04
n-Octanoic acid	3.78E-06	1.07E-04
Other Volatile Organic Compounds		
Phenol	7.06E-02	1.33E-01
meta-Cresol	3.73E-03	6.61E-03
para-Cresol	8.56E-02	1.51E-01
para-Ethyl phenol	1.93E-02	3.27E-02
Volatile Inorganic Compounds		
Hydrogen sulfide	4.06E-01	2.67E+00
Ammonia	2.34E+00	2.71E+00

Source: Minnesota 2001

Table 2: Average Annual VOC Emission Rate Estimates For Dairy Facilities (Minnesota 2001)

Compound	Dairy Outdoor Manure Basin (g/m ² /day)
Volatile Fatty Acids	
Acetic acid	1.87E-03
n-Propanoic acid	8.69E-04
iso-Butyric acid	5.13E-04
n-Butyric acid	1.50E-03
iso-Valeric acid	4.00E-04
n-Valeric acid	6.87E-04
iso-Caproic acid	4.19E-05
n-Caproic acid	1.81E-04
n-Heptanoic acid	4.23E-05
n-Octanoic acid	1.71E-05
Other Volatile Organic Compounds	
Phenol	1.99E-02
meta-Cresol	9.91E-04
para-Cresol	2.27E-02
para-Ethyl phenol	4.90E-03
Volatile Inorganic Compounds	
Hydrogen sulfide	3.75E-01
Ammonia	3.58E+00

Zahn et al. (2001) collected and analyzed 328 air samples from 29 swine facilities across Iowa, North Carolina, and Oklahoma for VOCs. The measured compounds, along with odour thresholds and workplace exposure limits are presented in Table 4. Air samples were collected at the end or centre of manure lagoons and basins and at a height of 1.5 meters. Based on the ratio between the odourant concentration and the odour thresholds, compounds with significant contribution to odour loading were butyric, isovaleric, propionic acids and possibly 3-methyl indole. With the exception of H₂S and other organic sulphides, organic amine-containing compounds were not routinely detected in emissions. A possible reason for this was that sulphide and amines compounds are unstable in oxygenated atmospheres (Zahn et al. 2001, Auvermann 2002).

In this study, Zahn et al. (2001) established that measuring 9 to 19 VOC odourants in ambient air, when compared to odour thresholds, is a reasonable tool to evaluate best management practices for swine manure management systems and as a method of identifying swine production facilities presenting a potential nuisance concern. The 9 VOCs were valeric, butyric, heptanoic, isobutyric and acetic acids and 4-methyl phenol, 4-ethyl phenol, 3-methyl indole, and phenol.

Table 3: Identified VOC Odourants from 29 Swine Production Facilities in the U.S., including Odour Thresholds and Workplace Exposure Limits (Zahn et al. 2001).

Chromatographic peak #, organic compound	Average air conc.†	Ref.‡	Odor characteristic	Odor threshold§	Recommended TWA limits¶
	mg m ⁻³			mg m ⁻³	
Hydrogen sulfide	0.090	1	rotten eggs	0.140	14
Ammonia	3.70	1	sharp, pungent	0.027–2.2	18
1. Dimethyl disulfide	0.017	1	putrid, decayed vegetables	0.0011–0.61	–
2. 2-Butanol	0.019	1	alcohol	0.11	305
3. Dimethyl trisulfide	0.013	1	nauseating	0.0072–0.023	–
4. Acetic acid	0.270	2	pungent	0.1–2.5	25
5. Propionic acid	0.130	2	fecal	0.0025	30
6. Isobutyric acid	0.110	2	fecal	0.00072	–
7. Butyric acid	0.590	2	fecal, stench	0.00025	–
8. Isovaleric acid	0.098	1	fecal	0.00017	–
9. <i>n</i> -Valeric acid	0.360	1	fecal	0.00026	–
10. Isocaproic acid	0.010	1	stench	0.0020	–
11. <i>n</i> -Caproic acid	0.110	2	fecal	0.0020	–
12. Heptanoic acid	0.008	1	pungent	0.0028	–
13. Butylated hydroxytoluene	–	–	nd	nd	–
14. Benzyl alcohol	0.002	2	alcohol	nd	–
15. Phenol	0.025	2	aromatic	0.23–0.38	19
16. 4-Methyl phenol	0.090	2	fecal	0.0021–0.009	22
17. 4-Ethyl phenol	0.004	2	pungent	0.0035–0.010	25
18. 2-Amino acetophenone	0.001	2	fruity, ammonia	nd	–
19. Indole	0.002	1	fecal	0.0019	–
20. 3-Methyl indole	0.002	1	fecal, nauseating	0.0000005–0.0064	–

† Average reported concentration of the analyte in air at a height of 1.5 m from the surface of a high-odor swine manure basin. Butylated hydroxytoluene added as a preservative.

‡ References: 1 = Zahn et al., 2000; 2 = Zahn et al., 1997.

§ Milligrams of analyte per cubic meter of air at standard temperature and pressure. nd = not determined.

¶ The time-weighted average concentration for a normal 8-h workday and a 40-h workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effect (Plog, 1988 p. 770–783).

CASA CFO Health Subgroup Note: The indicated odour threshold for H₂S of 160 ug/m³ is unrealistically high. The Alberta Ambient Air Quality Objective of 10 ug/m³ 1-hour average is based on odour.

O'Neill and Phillips in a 1992 literature review (Auvermann 2002) identified 168 on odorous compounds associated with livestock wastes and found 30 of which had odour threshold below 1 µg/m³ and 6 of the ten compounds with the lowest detection thresholds were sulfur-containing. The major odourants from a beef cattle confinement chamber under 3 different manure handling systems were methanol, multiple aldehydes, ethanol, ethyl formate, 2-propanol, indoles and assorted carboxylic acetates and propionates (Auvermann 2002). A study by Powers and Bastry in 2004 found a high correlation between CFO odours and the presence of H₂S followed by 4-methyl phenol, phenol, 3-methyl indole, 1-decene, butyric acid, and 4-ethyl phenol (Michigan 2006).

An overview of odourants emitted by livestock facilities is listed in Table 5.

Table 4. CFO Emission Odourants and associated occupational exposure limits and ambient air quality guidelines.

Class	Constituent	Exposure Limits (ppm)		Database Citation(s)	Hedonic Tone (a)
		Occup.	Ambient		
N	Ammonia	25-50	0.15	679; 737; 974; 747	ammoniacal
N	Methylamine	10	n/a	679; 974; 747	fishy
N	Dimethylamine	10	n/a	679; 974; 747	fishy
N	Trimethylamine	10	n/a	679; 974; 747	fishy <100 ppm
N	Indole	n/a	n/a	457; 960	fecal
N	Skatole	n/a	n/a	457	fecal
S	Hydrogen sulfide	10	.03-.05	355; 738	rotten egg
S	n-Propyl mercaptan	1.6 mg m ⁻³	n/a	495	onion
S	Methyl mercaptan	0.5-10	n/a	974	decayed cabbage
S	Butyl mercaptan	10	n/a	974	skunk
S	Dimethyl sulfide	1.0-20	n/a	159; 974	decayed vegetables
S	Dimethyl disulfide	1000 µg m ⁻³	n/a	974	decayed vegetables
VFA	Acetic acid	10	n/a	154; 974	vinegar
VFA	Propionic acid	10	n/a	154; 974	sour
VFA	n-Butyric acid	n/a	n/a	154; 669	sour
VFA	n-Valeric acid	n/a	n/a	457	fecal
VFA	iso-Valeric acid	n/a	n/a	457	rancid cheese
PHN	p-cresol	5	n/a	457; 974	creosote
PHN	phenol	19 mg m ⁻³	n/a	154;	medicinal
CHO	Acetaldehyde	100	9 µg m ⁻³	159; 974	fruity
CHO	Acrylaldehyde	0.1	0.02 µg m ⁻³	974	fruity
CHO	Valeraldehyde	175 mg m ⁻³	n/a	974	fruity
CHO	Toluene	375 mg m ⁻³	0.4 mg m ⁻³	974	n/a
CHO	Vinyl acetate	30 mg m ⁻³	0.2 mg m ⁻³	974	n/a
CHO	Dimethyl ketone	2400 mg m ⁻³	n/a	974	sweet
CHO	Methyl ethyl ketone	590 mg m ⁻³	1 mg m ⁻³	159 974	sweet
BDT	Endotoxin	10 ng m ⁻³	80-170 ng m ⁻³	586; 260; 260; 295	n/a

Class

- N Nitrogen-containing
- S Sulfur-containing
- VFA Volatile fatty acid
- PHN Phenolic
- CHO Containing only carbon, hydrogen and oxygen
- BDT Biologically-derived toxin

McGinn et al (2003) measured concentrations of volatile fatty acids (VFAs) at increasing distances from three beef feedlots near Lethbridge, Alberta. VFAs were measured during the period March 23 to Sept 24 1999 and as 2-3 day averages. VFA concentrations measured 3 meters from the edge of the feedlots are presented in the table below. VFA concentrations were significantly higher at the 12,000 head feedlot and was attributed to increased animal density. Animal densities for the 6,000, 12,000 and 25,000 head feedlots were 20, 13.3 and 25.6 m² per animal, respectively.

Table 5: VFA concentrations, 2-3 day averages, measured 3 meters from the edge of 3-feedlots. n=8 per feedlot

Feedlot Capacity (# of animals)	Range of VFA (µg/m ³)	Average VFA (µg/m ³)
6,000	16.1-45.0	23.2*
12,000	37.8-177.6	73.5*
25,000	17.4-47.7	25.5*

* results significantly different

In terms of VFA composition, acetic acid was quantitatively predominant, comprising ~60% of the samples, and ranged in maximum concentration from 26, 114 and 32 µg/m³ at the 3-feedlots, respectively. Maximum levels of propionic and butyric acid were lower than acetic acid, comprising ~20% of the samples. Concentration maximums for propionic and butyric acid at the 3-feedlots were virtually identical and were as follows: 9, 34 and 7 µg/m³. Maximum levels of isobutyric, valeric, isovaleric, and caproic acids were ~6 to 8x less than propionic and butyric acid levels. Cresols, phenol, indole and skatole maximum concentrations were orders of magnitude lower than acetic acid, and were considered close to background. McGinn reports that the relative abundance of measured VFA at the cattle feedlot were similar to swine slurry air from a 1993 study by Kirchmann and Lundvall.

McGinn also collected samples following manure spreading. In contrast to VFA composition at the feedlot edge, butyric acid was the quantitatively predominant compound at 104 µg/m³, followed by propionic acid (60 µg/m³), acetic acid (54 µg/m³), isovaleric acid (29 µg/m³), and isobutyric acid (17 µg/m³). Valeric and caproic acid averaged 8 and 6 µg/m³, respectively. Other compounds were below detection limit with the exception of p-cresol and phenol at 0.002 and 0.100 µg/m³.

In terms of odour potential, McGinn compared the above maximums measured near the feedlots, to odour thresholds. Odour thresholds were exceeded for the following compounds, with the first number within the parenthesis indicating the number of exceedences and the second the range in the magnitude of the exceedences: acetic (1 exceedence event, 1.1 times the odour threshold), butyric (3, 3-14x), isobutyric (3, 1.7-6x), isovaleric (3, 10-39x), valeric (3, 10-24x) and caproic (3, 1.2-3x) acids. The 12,000 head feedlot was the site of the most frequent and largest magnitude of exceedences. In terms of manure spreading, exceedence analysis is as follows: propionic acid (2.4 x the odour threshold), butyric (42x), isobutyric (23x), isovaleric (170x), valeric (33x), and caproic (3x) acids.

McGinn surmised, based on a 1994 study by Luebs et al. on ammonia, that odourant concentrations are likely higher in the early morning and in the night when atmospheric mixing is less (i.e., heat from the sun promotes atmospheric turbulence).

McGinn also measured VFA concentrations with increasing distance away from the 12,000 and 25,000 head feedlots, at 3, 100 and 200 meters distance, over 4 monitoring periods. VFA levels were on average 3x higher at the 12,000 head feedlot (75 versus 25 $\mu\text{g}/\text{m}^3$), possibly due to higher animal densities but also reflecting that some of the 12,000 head feedlots samples were collected in the spring, a period of poorer atmospheric mixing and/or higher VFA emissions). VFA values at the 2 feedlots were similar when compared to samples collected in the summer.

At 200 meters distance, VFA levels fell by 77% and 46% at the 12,000 and 25,000 head feedlots, respectively. Analysis indicated that only butyric acid exceeded the odour threshold of 2.5 $\mu\text{g}/\text{m}^3$, on two monitoring periods and at the 3, 100 and 200 meters distances. For the 12,000 head feedlot, the exceedence occurred in spring and the levels at 3, 100 and 200 meters were 25, 7.5 and 3.0 $\mu\text{g}/\text{m}^3$, respectively. For the 25,000 head feedlot, the exceedence occurred in summer and the levels were 6.1, 4.4 and 3.1 $\mu\text{g}/\text{m}^3$.

McGinn observed that VFA concentrations measured at the edge of the feedlots correlated with higher wind speeds. McGinn suggested that wind speed is a key factor in governing transport loss of VFAs from a manure surface. Zahn (2001) cites a 1995 study by MacIntyre as confirming this finding, where wind and temperature differences in indoor and outdoor environments accounted for between 51 and 93% of the difference in VOC emissions from manure.

Appendix D-2: Volatile Organic Compounds Identified In and Around Confined Feeding Operations

Listing of Chemical Substances Identified In and Around Livestock Manure
(Adapted from O'Neill and Phillips 1992)

	Compound (names)	EPA Classification
Carboxylic Acids		
1	formic acid methanoic acid	VOC
2	acetic acid ethanoic acid	VOC
3	propionic acid propanoic acid	VOC
4	n-butyric acid butanoic acid	VOC
5	i-butyric acid 2-methylpropanoic acid	VOC
6	n-valeric acid pentanoic acid	VOC
7	i-valeric acid 3-methylbutanoic acid	VOC
8	2-methylbutanoic acid	VOC
9	2-methyl-2-butenic acid (angelic acid)	VOC
10	n-caproic acid hexanoic acid	VOC
11	i-caproic acid 4-methylpentanoic acid	VOC
12	2-methylpentanoic acid	VOC
13	oenanthic acid heptanoic acid	VOC
14	caprylic acid octanoic acid	VOC
15	pelargonic acid nonanoic acid	VOC
16	capric acid decanoic acid	VOC
17	hendecanoic acid undecanoic acid	VOC

**Listing of Chemical Substances Identified In and Around Livestock Manure
(Adapted from O'Neill and Phillips 1992) (Continued)**

	Compound (names)	EPA Classification
18	lauric acid dodecanoic acid	VOC
19	tredecanoic acid	VOC
20	myristic acid tetradecanoic acid	VOC
21	benzoic acid benzenecarboxylic acid	VOC
22	penylacetic acid phenylethanoic acid α -toluic acid	VOC
23	3-phenylpropionic acid 3-phenylpropanic acid hydrocinnamic acid	VOC
Alcohols		
24	methanol methylalcohol	HAP, VOC
25	ethanol ethyl alcohol	VOC
26	n-propyl alcohol l-propanol	VOC
27	i-propyl alcohol 2-propanol	VOC
28	n-butyl alcohol l-butanol	VOC
29	sec-butyl alcohol 2-butanol	VOC
30	isobutyl alcohol 2-methyl-l-propanol	VOC
31	pentanol n-amyl alcohol	VOC
32	i-pentanol 3-methylbutanol iso-amyl alcohol	VOC
33	l-hexanol n-hexyl alcohol	VOC

	Compound (names)	EPA Classification
34	hex-3-ene-1-ol	VOC
35	2-methy-2-pentanol demethyl-n-propyl-carbinol	VOC
36	1-heptanol	VOC
37	iso-heptanol	VOC
38	3-octanol amylethyl alcohol	VOC
39	2-ethylhexanol	VOC
40	2-methoxyethanol methyl cellosolve methyl glycol	VOC
41	2-ethoxy-1-propanol	VOC
42	2,3-butanediol	VOC
43	benzyl alcohol hydroxytoluene	VOC
44	α -methylbenzyl alcohol	VOC
45	4-methylcyclohexanol	VOC
46	2-penylethanol	VOC
Phenolics		
47	phenol carbolic acid benzenol hydroxybenzene	HAP, VOC
48	p-cresol 4-hydroxytoluene 4-methylphenol	HAP, VOC
49	m-cresol 3 hydroxytoluene 3-methylphenol	HAP, VOC
50	o-cresol 2-hydroxytoluene 3-mthylphenol	HAP, VOC

	Compound (names)	EPA Classification
51	p-methoxyphenol 4-methoxyphenol hydroquinone mono-methylether	VOC
52	o-methoxyphenol 2-methoxyphenol guaiacol	VOC
53	p-ethylphenol 4-ethylphenol 1-ethyl-4-hydroxybenzene	VOC
54	m-ethylphenol 3-ethylphenol 1-ethyl-3-hydroxybenzene	VOC
55	o-ethylphenol 2-ethylphenol 1-ethyl-2-hydroxybenzene phlorol	VOC
56	2,6-dimethyl phenol 1,3-diethyl 2-hydroxybenzene	VOC
57	3,4-dimethylphenol 1,3-dimethyl- 5-hydroxybenzene	VOC
58	3-hydroxy-2-methyl-4-pyrone lanxinic acid maltol	VOC
Aldehydes		
59	formaldehyde methanal	HAP, VOC
60	acetaldehyde ethanal	HAP, VOC
61	propionaldehyde propanal	HAP, VOC
62	acrolein 2-propenal acrylaldehyde	HAP, VOC
63	butyraldehyde butanal	VOC

	Compound (names)	EPA Classification
64	iso-butyraldehyde 2-methyl propanal	VOC
65	crotonaldehyde 2-butenal	VOC
66	valeraldehyde pentanal	VOC
67	iso-valeraldehyde 3-methylbutanal	VOC
68	2-pentenal	VOC
69	caproaldehyde hexanal	VOC
70	2-hexenal	VOC
71	oenanthaldehyde heptanal	VOC
72	2-heptenal	VOC
73	2,3-heptadienal	VOC
74	caprylaldehyde octanal	VOC
75	pelargonaldehyde nonanal	VOC
76	2-nonenal	VOC
77	2,4-nonadienal	VOC
78	capraldehyde decanal decylaldehyde	VOC
79	2,4-decadienal	VOC
80	benzaldehyde benzenecarbonal	VOC
81	acetone dimethylketone (2-)propanone	

	Compound (names)	EPA Classification
82	diacetyl dimethylglyoxal 2,3-butanedione	VOC
83	(2-)butanone methylethylketone	HAP, VOC
84	acetoin 3-hydroxy-2-butanone	VOC
85	3-pentanone diethylketone propione	VOC
86	cyclopentanone adipic ketone	VOC
87	2-methyl cyclopentanone	VOC
88	2-octanone hexylmethylketone	VOC
89	amylvinylketone 1-octene-3-one	VOC
90	acetophenone acetylbenzene methylphenylketone	HAP, VOC
Esters		
91	methylformate formic acid methyl ester	VOC
92	methylacetate acetic acid methyl ester	VOC
93	ethylformate formic acid ethyl ester	VOC
94	ethyl acetate acetic acid ethyl ester	VOC
95	propylacetate acetic acid propyl ester	VOC

	Compound (names)	EPA Classification
96	i-propylacetate acetic acid isopropyl ester	VOC
97	butylacetate acetic acid butyl ester	VOC
98	i-butylacetate acetic acid isobutyl ester	VOC
99	i-propylpropionate propanoic acid iso-propyl ester	VOC
Nitrogen heterocycles		
100	indole l-benzopyrrole	VOC
101	skatole 3-methylindole	VOC
102	pyridine azine	VOC
103	3-aminopyridine	VOC
104	(2)-methylpyrazine	VOC
105	methylpyrazine	VOC
106	trimethylpyrazine	VOC
107	tetramethylpyrazine	VOC
Amines		
108	methylamine aminomethane	VOC
109	ethylamine aminoethane	VOC
110	n-propylamine aminopropane	VOC
111	i-propylamine amino iso-propane	VOC

	Compound (names)	EPA Classification
112	pentylamine 1-aminopentane amylamine	VOC
113	trimethylamine	VOC
114	triethylamine	HAP, VOC
Sulphides		
115	carbon disulphide	HAP, VOC
116	carbonylsulphide carbon oxysulphide	HAP, VOC
117	dimethylsulphide methylthiomethane	VOC
118	diethylsulphide ethylthioethane	VOC
119	dimethyldisulphide meethydithiomethane	VOC
120	dimethyltrisulphide methylthiomethane 2,3,4-trithiapentane	VOC
121	diethyldisulphide ethylthioethane	VOC
122	dipropyldisulphide propyldithiopropane	VOC
123	methylpropyldisulphide methylthiopropane	VOC
124	propylprop-1-enyl disulphide	VOC
125	diphenylsulphide phenylthiobenzene	VOC
126	3,5-dimethyl-1,2,4- trithiolane	VOC
127	3-methyl-5-propyl-1,2,4- trithiolane	VOC
128	3,6-dimethyltetra-thiane	VOC
129	2,6-dimethylthi- 3-inc-carbonyldehyde	VOC

	Compound (names)	EPA Classification
Thiols (mercaptans)		
130	methanethiol methyl mercaptan	VOC
131	ethanethiol ethylmercaptan	VOC
132	propanethiol n-propylmercaptan	VOC
133	2-propanethiol isopropylmercaptan	VOC
134	2-propene-1-thiol allylmercaptan	VOC
135	butanethiol n-butylmercaptan	VOC
136	2-butene-1-thiol crotylmercaptan	VOC
137	benzenethiol thiophenol	VOC
138	α -toluenethiol benzylmercaptan	VOC
Unclassified		
142	sulphur dioxide	Criteria
143	methane	
144	pentane	VOC
145	2-methylpentane	VOC
146	hexane	HAP, VOC
147	hexene	VOC
148	heptane	VOC
149	octane	VOC
150	octene	VOC
151	undecene hendecene	VOC

	Compound (names)	EPA Classification
152	dodecane	VOC
153	benzene	HAP, VOC
154	toluene	HAP, VOC
155	xylene dimethylbenzene (isomer not specified)	HAP, VOC
156	indane hydrindene	VOC
157	naphthalene	HAP, VOC
158	methylnaphthalene	VOC
159	chloroform trichloromethane	HAP, VOC
160	tetrachloroethane perchloroethylene	VOC
161	hydrazine	HAP, VOC
162	2-methylfuran sylvan	VOC
163	2-pentylfuran	VOC
164	2-methylthiophene 2-methylthiofuran	VOC
165	2,4-dimethylthiophene 2,4-thioxene	VOC
166	diethylether ether ethoxyethane	VOC
167	limonene citrene carvene	VOC
168	ocimene	VOC

	Compound (names)	EPA Classification
152	dodecane	VOC
153	benzene	HAP, VOC
154	toluene	HAP, VOC
155	xylene dimethylbenzene (isomer not specified)	HAP, VOC
156	indane hydrindene	VOC
157	naphthalene	HAP, VOC
158	methylnaphthalene	VOC
159	chloroform trichloromethane	HAP, VOC
160	tetrachloroethane perchloroethylene	VOC
161	hydrazine	HAP, VOC
162	2-methylfuran sylvan	VOC
163	2-pentylfuran	VOC
164	2-methylthiophene 2-methylthiofuran	VOC
165	2,4-dimethylthiophene 2,4-thioxene	VOC
166	diethylether ether ethoxyethane	VOC
167	limonene citrene carvene	VOC
168	ocimene	VOC

Appendix E-1: Monitoring and Managing PM in CFOs

All confined feeding operations are sources of particulate emissions. However, the composition of these emissions vary. For poultry and swine, feed particles will constitute a significant fraction of particulate matter emissions because the dry, ground feed grains and other ingredients used to formulate these feeds are inherently dusty. The mass of particulate matter emitted from the confinement facilities depend on the type of ventilation and ventilation rate. Mechanically ventilated buildings will emit more PM than naturally ventilated buildings. The rate of emissions also depend on whether or not the manure is covered (USEPA 2001).

In Alberta, McGinn (2003) measured weekly average TSP concentrations 3 miles downwind of cattle feedlots near Lethbridge. Data was collected from late March to late September 1999 using a 5 µm pore vinyl chloride filter. Based on the animal capacity of the feedlot, weekly average TSP levels were:

Feedlot Capacity (head)	Weekly Average TSP (µg m ⁻³)	Comment
6,000	25.3	
12,000	53.6#	# indicates statistically significant
25,000	34.9#	differences from 6,000 head feedlot
25,000	97.2#,*	*Road dust suspect to be a contributing factor

The higher TSP concentration for the 12,000 head feedlot compared to the 25,000 lot may be due to differences in animal density. Animal densities for the 6,000, 12,000 and 25,000 head feedlots were 20, 13.3 and 25.6 m² per animal, respectively.

The CFO PM_{2.5} fraction (NRC 2003) includes NH₄⁺ aerosols produced from NH₃, nitrous oxide (N₂O) formed and released into the air via microbial processes, nitric oxide (NO) primarily release from the combustion of fossil fuels (a minor CFO source) with aerobic nitrification of soils the dominant agricultural source. Direct emissions of NO from livestock and manure are believed to be minor, but a substantial fraction of manure nitrogen applied to soils as fertilizer can be emitted as NO. The amount of NO produced by fertilizer nitrogen depends on the amount and form of nitrogen, the vegetative cover, temperature, soil moisture, and agricultural practices (e.g., tillage) (NRC 2003). Various nitrogen oxides, including NO, NO₂, nitrogen trioxide (N₂O₃), nitrogen tetroxide (N₂O₄), can formed during the fermentation of silage with airborne concentrations reaching several hundred to several thousand ppm. Fermentation occurs within hours of filling a silo and nitrogen oxides may reach lethal levels within 12 hr and persist for 2 weeks afterward (Kirkhorn et al. 2000, ATS 1998). A small fraction of NH₄⁺ and other reduced nitrogen compounds in animal manure can also be converted to NO by microbial action. Nitric oxide and nitrogen dioxide (NO₂) are rapidly interconverted in the atmosphere and are jointly referred to as NO_x. NO_x can be incorporated into organic compounds in the presence of sunlight to form compounds such as peroxyacetyl nitrate (PAN), or further oxidized to HNO₃. In turn, HNO₃ can be converted to aerosol nitrate (NO₃⁻) (e.g., by reaction with ammonia). The residence time of NO_y (all oxidized nitrogen compounds with the exception of N₂O) in the lower atmosphere is measured in days. The principal removal mechanisms are wet and dry deposition for HNO₃ and aerosol NO₃⁻. NO₃⁻ is a contributor to PM_{2.5} formation (NRC 2003).

Appendix F-1: Odour Complaint Investigation and Odour Management

In 2005, the Alberta Environment Ambient Air Quality Objective Working Group endorsed the recommendation of the Reduced Sulphur Compound Subgroup on the need to develop a provincial odour management work. Further, the Working Group recommended that the development of an Odour Management Framework begin with the CASA CFO subgroup. The Working Group drafted Terms of Reference for an Odour Management Framework, see Appendix F-4.

Odour Management Frameworks can be either quantitative or qualitative, or both, and provide a systematic and transparent process for investigating and possibly mitigating odour complaints and sources. New Zealand (<http://www.mfe.govt.nz/issues/air/programme/odour.html>) is an example of a well developed qualitative approach to odour investigation and mitigation.

The New Zealand approach (2002, 2003) is qualitative and consists of FIDOL, an acronym for Frequency, Intensity, Duration, Offensiveness and Location. Investigations by trained field inspectors assess these variables, which includes both personal assessment and stakeholder interviews, in determining whether an odour nuisance requiring mitigation exists. **Frequency** assesses how often an individual is exposed to odour (e.g., hourly, daily, weekly, etc.), **intensity** the strength of the odour, **duration** the length of a odour events, **offensiveness** the character of the odour that relates to the 'hedonic tone' of the odour, which may be pleasant, neutral or unpleasant, and **location** references the type of land use and nature of human activities in the vicinity of an odour source (e.g., rural or urban residential, commercial, industrial, recreational). The investigation process can include complainant interviews, community meetings, odour diaries, panel), meteorological and topographic considerations, and dialogue with and actions by the odour emitter. The assessment process can be both reactive and proactive in nature. Proactively, the odour assessment process can be used to assess whether the proposed development is suitable or engineering controls are sufficient. Finally the various outcomes of an investigation can include mitigative requirements, which can, if required, take the form of an enforcement order.

FIDOL provides a qualitative approach to community odour investigation, however, two quantitative approaches to odour assessment can be also be used. These alternative approaches can be used either independently or in concert with FIDOL. The 2 approaches are to (1) measure the concentration of individual odourant constituents in air and compare it to an ambient air quality objective or standard or an odour threshold or (2) subjectively determine the odour concentration in odour units, or OUs, in the air. One OU is defined as the concentration of a substance at the odour detection threshold, which is the concentration at which 50% of a trained panel detects an odour. For a sample of collected ambient air, the dilution at which 50% of a panel detects an odour is the number of OUs in the sample. For example, if a sample of air diluted by 500x with odour free air is detected by 50% of the panel then the air contains 500 odour units. OUs are often expressed as OUs per cubic metre of air. This technique can also be applied to quantitative measurements (JWEL 2003). For instance, the Alberta objective for H₂S is 10 ug/m³ 1-hour average based on the odour threshold. An ambient air measurement of 40 ug/m³ indicates 4 O.U.s in the air. Other commonly cited odour unit are D/T or Dilution Threshold, OUE (European Odour Units), OC (Odour Concentration). All of these units are conceptually equivalent in that 1 OU = 1 OU/m³ = 1 OUE/m³ = 1OC = 1 D/T. However, differences in measurement methodologies can lead to differences in the measured odour concentration (RWDI 2005).

Measuring individual odour concentrations in air can be expensive and limited in functionality. Odours from CFOs are determined by a myriad of compounds. The ability to measure individual odourants will be technologically limited in number and is unlikely to represent the full odour potential of emissions. Although such an approach may be helpful in assessing ambient odours, it is likely to be limited in scope and expensive. Although Schaefer in 1977 CFO study (NRC 2003) correlated 13 compounds with odour intensity measured by a mobile olfactometer and found odour intensity had the highest correlation with *p*-cresol. Hobbs in a 2001 study (NRC 2003) found that determining the odour intensity of 4 gases, H₂S, NH₃, acetic acid and 4-methylphenol, would be a suitable approach.

Various U.S. states have developed OU based air quality standards or guidelines to quantitatively manage odour sources (Iowa 2006). These standards or guidelines are generally applied at the source property line using commercially available portable olfactometers or scentometers. Wyoming Department of Environmental Quality requires that air at the property line be undetectable at 7 dilutions. Colorado in Regulation Number 2 regarding Housed Commercial Swine Feeding Operations (Subpart III) requires undetectable odour at 7 dilutions at the property line or 2 dilutions for offsite receptor locations such as a home, school, and business or at the boundaries of an incorporated municipality that has not waived protection. Other states stipulating no odours at 7 dilutions at the property line or beyond are North Dakota and Kentucky. Nevada defines an objectionable odour as requiring an investigation when at 30% or more of people at their usual places of occupancy complain. A violation is declared when 2 odour measurements made within a 1 hour period contain 8 or more OUs. Illinois defines an objectionable odour nuisance at the property line or at the nearest premise as occurring when 8 or more OUs are measured on or adjacent to a residence, institution, hotel, school, business place or recreational premise. For industrial premises the standard is 25 OUs. In all circumstances the determination must be made by 3 trained inspectors for air samples collected within a 1 hour period that results in at least 2 positive determinations.

Odour emissions from CFOs, in OUs per cubic meter of air, can also be dispersion modeled. In Alberta, Jacques Whitford Environmental Limited (JWEL 2003), under contract to NRCB, used dispersion modeling and odour emission estimates for a 600-sow farrow-to-finish operation with a liquid manure handling system to estimate downwind OU levels. The purpose of the study was to refine 3 dilution factor inputs used in 2 formulas of Schedule 2 of the Alberta Agricultural Operation Practices Act, Standards and Administration Regulation (2002), to calculate odour-based Minimum Distance Separations (MDS) for siting new or expanding existing CFOs. For this study, an acceptable odour criterion for the most restrictive land use, Category 4 or development in proximity to a hamlet, village or town, was set at 2 OU 24-hour average.

For dispersion modeling, New Zealand applies sensitivity ratings ranging from high (unstable or semi-stable meteorology) and a guideline of 1 OU/m³ occurring 0.1 (infrequent source) and 0.5% (constant source) of the time to low sensitivity ratings (all meteorological conditions) and a guideline of 5-10 OD/m³ for 0.5% of the time.

Details of the Australian quantitative approach to odour investigation and mitigation is available at <http://www.epa.nsw.gov.au/air/odour.htm>. Acceptable odour criteria range from 7 OUs for a single affected residence to 2 OUs for larger population centers (<2000 population) (Australia 2006, 2006a).

Table 1, from RWDI (2005), summarizes odour based standard or guidelines from North America, Europe, Australasia and Asia. Note that the OU criteria often have an averaging time of a few

seconds or minutes. This is because the human nose is very responsive to odours lasting only a few seconds. Most of the odour criteria are 2, 5 or 7 OUs. Two OUs is considered a background concentration for ambient air and is regarded as a low odour strength that does not cause odour nuisance complaints. The OU criteria are also often associated with frequency criteria. A frequency criterion of 99% requires that 99% or more of the modeling results for a one year period would not exceed the acceptable OU level (exceedences must occur ≤ 1 % of the time) (JWEL 2003).

The above RWDI (2005) report is a comprehensive review of quantitative and qualitative approaches to odour management, including a summary of Minimum Distance Separations for CFOs from across the world.

Appendix F-2: CFO Odour Sources and Generation

The primary sources of odour emissions from CFOs include (JWEL 2003):

- Production facilities (housing units and open lots)
- Manure and wastewater storage and treatment systems (lagoons, pits, ponds, lagoons, composters)
- Land application of solid, liquid or treated waste and open lot runoff.

Gases arising from the anaerobic decomposition of manure include H₂S, methane, NH₃, and many volatile and semivolatile organic compounds. Livestock wastes have as many as 168 volatile organic compounds and volatile fatty acids, the most important contributors to odours, besides NH₃, are volatile fatty acids (acetic, propionic, formic, butyric, valeric), phenols, *p*-cresole, indoles, volatile amines, methyl mercaptan, and skatoles (Kirkhorn 2000, EPA 2001). Odourous volatile fatty acids may be more offensive than NH₃ or H₂S (Cole 2000). CFO odours are minimized when conditions for aerobic decomposition are maintained (EPA 2001). Under aerobic conditions, wastes are oxidized to CO₂ and water. Well managed anaerobic decomposition requires that (1) complex organic wastes are degraded to simpler organic compounds, some of which are volatile, and (2) these compounds are degraded by methanogenic bacteria to methane and CO₂. Conditions which inhibit methanogenic bacteria, and promote the formation and volatilization of organic compounds, are low temperatures or excessive loading rates of volatile solids in liquid storage facilities.

VOC emissions will be minimized from properly designed and operated stabilization processes, such as anaerobic lagoons, and the associated manure application site. Properly designed and operated anaerobic lagoons should have relatively low odour emissions. However, odour emissions can increase and become problematic during seasonal transitions, such as spring and fall, when sudden temperature changes can upset the microbial balance, and if lagoons are overloaded with organic waste. VOC emissions will be higher from storage tanks, ponds, overloaded anaerobic lagoons, and during land application of wastes. Odours from dry lots can be produced with combined warm temperatures and wet conditions (e.g., rain) which promotes the development of transient anaerobic conditions (EPA 2001).

The following variables have been identified as important determinants of odour emissions (EPA 2001):

- Wet (anaerobic)/dry (aerobic) manure management systems: Liquid or slurried manure handling systems promote anaerobic conditions that promote the formation and release of H₂S and VOCs. NH₃ formation can occur in both wet and dry manure. Nitrous oxide formation is promoted when the manure is first handled in a dry state and then becomes wet or damp (transient anaerobic conditions).
- pH. Manure pH affects the partitioning of NH₃ and H₂S between volatile or gaseous states and their nonvolatile ionized forms (NH₄⁺ and HS⁻).
- Temperature. Higher temperatures promote volatilization (i.e., higher temperatures increase a substance's vapour pressure) and microbial metabolism, promoting the development of anaerobic conditions and the formation of odourous decomposition byproduct.
- Time in storage. Long term manure confinement and storage promotes the development of anaerobic decomposition, with increased rates of odourous byproducts formation and release.
- Precursors. Nutritional feeds and additives with increased amounts of sulfur can promote H₂S formation. Feeds high in nitrogen (e.g. proteins and amino acids) can promote NH₃ and nitrous oxide formation. The amount of carbon can affect methane and carbon dioxide

formation. The potential for emissions can be minimized by selecting feedstuffs with a composition that does not exceed the nutritional requirements of the animals. However, Zahn 2001 cites a 1997 study by Obrock-Hegel where airborne NH₃, cresol and indole levels were reduced by nutritional manipulation of amino acid intake but there was no reduction in odour intensity compared to the controls.

Zahn (2001) cites a 1997 study by Jacobson et al. who surveyed H₂S and odour emissions from ~60 different pig, dairy, beef and poultry manure storage units in Minnesota farms. Jacobson et al. categorized data based on animal species and type of manure management system (pit, basin, lagoon). Low correlation was observed between H₂S and odour concentration based on the categories. Which suggests that H₂S is not a suitable indicator of odour.

The operational variables affecting emissions at CFOs are summarized in Table 1.

Table 1: Factors That Increase Emissions (Source EPA 2001)

Substance Emitted	Wet Manure Handling	Dry Manure Handling	pH	High Temperature	Manure Residence Time	Precursors
Ammonia			>7.0	✓	✓	Nitrogen
Nitrous Oxide		✓				Nitrogen
Hydrogen Sulfide	✓		<7.0	✓	✓	Sulfur
Methane	✓			✓	✓	Carbon
VOC	✓			✓	✓	Carbon
Particulate Matter ¹		✓				

¹ Total suspended particulate. Fine particles (PM_{2.5}) in the form of ammonium sulfate and ammonium nitrate can be secondarily formed in the atmosphere from ammonia emissions; if sulfur oxides or nitrogen oxides are present in the air.

Odourous compounds often adsorb onto PM₁₀ dust particulates (Cole 2000). Workers using particulate filter respirators in swine confinement buildings find the air rendered odourless by this phenomenon. Without the respirator, particulates are deposited or filtered out in the nose and odourous compounds are released onto the mucous membranes, enabling odour perception.

Odourants can exist in much higher concentrations in the dust particles than in equivalent volumes of air (Bottcher, 2001). Thus, inhalation of odourous dust and deposition of the dust particles in the mucous overlying the olfactory mucosa are likely responsible for odour related complaints by swine farm neighbors.

Table 1: Global Odour-Based Ambient Air Quality in Odour Units (OU/m³, OU, OU_E/m³) or Dilutions to Threshold (D/T) (Source: RWDI 2005)

JURISDICTION	OFFSITE STANDARD OR GUIDELINE	AVERAGING TIME	FREQUENCY CRITERIA	LAND USE	SOURCE TYPE	USE (PERMIT, GUIDANCE ETC.)	OTHER COMMENTS
NORTH AMERICA							
Allegheny County Sanitation District (Pennsylvania, USA) ^{kl}	4 D/T	2 minutes	<50 hours/year non-compliance	Residential with highway	Wastewater treatment plant	Design goal	Model output adjusted from 60- to 2-minute averaging time using a factor of 2
Bay Area Air Quality Management District (California, USA) ^g	5 D/T			Fence-line		Standard	Applied after at least 10 complaints within a 90-day period
California Air Resources Board (California, USA) ^{h, n}	5 D/T			Property line	Wastewater treatment plant	Not a statewide requirement – has been used for WWTPs	
Central Contra Costa County Sanitary District (California, USA) ^l	4 D/T		<100 hours/year non-compliance	Industrial with some residential and highway	Wastewater treatment plant		
City of Calgary (Canada) ⁱ	20 D/T		<100 hours/year non-compliance	Rural with growing residential	Wastewater treatment plant		
City of Oakland (California, USA) ^g	50 D/T	3 minutes					
City of Philadelphia (Pennsylvania, USA) ^j	20 D/T		<100 hours/year non-compliance	Residential	Wastewater treatment plant		
City of San Diego WWTP (California, USA) ^a	5 D/T	5 minutes	99.5% compliance	At plant fence-line	Wastewater treatment plant		Model output adjusted from 60- to 5-minutes using factor of 2.29
City of Seattle WWTP (Washington, USA) ^a	5 D/T	5 minutes			Wastewater treatment plant		

JURISDICTION	OFFSITE STANDARD OR GUIDELINE	AVERAGING TIME	FREQUENCY CRITERIA	LAND USE	SOURCE TYPE	USE (PERMIT, GUIDANCE ETC.)	OTHER COMMENTS
Colorado (USA) ^f	7 D/T			Residential or commercial	Anything but manufacturing process or agricultural operation	Regulation	Barnebey-Chaney Scentometer: 2 measurements taken at least 15 minutes apart in one hour
	15 D/T			Other land uses			
	127 D/T			All			
	7 D/T			Property Boundary	Housed Commercial Swine Feeding Operations		
	2 D/T			Any receptor (occupied dwelling, school, place of business or boundaries of a municipality)			
Connecticut (USA) ^l	7 D/T			Beyond property boundary			Scentometer: 3 samples or observations in one hour separated by 15 minutes
East Bay Municipal Utility District (California, USA) ^l	50 D/T		<10 hours/year non-compliance	Industrial turning into residential	Wastewater treatment plant		Phase 1 of odour control
	20 D/T		<100 hours/year non-compliance				Phase 2 of odour control
Iowa (USA) ^e	15 D/T	2 hours		Odour at CFO property line.		Recommended Standard	This concentration can be exceeded up to 14-days per year with 48 hour notice
	7 D/T			Odour at residence or public use area.			Exceedance = 2 excessive measurements separated by 4 hours in one day

JURISDICTION	OFFSITE STANDARD OR GUIDELINE	AVERAGING TIME	FREQUENCY CRITERIA	LAND USE	SOURCE TYPE	USE (PERMIT, GUIDANCE ETC.)	OTHER COMMENTS
Kankakee Wastewater Utility (Illinois, USA) ^j	4 D/T	2 minutes			WWTP		ISC model output was adjusted from 60- to 2-minute impact time using a factor of 2
Kentucky (USA)	7 D/T						Scentometer
King County (Washington, USA) ^j	0 – 3 D/T		<50 hours/year exceeding threshold			Recommended policy for <u>new</u> WWTPs	
	0 – 5 D/T		<100 hours/year exceeding threshold			Recommended policy for <u>existing</u> WWTP retrofits	0-3 routine operating range, 3-5 non-routine operating range
Manitoba (Canada) ^p	2 OU	2 tests not less than 15 minutes apart nor more than 60 minutes apart		Residential Zone		Guideline – maximum acceptable level	
	7 OU			Industrial Zone		Guideline – maximum acceptable level	
	<1 OU					Guideline – maximum desirable level	Less than the odour threshold
Massachusetts (USA) ^{ku}	5 D/T	1 hour		Offsite	Composting	Draft guidance	Converted to lower averaging times by power law equation, case-by-case. Draft policy. Regional agencies can set more stringent limits based on site-specific conditions

JURISDICTION	OFFSITE STANDARD OR GUIDELINE	AVERAGING TIME	FREQUENCY CRITERIA	LAND USE	SOURCE TYPE	USE (PERMIT, GUIDANCE ETC.)	OTHER COMMENTS
Missouri (USA) ^q	5.4 D/T			At the property line			Department of Natural Resources
New Jersey (USA) ^{rl}	5 D/T	5 minutes or less		At sensitive receptor with the highest impact as predicted by dispersion modelling	For biosolids/ sludge handling and treatment facilities		Alternative for existing facilities is to remove 95% of target odour-causing compounds such as H ₂ S or NH ₃ and achieve an outlet concentration below the individual compound thresholds
North Carolina (USA) ^j	4 D/T	30 seconds			Composting facility	"conservative nuisance threshold"	ISCST model output adjusted to 30-second averaging time using a factor of 1.97
North Dakota (USA) ^q	2 D/T			Fence-line			Scentometer
Ontario (Canada) ^q	1 OU/m ³	10 minutes		At the most impacted Sensitive Receptor			Proposed standard
Orange County Sanitation District (California, USA) ^j	20 D/T		<100 hours/year non-compliance	Residential with highway	Wastewater treatment plant		
Palm Beach County Solid Waste Authority (Florida, USA) ^j	7 D/T			Property line	Composting facility		No statewide requirement

JURISDICTION	OFFSITE STANDARD OR GUIDELINE	AVERAGING TIME	FREQUENCY CRITERIA	LAND USE	SOURCE TYPE	USE (PERMIT, GUIDANCE ETC.)	OTHER COMMENTS
Portland (Oregon, USA) ⁵¹	1 to 2 D/T	15 minutes				Considered a nuisance	Measured with scentometer. Odour with duration < 15 minutes is exempt.
Sacramento County Regional Sanitation District (California, USA) ¹	20 D/T		<100 hours/year non-compliance	Rural with growing residential	Wastewater treatment plant		
Wyoming (USA) ⁴	7 D/T						
Yountville (California, USA) ¹	4 D/T		<100 hours/year non-compliance	Golf course	Wastewater treatment plant		
AUSTRALASIA							
New Zealand ⁵¹	1 OU/m ³	1 hour	99.5% compliance	-high-density residential - light commercial / retail / business / education / institutional		Interim odour-modelling guideline	Worst-case impacts during unstable to semi-unstable conditions
	2 OU/m ³	1 hour	99.9 % and 99.5%	- open space / recreational - tourist / conservation / cultural / marae			Worst-case impacts during neutral to stable conditions
	5 OU/m ³	1 hour	99.9 % and 99.5%	- rural residential (low density) - light industrial			All conditions
	5 OU/m ³	1 hour	99.5%	- rural land - heavy industrial			All conditions

JURISDICTION	OFFSITE STANDARD OR GUIDELINE	AVERAGING TIME	FREQUENCY CRITERIA	LAND USE	SOURCE TYPE	USE (PERMIT, GUIDANCE ETC.)	OTHER COMMENTS
New South Wales (Australia) ⁴	2 OU/m ³	0.1-1 second	99 th percentile	Urban area (≥2,000 people)		Criteria are not used in permits. They are used for new facility design.	Odour performance criteria shall be applied at the nearest existing or likely future off-site sensitive receptor based on population density (see Eqn. 3.2 of NSW, 2001). NSW also has criteria for individual pollutants.
	3 OU/m ³	0.1-1 second	99 th percentile	500 to 2,000 people			
	4 OU/m ³	0.1-1 second	99 th percentile	125 to 500 people			
	5 OU/m ³	0.1-1 second	99 th percentile	30 to 125 people			
	6 OU/m ³	0.1-1 second	99 th percentile	10 to 30 people			
	7 OU/m ³	0.1-1 second	99 th percentile	Single residence (<=2people)			
Queensland (Australia) ⁵²	2.5 OU	1 hour	99.5% compliance		Developments with ground level sources or short stacks		
	5 OU	1 hour	99.5% compliance		Developments with tall stacks		
	10 OU	1 hour	99.5% compliance				
South Australia (Australia) ⁷	2 OU	3 minutes	99.9% compliance	2,000 or more people		These are guidelines used for determining setback distances. They are not enforceable per se.	
	4 OU	3 minutes	99.9% compliance	350 or more people			
	6 OU	3 minutes	99.9% compliance	60 or more people			
	8 OU	3 minutes	99.9% compliance	12 or more people			
	10 OU	3 minutes	99.9% compliance	Single residence (<12 people)			

JURISDICTION	OFFSITE STANDARD OR GUIDELINE	AVERAGING TIME	FREQUENCY CRITERIA	LAND USE	SOURCE TYPE	USE (PERMIT, GUIDANCE ETC.)	OTHER COMMENTS
Tasmania (Australia) ^a	1 OU/m ³	3 minutes	99.9% compliance				Tasmania also has criteria for individual pollutants
Victoria (Australia) ^d	1 OU/m ³	3 minutes	99.9% compliance				
Western Australia (Australia) ^e	2 OU/m ³	3 minutes	99.5 th percentile	Sensitive land uses, e.g. residences, hospitals, schools, play grounds, aged care facilities etc.	Other than poultry farms	Used to determine setback distances for new proposals or expansion only	2 and 4 OU/m ³ are screening criteria – if both of these are met, no further assessment of odour is needed. If the screening criteria are not met, the proponent has to undertake an odour intensity study to determine whether the “distinct” odour criterion is met (see Table 2-13).
	4 OU/m ³	3 minutes	99.9 th percentile		Poultry farms		
EUROPE							
Austria ^b	1 OU/m ³		92% compliance				
	3 OU/m ³		97% compliance				

JURISDICTION	OFFSITE STANDARD OR GUIDELINE	AVERAGING TIME	FREQUENCY CRITERIA	LAND USE	SOURCE TYPE	USE (PERMIT, GUIDANCE ETC.)	OTHER COMMENTS
Denmark ^d	5 - 10 OU/m ³	1 minute	99% compliance	Residential areas outside the plant site (limit in industrial and rural areas may in some cases be increased by a factor of 2-3)			Equivalent 60-min. average standard is 0.6 - 1.2 OU/m ³ . Calculated as the average of anticipated peak values in neutral to moderately unstable conditions with a wind speed of 4.5 m/s.
Ireland ^f	1.5 ou ₆ /m ³	1 hour	98%	all	All pig production units	Licensing	Target Value - draft
	3.0 ou ₆ /m ³	1 hour	98%	rural	New pig production unit	Licensing	Limit Value - draft
	6.0 ou ₆ /m ³	1 hour	98%	rural	Existing pig production unit	Licensing	Limit Value - draft
Newbiggin-by-the-Sea & Debby WWTPs (UK) ^g	5 OU/m ³		98% compliance		Wastewater treatment plant		
The Netherlands ^h	>>5 ou ₆ /m ³	1 hour	98%		Bakeries	Used in permitting process to compare with results of dispersion models or nomograms used to calculate dispersion of emissions calculated using emission factors.	No limit value
	2.5 ou ₆ /m ³	1 hour	98%	Built-up areas or other objects sensitive to odours	Meat Processing		Limit value
	0.95 ou ₆ /m ³	1 hour	98%				Target value
	2.5 ou ₆ /m ³	1 hour	98%	Built-up areas etc.	Grass dryers		Limit value
	5 ou ₆ /m ³	1 hour	98%	Built-up areas etc.	Bakeries, pastry		Target value
	3.5 ou ₆ /m ³	1 hour	98%		Coffee roasters		Limit value for existing facilities (limits lower for new facilities)
	3.5 ou ₆ /m ³	1 hour	98%	Built-up areas etc.	Flavours & fragrances		Limit value
	2.0 ou ₆ /m ³	1 hour	98%				Target value

JURISDICTION	OFFSITE STANDARD OR GUIDELINE	AVERAGING TIME	FREQUENCY CRITERIA	LAND USE	SOURCE TYPE	USE (PERMIT, GUIDANCE ETC.)	OTHER COMMENTS	
The Netherlands ⁶⁰	0.5 ou _g /m ³	1 hour	98%	Densely populated residential areas	WWTP, greenfield site		Limit value	
	1.0 ou _g /m ³	1 hour	98%	Rural area or industrial estate	WWTP, greenfield site		Limit value	
	1.5 ou _g /m ³	1 hour	98%	Densely populated residential areas	WWTP, existing site		Limit value	
	3.5 ou _g /m ³	1 hour	98%	Rural area or industrial estate	WWTP, existing site		Limit value	
	1 ou _g /m ³	1 hour	98%	Densely populated residential areas	Livestock feed production		Limit value	
	1.5 ou _g /m ³	1 hour	98%	Residential area or other sensitive receptors	Composting, organic fraction of domestic waste, greenfield site		Limit value	
	0.5 ou _g /m ³	1 hour	98%				Target value	
	3.0 ou _g /m ³	1 hour	98%		Composting, organic fraction of domestic waste, existing facility		Limit value	
	1.5 ou _g /m ³	1 hour	98%				Target value	
		1.5 ou _g /m ³	1 hour	98%	Built up areas	Slaughterhouses		Limit value
		0.55 ou _g /m ³	1 hour	98%	Built up areas			Target value
	1.5 ou _g /m ³	1 hour	98%	Sensitive receptors	Large breweries		Limit value	
Wales ⁶¹	5 to 10 ou _g /m ³			Property boundary	Sewage treatment plants			
ASIA								
Hong Kong (Siu Ho Wan WWTP) ⁶²	5 OU	5 seconds			Wastewater treatment plant			
Korea ⁶³	20 OC			Plant boundary	Companies in industrial areas		Measure using "Air Dilution Sensory Test" described in Park (2003)	
	15 OC			Plant boundary	Companies in other areas			
JURISDICTION	OFFSITE STANDARD OR GUIDELINE	AVERAGING TIME	FREQUENCY CRITERIA	LAND USE	SOURCE TYPE	USE (PERMIT, GUIDANCE ETC.)	OTHER COMMENTS	
Taiwan ⁶⁴	50 OU/m ³				Petrochemical park			

⁶⁰ Mahin (2001)

⁶¹ Schauberg et al. (2001)

⁶² South Australia EPA (2003)

⁶³ NSW EPA (2001a)

⁶⁴ Osterberg and Melvin (2002)

⁶⁵ Colorado Air Quality Control Commission (1999)

⁶⁶ Miedema et al. (2000)

⁶⁷ Park (2003)

⁶⁸ Ireland EPA (2001)

⁶⁹ Mahin et al. (2000)

⁷⁰ Welsh Assembly (2005)

⁷¹ King County (2003)

⁷² Western Australia EPA (2002)

⁷³ Witherspoon et al. (2004)

⁷⁴ InfoMil (2003)

⁷⁵ Manitoba Conservation (2005)

⁷⁶ New Zealand Ministry for the Environment (2002)

⁷⁷ Queensland EPA (2004)

Appendix F-3: Executive Summary from RWDI 2006

“The objective of this report is to provide the Ministry of Water, Land and Air Protection (WLAP), the Greater Vancouver Regional District (GVRD), and the other members of the Steering Committee with recommendations for odour management approaches that would be effective in British Columbia (BC), based on a review of successful odour management programs in other jurisdictions.

A review of odour management programs in jurisdictions around the world was conducted. It was found that there are ten different approaches that are used to manage odour.

Avoidance of Nuisance Laws: This type of law is based on either “nuisance” or “quality of life” narrative standards. The exact wording varies from jurisdiction to jurisdiction but essentially requires that odour from a facility will not result in a nuisance or cause pollution. This is the most common and oldest approach to managing odours. Odour regulations in 42 of the 50 states in the United States of America (USA) are of this type. Six of the jurisdictions that were interviewed have a law that is related to odour nuisance.

2. **Ambient concentration criteria for individual chemicals:** Many jurisdictions in North America and a few elsewhere in the world have quantitative ambient concentration criteria for individual chemicals that are odorous. The regulatory status of these criteria varies from guidelines or objectives to enforceable standards. Of the jurisdictions that were interviewed, four had ambient concentration criteria for specific chemicals.

3. **Ambient concentration criteria for odour:** Odour can be measured using an odour panel, which consists of a number of specially trained personnel, and an olfactometer. The general concept is to dilute a sample with odour free air until it can be detected by only 50% of the odour panel. The most common units for odour concentration are dilution to threshold (D/T) and odour units (OU). Ambient odour concentration criteria are used to manage odour in numerous jurisdictions in North America, Australasia, Europe, and Asia. Of the jurisdictions that were interviewed, six use ambient odour criteria. In many jurisdictions these criteria are used for design purposes only, not for enforcement.

4. **Episode duration-frequency:** Germany has a unique system for assessing whether an odour nuisance is significant that considers not only the intensity of an odour but also its duration and frequency. They assess the existing odour impact in the field, using a systematic process that is described below, and add to it the predicted odour impact of a new or modified facility. The total odour impact is compared with **immission** limit values, which are relative frequencies of odour-hours.

5. **Minimum separation distances:** Many jurisdictions manage nuisance, including odours, using fixed or variable minimum separation distances or buffer zones. South Australia has minimum separation distances for a large number of industries and types of facility. However, in most jurisdictions the use of separation distances is limited to agricultural sources, sewage treatment plants and composting. Of the jurisdictions that were interviewed, five use minimum separation distances.

6. **Odour intensity scales:** A number of jurisdictions have developed semi-quantitative odour intensity scales to assist field personnel when they are investigating an odour complaint. Odour intensity scales are used as guidelines. Three of the jurisdictions that were interviewed have odour intensity scales.

7. **Odour index:** The “Odour Index” is used in Japan to quantify the intensity of odours. The odour index is equal to ten times the log of the odour concentration. It differs from an odour intensity scale because it is a calculated value.

8. **Complaint criteria:** Most jurisdictions have a system in place for responding to odour complaints. In many cases, there is a policy to respond to all complaints. In some jurisdictions, such as Wellington, New Zealand, the Bay Area Air Quality Management District (BAAQMD) and Minnesota, there are complaint criteria in terms of a minimum threshold of complaints required before an investigation is launched or an odour is considered a nuisance. Some jurisdictions clearly set out how they will determine whether a complaint is justified or verified.

9. **Quantitative emission criteria:** Seven jurisdictions were found to have quantitative emission criteria for either odour or for specific chemicals. Four of these jurisdictions were interviewed. The other jurisdictions that have emission criteria but were not interviewed are Korea, Denmark and Switzerland. The format of the emission criteria appears to be different for each jurisdiction.

10. **Technology criteria:** Many jurisdictions have requirements for implementation of state-of-the-science control technology or similar approaches that specify required levels of odour treatment controls or best management practices for new or existing facilities. These requirements are mostly qualitative in nature. Four of the jurisdictions that were interviewed have technology criteria.

To determine which of these approaches have been successfully applied, nine jurisdictions were interviewed using a standard set of questions that was developed in consultation with the Steering Committee.

1. **Ontario, Canada:** Ontario does not have an odour management program per se. It has a nuisance law that forbids the discharge of a contaminant that may cause an adverse effect and odour is included in the definition of a contaminant. Ontario also has a number of points of impingement (POI) standards and guidelines and ambient air quality criteria (AAQC) that are odour-based. In addition, there is a proposed ambient odour limit of 1 OU/m³ that has been used to-date on a case-by-case basis. Finally, Ontario makes use of minimum distance separation guidelines for agricultural operations and sewage treatment plants.

2. **Bay Area Air Quality Management District, California, USA:** The BAAQMD considers its odour management program to be successful. Its odour management framework consists of a nuisance law, quantitative ambient concentration limits for individual chemicals and odour, complaint criteria, and quantitative emission criteria. The BAAQMD has considerable resources with a staff of 350 with over 100 inspectors and field personnel as well as a team of lawyers who prosecute court cases. As a result, the most effective element of their odour management framework has been the general odour nuisance law and associated good case law.

3. **King County, Washington, USA:** The King County Department of Natural Resources and Parks Wastewater Treatment Division has an Odour Prevention Policy that defines odour prevention levels and includes recommendations for retrofitting existing facilities and for designing new facilities. The focus is on odour prevention not just odour control. One of the most interesting features of this policy is that it includes a number of methods of measuring the success of the program. To date, this program has been successful.

4. **New South Wales, Australia:** New South Wales (NSW), Australia has a very comprehensive policy for assessing and managing odour from stationary sources. It includes an over-arching nuisance law, odour performance criteria, a three-level system of odour impact assessment, avoidance and mitigation strategies, negotiation between stakeholders, performance monitoring and complaint management, and regulation and enforcement options. Although this policy is still in draft form, it has been implemented since it was released in 2001. The odour management program set out in the policy is considered to be a big improvement on the previous ad-hoc system and is believed to be successful.

5. **South Australia:** The primary tool that South Australia uses to manage odour is minimum separation distance, both fixed and variable. A more detailed odour impact assessment using dispersion models may be required for development applications depending on the size or nature of the industry, the sensitivity of the location or the sensitivity of neighbouring receptors. South Australia also has a nuisance law, ambient odour criteria, and technology criteria. The odour management program of this jurisdiction is considered to be successful.

6. **Wellington, New Zealand:** The Wellington Regional Council developed an Air Quality Management Plan for the Wellington Region that includes odour. They make use of technology criteria in the form of the “Best Practicable Option” to prevent or minimize adverse effects. They do not have ambient or emission criteria but they could include an emission limit in a permit. They also have an odour intensity scale that is used by inspectors in the field. They also have a minimum threshold of 10 complaints before responding for facilities with chronic odour problems. This odour management program is not considered to be successful.

7. **Germany:** Germany has a unique approach to managing odours that incorporates all of the Frequency, Intensity, Duration, Offensiveness, Location (FIDOL) factors. The frequency, duration and intensity are measured using odour-hours. The immission limit values used to evaluate the measured odour-hours differ depending on the land use (residential vs. industrial and commercial). Recently, a system was developed to assess the hedonic tone or offensiveness of the odour as well. Pleasant odours are treated differently from neutral or unpleasant odours because they are less annoying. Several other approaches are also used to manage odours in Germany including an odour nuisance law, minimum separation distances (used primarily for agricultural and waste sources), an odour intensity scale, and quantitative emission criteria. The German odour management program is considered to be successful.

8. **The Netherlands:** The Netherlands has a relatively prescriptive, source-specific approach to managing odours. Some of the most interesting features of their approach are: the ambient odour criteria reflect the degree of offensiveness of the odour: criteria are more stringent for industries that emit odours that are more unpleasant; for many industries, emission factors have been developed for use in assessing the odour impact of a facility; source-specific odour abatement measures are provided; the licensing authority can revise existing permits as a result of new insights, facts or circumstances; and biannual national surveys are conducted to gauge the level of annoyance due to odours. The odour management program in the Netherlands is successful.

9. **Japan:** The odour management program in Japan is quite different from that of any other jurisdiction that was interviewed. The program itself is embodied in a national law. There are a number of ambient and emission standards that are enforceable by law and significant penalties for

disobeying the law. There are also detailed measurement methodologies. They consider their odour management program to be successful at addressing issues related to large industry but not those related to household activities or smaller businesses.

Air quality complaints to BC regulatory agencies are frequently related to odour concerns. Sources of concern in BC include pulp and paper mills, petroleum refineries, fibre-reinforced plastic manufacture, auto body shops, rendering plants, agricultural activities, feed manufacture, composting operations, and landfills. A great deal of time and resources are expended by regulatory agencies in addressing odour-related complaints, which in many cases are not effectively resolved.

There are currently a number of regulatory agencies in BC that are involved in managing odour issues in the province. Under the authority of the provincial Environmental Management Act and GVRD Bylaw No. 937, WLAP and the GVRD are responsible for managing air quality, which can include odour issues. Pursuant to the Farm Practices Protection (Right to Farm) Act, the Ministry of Agriculture, Food and Fisheries (MAFF) is assigned the responsibility to resolve nuisance concerns, including odour concerns, relating to farm operations. Individual municipalities may also manage odour issues within their boundaries, typically relating to commercial or residential sources.

The GVRD has recently published a draft Odour Management Strategy that consists of a comprehensive, six-level approach to resolve odour issues in that jurisdiction. The nature, severity, frequency and duration of specific odour problems, as indicated by the number of complaints and information gathered via inspection, determine the level of enforcement action. The draft Strategy clearly communicates to operators of odour-emitting sources and to the public how the GVRD intends to resolve odour problems as they occur.

New composting facilities in BC are regulated by the Organic Matter Recycling Regulation (pursuant to the Environmental Management Act and the Health Act) that requires that plans and specifications for new composting facilities must include an odour management plan. The accompanying “Compost Facility Requirements Guideline” points out that the least cost odour control option is to initially design the facility to reduce odours to the lowest possible level. The underlying principle is that *“it is much better to prevent odours proactively than to play catch up after an odour problem has already occurred.”*

The following recommendations were developed based on our understanding of which approaches might be successfully applied in British Columbia.

1. Air quality regulators in BC could develop an odour management program that incorporates a combination of several approaches, both reactive and proactive, that have proven to be successful in other jurisdictions, such as a nuisance law, ambient odour concentration criteria for design purposes, complaint criteria and technology criteria.
2. The Environmental Management Act definitions could be amended to refer to offensive odour as a substance that is controllable.
3. The Ministry of Water, Land and Air Protection could develop an odour complaint logging process that may include an odour hotline as well as a complaint database.
4. As a proactive measure to prevent new odour problems, air quality regulators in BC

could adopt ambient odour criteria for design purposes and provide guidelines for odour impact assessments.

5. Air quality regulators in BC could use olfactometers to characterize odour source emission rates but further investigation of its use for ambient measurements and as a regulatory tool is needed.

6. Regulators could require, as a minimum, that state-of-the-art emission control equipment be installed at new facilities to control odours; that similar equipment be installed on existing odour-causing facilities; that best management practices (e.g., maintenance, good housekeeping) be implemented; and that pollution prevention (reduction of process emissions) be practiced.

7. Regulators could develop an odour character index based on the FIDOL factors for use as an odour reporting and complaint verification tool.

8. Regulators could require the submission of Odour Management Plans with applications for new facilities or for existing facilities that become the subject of odour complaints.

9. Regulators in BC could develop scientifically-based, variable minimum distance separation guidelines for agricultural sources.

10. The Ministry of Water, Land and Air Protection (and the GVRD) could work with other ministries and local government to develop consistent and complementary requirements for locating facilities that have significant odour generation potential.

11. Regulatory agencies could involve the public and stakeholders in the resolution of odour problems directly by facilitating the formation of advisory committees.

12. As part of an odour management program for the province and the GVRD, key measures of success could be developed for future evaluation of the program.”

Appendix F-4: Terms of Reference for Proposed Odour Management Framework

Ambient Air Quality Objectives Working Group RSC Subgroup Recommendation Draft for Discussion

Terms of Reference Proposed Odour Management Framework

Recommendation

The Reduced Sulphur Compounds (RSC) Subgroup recommended the development of a provincial odour management framework as part of the Alberta Ambient Air Quality Objectives.

Introduction

Odour management is an important ongoing issue for the public, government, and industry. Odours can adversely affect quality of life for many Albertans. Some stakeholders also believe odour can cause negative health effects below threshold levels documented for physiologically based adverse effects; while other stakeholders believe that odour may be modified by psychological influences and should not be confused with adverse health effects. All subgroup members agree, however, that odour management should be addressed.

Odour management is a complex issue. The frequency, intensity and duration of an odour incident are difficult to measure because of its qualitative and subjective characteristics and, in many instances, its transient nature. There is limited technology available to sample and analyse odour.

In Alberta odour is regulated by various government agencies including Municipal Governments; the Natural Resources Conservation Board (NRCB), the Energy and Utility Board (EUB Guide 60, Section 8); Regional Health Authorities under legislation such as the Alberta Public Health Act, the Agricultural Operation Practices Act and the Nuisance and General Sanitation Regulation; and Alberta Environment's complaint/response system.

The addition of formalized investigation, decision-making, and enforcement tools to the current odour management system will make it more transparent, easy to understand, consistent, and enforceable. The proposed odour management framework will identify reasonable expectations for odour management (we do not live in an odour-free world). It will also address any gaps in the existing Ambient Air Quality Objectives for odourous compounds. Alberta's Ambient Air Quality Objectives (AAQO) do not include all of the odourous compounds of concern to Albertans. In addition, averaging times for ambient objectives are often too long (minimum 1-hour) to capture short-lived but reoccurring odour events.

The odour management framework will provide a basis for regulators to address off-site odour issues identified through public complaints, site inspections and compliance assessments.

Terms of Reference

Development of an odour management framework by a multi-stakeholder working group will include the following steps:

1. Characterize the current odour management situation in Alberta

The working group will review and summarize current regulations and operating practices for odour management by Municipal Governments, Alberta Environment, the EUB, the Natural Resources and Conservation Board (NRCB), Regional Health Authorities and others. It will also look at voluntary programs such as the Northeast Capital Industrial Association's (NCIA) community notification system and odour complaint response protocol. The group will collect and analyse information about the number and nature of past odour complaints, resources invested in odour management, resolution success, and difficulties encountered when addressing odour issues. The group will also identify and document regulatory and science-based deficiencies that need to be addressed to ensure or improve the effectiveness of odour management in Alberta.

2. Define goals and objectives for the state of odour in Alberta

The working group will establish reasonable expectations for odour management. This includes defining the type, origin, and extent of odour issues the system would be designed to address.

3. Develop odour management objectives, tools, protocols, and communication plan

The working group will review other jurisdictions' odour management systems, and advancements from odour related research as an initial step in developing a framework for Alberta. The proposed framework will follow the adaptive management model recommended by the Clean Air Strategic Alliance (CASA). Odour management objectives could be quantitative or qualitative in nature. An accountability component will be included in the framework to report on performance indicators such as complaint characterization, source identification, mitigation and resolution. The odour investigation, assessment, and management tools and protocols forming the framework could be a combination of existing practices in Alberta and those developed by other jurisdictions or through research. The framework will address gaps in the existing Alberta Ambient Air Quality Objectives for addressing odourous compounds (i.e. limited scope of compounds and ability to capture short-lived, reoccurring events). The proposed odour management framework will include a communication plan to educate and consult with regulators, industry and the public.

4. Identify resources required

The working group will identify resource commitments required to implement and maintain the proposed odour management system.

Proposed Membership of Odour Management Framework Work Group

The multi-stakeholder work group to develop the odour management framework should, at a minimum, include representatives from the following groups:

- Regulators:
 - Municipal Governments
 - Alberta Environment
 - Alberta Health and Wellness
 - Regional Health Authorities
 - Energy and Utilities Board
 - Natural Resources Conservation Board

- Industry:
 - Agriculture
 - Upstream Petroleum Industry
 - Pulp and Paper Industry
 - Northeast Capital Region Industry Association (NCIA)

- Public:
 - Non-Governmental Organizations

Appendix G-1: Measurement and Management Mechanisms Related to Odour, Bioaerosols and Community Health Effects

Note to Sub-group: This is text that was extracted from other sections and moved here because it is more related to measurement (monitoring) and management than to effects.

From ODOUR Chapter

Qualitative analysis of the gas chromatograms revealed that the spectrum from Type 1 (pits) and 2 (basins) were more intense but less diverse than the spectrum from Type 3 and 4 (lagoons). These observations suggest two important factors in determining odour emissions and perception from manure: (1) VOC concentration is a predominant component in perceiving odour intensity rather than the presence of a diversity of VOC compounds, and (2) measured total VOCs can be used to predict odour intensity and perception from swine manure management systems, and hopefully for other animals as well. Total VOC (non-methane) concentrations at the Type 1, 2, 3 and 4 facilities were: 806, 1647, 126 and 25 $\mu\text{g}/\text{m}^3$. The Total VOC emission rates for the Type 1, 2, 3 and 4 facilities were: 8.6, 23.2, 3.4 and 0.9 kg VOC per site per day (per hour rates were 89.9, 394, 113, and 14.5 grams VOC per system per hour).

Operational and other emission differences between Type 1 and 2 (high odour and total VOC emissions) and Type 3 and 4 (low odour and total VOC emissions) manure management systems are as follows. Type 1 and 2 had:

- lower airborne emission rates of methane (636 and 1830 grams per system per hour for Type 1 and 2 versus 13,900 and 11,990 for Type 3 and 4).
- generally similar airborne concentrations of NH_3 , with the possible exception of a lower concentration for Type 2 (9,623 and 7,923 $\mu\text{g}/\text{m}^3$ for Type 1 and 2 versus 9,362 and 10,843 for Type 3 and 4).
- higher volatile solids loading (79 and 35 kg per day per m^3 for Type 1 and 2 versus 0.3 and 0.07 for Type 3 and 4).
- higher airborne concentrations of H_2S (54 and 48 $\mu\text{g}/\text{m}^3$ for Type 1 and 2 versus 27 and 29 for Type 3 and 4).

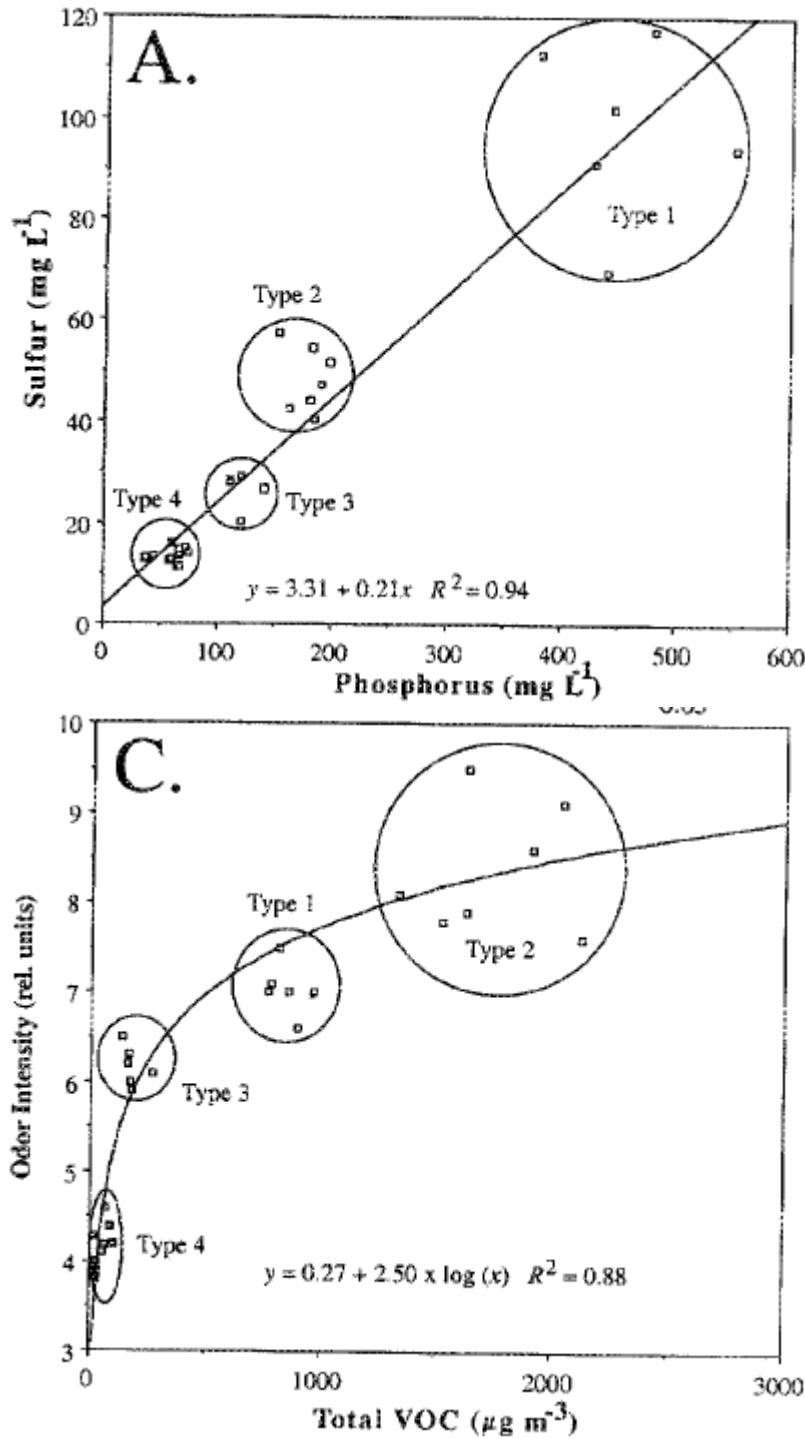
Operationally, Zahn (2001) noted that overloaded anaerobic manure management systems produce higher emissions of VOCs and lower emissions of methane. Optimal loading promotes tightly coupled metabolic processes which efficiently convert organic matter to methane, minimizing emissions of VOCs.

Zahn (2001) also speciated the VOCs from the different manure handling systems. As with McGinn (2003) discussed later in the chapter, the top 4 VOCs in Type 1 and 2 and in Type 3 and 4 systems were similar to McGinn:

- Type 1 and 2 in no particular order were: acetic, butyric, isobutyric, propionic, valeric, and isovaleric acids and n-methyl phenols (7 compounds reflect differences between Type 1 and 2).
- Type 3 and 4 in no particular order were: acetic, butyric, and propionic acids and phenol and n-methyl phenols (5 compounds reflect differences between Type 1 and 2).

Note that the concentrations of Type 1 and 2 VOC compounds are at least an order of magnitude larger than Type 3 and 4.

Figure w. Cluster analysis for (A) concentration of total phosphorous versus total sulfur in manure effluent (C) Correlation between the concentration of airborne VOCs from manure management systems and mean odour intensity.



McGinn (2003) investigated emissions, including odours, from cattle feedlots near Lethbridge. Odour intensities were determined for samples of air collected up to 800 m downwind of cattle feedlots with averaging times of 5 minutes to 4 hours. Although all samples were collected on feedlot property in this study, there are many feedlots in Alberta where these sample locations (i.e., 200 and 800 meters) would have been beyond the feedlot property line. Thus samples collected at 200 and 800 m may be considered as indicative of levels outside of a feedlot property boundary. Samples were collected over seven monitoring intervals during the period late March to late September 1999. Based on the animal capacity of the feedlot, average Dilution to Odour Threshold or Odours Units levels, 3 m from the feedlot edge were:

Feedlot Capacity (head)	Average Odour Intensity (Odour Units)	Comment
Control	8-11	Upwind samples
6,000	20	
12,000	42*	* odour units significantly higher at the 12,000
25,000	28	versus 6,000 and 25,000 head feedlots

The significantly higher odour intensity at the 12,000 head feedlot compared to the 25,000 lot may be due to differences in animal density. Animal densities for the 6,000, 12,000 and 25,000 head feedlots were 20, 13.3 and 25.6 m² per animal, respectively.

McGinn also measured odour intensity with increasing distance away from the 12,000 and 25,000 head feedlots, Figure xx. Control, or upwind, odour intensity was generally in the range of 8 to 11 Odour Units, except for July 19 at the 12,000 head feedlot where a value of ~23 OU was recorded due to manure spreading in the vicinity. Odour levels were generally higher at the 12,000 head feedlot for reasons described in the previous paragraph (i.e., higher animal density), specifically on May 27 and July 19. McGinn writes that the MDS (Minimum Distance Separation) for a 12,000 head feedlot under the Alberta Code of Practice was 942 m for a single residence and 2,515 m for a town. McGinn concluded that objectionable odours were likely at the single residence but not at the town. Meteorological conditions, poor atmospheric dispersion and elevated particulates, which carry odourants, may also have played a role. The background odour level, 22 OUs, was higher on July 19. Meteorological and particulate variables were not described.

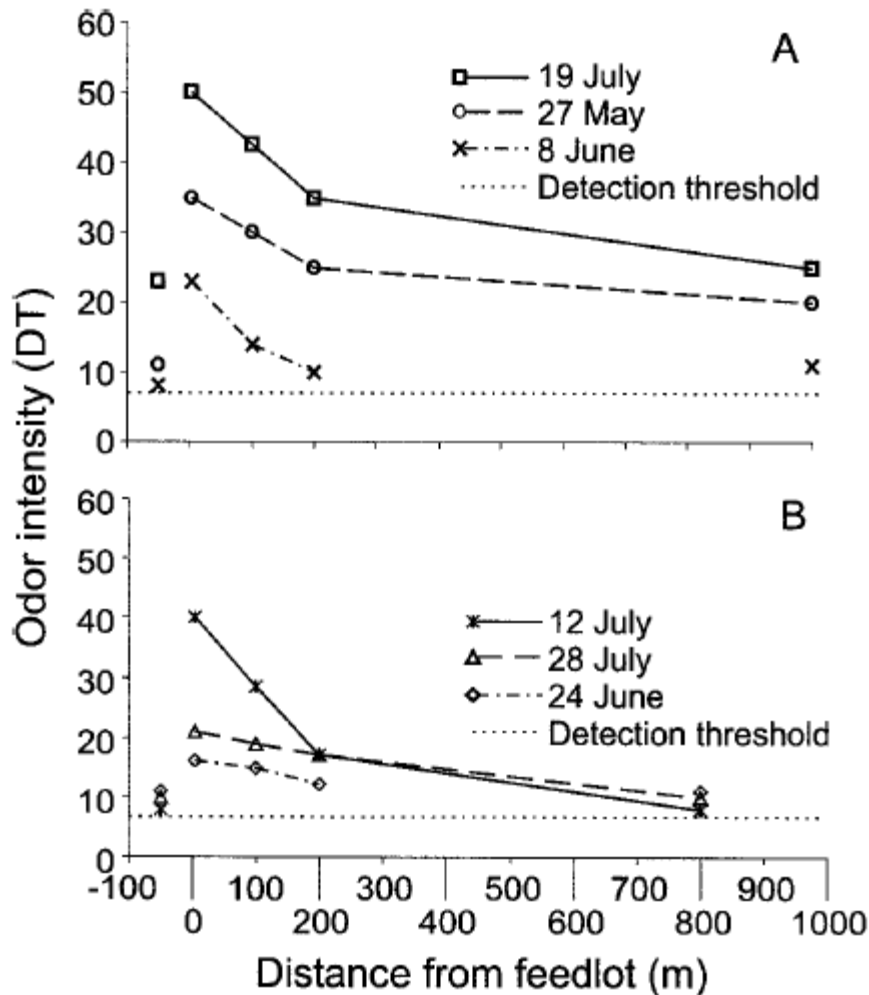


Figure xx. Odour intensity at downwind distances (within feedlot) of (A) 12 000- and (B) 25 000-head feedlots. 5-min sampling durations. Upwind value shown at a distance of -50 m. DT=Dilutions to Threshold or Odour Units. Source: McGinn 2003. DT

McGinn (2003) also measured VFAs (volatile fatty acids) and ammonia levels at varying distances from the feedlots (see the Chapters on VOCs and Ammonia for more information). In the context of odours, ammonia concentrations positively correlated with odour intensity ($r=0.84$), suggesting that ammonia may be a useful indicator of odour intensity (but not necessarily causal). Ammonia concentrations were inversely related to wind speed ($r=0.94, 0.69$ and 0.91 for 6,000, 12,000 and 25,000 head feedlots, respectively), which is not unexpected, as higher wind speeds increase mechanical mixing in the atmosphere and dilute downwind concentrations.

However, for VFAs, VFAs at 3 m distance were highest when speed was greatest. For instance, the VFA concentration at the 12,000 head feedlot at 5.7 m/sec was 29% of that at 6.2 m/sec. Unlike ammonia, increasing wind speed is one of the key factors in controlling VOC emissions or loss from manure piles. Other factors include precipitation, thickness and moisture content. Whereas ammonia from manure is generated by the hydrolysis of urea in urine, VFAs are formed by microbial activity. The correlation coefficient between wind speed and VFA were 0.59, 0.39 and 0.45, at the 6,000, 12,000 and 25,000 head feedlots, respectively. McGinn cites the 1974 work of Barth et al. as

demonstrating the linkage between volatile organic acids and ammonia, and odour intensity from dairy slurry, and Spoelstra 1980 for a link between p-cresol and odours from swine slurry.

VFAs were measured as 2-3 day averages at 3 m distance from the feedlot edge, over 8 nonconsecutive monitoring periods. Average (SD) VFAs levels were 6,000 head @ 23.2 (11.2) $\mu\text{g}/\text{m}^3$, 12,000 head @ 73.5 (51.8) $\mu\text{g}/\text{m}^3$, and 25,000 head @ 25.5 (10.4) $\mu\text{g}/\text{m}^3$. Individual VFA compounds are shown in Table xx McGinn (2003). The largest proportion of VFAs, in decreasing order for the 3 feedlots, were: acetic acid (54 to 67% of total VFAs), propionic acid (12 to 22%) and butyric acid (16-23%). Specific VFAs with an least an order of magnitude increase above odour detection thresholds were: isovaleric acid (range of maximum exceedences from 10x - 39x), butyric acid (13x @ 12,000 feedlot only), and valeric acid (10x-24x). Exceedences, >2x but <10x, were also observed but only at the 12,000 head feedlot: isobutyric acid (2x) and caproic acid (3x). As with previous, exceedence levels were higher for the 12,000 head feedlot with higher animal densities, with the exception of valeric acid for the 6,000 head feedlot. Not unexpectedly, VFA levels were higher for manure spreading; isobutyric acid (23x), isovaleric acid (170x), valeric acid (32x). McGinn notes that the relative abundance of VFAs at the 3 feedlots were similar to that found in a 1993 study by Kirchmann and Lundvall for swine slurry. McGinn also writes that Zahn in a 2001 study found much higher levels of VFAs at a swine lagoons, where the levels for acetic and butyric acid were 270 and 590 $\mu\text{g}/\text{m}^3$.

Table xx. Maximum VOC concentrations, including NH_3 , as 2-3 day averages measured 3-m adjacent to 3 feedlots and to where manure was recently spread. Concentration units are $\mu\text{g}/\text{m}^3$. Odour thresholds are provided. Note that the Alberta odour threshold for NH_3 is 1,400 $\mu\text{g}/\text{m}^3$ or 2 ppm.

Compound	Maximum concentration				
	Feedlot capacity (animals)			Spreading	Odor threshold†
	6000	12 000	25 000		
				$\mu\text{g m}^{-3}$	
Acetic	25.8	114.1	31.8	54.1	100‡, 2500§
Propionic	8.7	34.2	7.3	60.0	25‡, 86¶
Butyric	9.1	33.6	6.5	104.5	2.5‡, 3.7§#
Isobutyric	1.4	4.5	1.2	16.6	0.72‡††
Isovaleric	1.9	6.6	1.7	28.9	0.17‡††
Valeric	6.3	5.6	2.6	8.5	0.26‡††
Caproic	2.4	5.7	2.7	5.8	2.0‡††
<i>o</i> -Cresol	0.004	0.029	0.003	0	-
<i>p</i> -Cresol	0.003	0.039	0.020	0.002	4.5#
<i>m</i> -Cresol	0.002	0.014	0.014	0	-
Phenol	0.003	0.434	0.154	0.100	20# (230-380)††
Indole	0	0	0	0	1.9‡††
Skatole	0	0.098	0	0	-
Ammonia N	205	1488 (1805)	1050	-	2730#

† In a population exposed to a gas concentration greater than these thresholds, 50% of the individuals will detect an odor or show signs of physical irritation.

‡ Data from Zahn et al. (1997).

§ Data from Hasimoglu (1998). Units were converted from ppm to $\mu\text{g m}^{-3}$ with the equation ($\mu\text{g m}^{-3}$) = (ppm, $M/1000P/RT$), where M is the molecular weight, P is the pressure (1 atm), R is the universal gas constant (0.08205 L atm/mol K), 1000 is a conversion factor (1000 L = m^3), and T is the temperature (293 K).

¶ Data from Hellman and Small (1974). Data were converted from ppm to $\mu\text{g m}^{-3}$.

Data from Mackie et al. (1998). Units were converted from ppm to $\mu\text{g m}^{-3}$.

†† Data from Zahn et al. (2001).

From new BIOAEROSOLS chapter

The most pressing issue with regard to bioaerosols is the challenge associated with their measurement and monitoring in the outdoor environment. There are a number of commercial samplers currently available but a standardized efficient bioaerosol sampling method is still lacking in order to properly assess exposures. When sampling for endotoxin in particular, the results may not reflect accurate concentrations in air. The conditions under which they are collected, extracted, and stored can all affect the accuracy of the analytical results. A difference of up to 17-fold in endotoxin yield was found using different methods of processing samples. Even with the widely used *Limulus* amoebocyte lysate assay method for quantification of endotoxin, interferences could result in a 36-fold underestimation to a 34-fold overestimation of endotoxin concentration (Cole 2000).

From COMMUNITY EFFECTS Chapter

A 2006 Alberta study of antibiotic use in 90 swine farms, representing 25% of the Alberta market, found that the vast majority of antibiotics were delivered through feed (Rajić et al. 2006). The continuous use of in-feed antibiotics was reported in 96.1% of weaner farms, 85.2% of growers and 60% finishers. The most common in-feed antibiotics given to weaners and growers/finishers were tylosin and a combination of chlortetracycline, sulfamethazine and penicillin. Penicillin was commonly added to drinking water, but frequency was considered occasional. Injection of antibiotics was limited to pigs that were ill. The low frequency of important human antibiotics, quinolones and third generation cephalosporins, was a positive finding.

However, the use of penicillin and tetracycline antibiotics and the development of antibiotic resistant bacteria was a public health concern. The authors recommended the voluntary or mandatory cessation of the non-therapeutic use of in-feed antibiotics in farrow-to-finish farms. 18 or 20% of the finisher farms in the Alberta study, mostly farrow-to-finish, reported no use of in-feed antibiotics. This action was viewed as having a potential positive economic impact on these farmers as antibiotics are a substantial cost associated with feeding pigs. In addition, cited studies have indicated that the only benefit from antibiotic use was at the nursery stage, while the growth rate of finishers was not significantly improved, which also suggested that antibiotic use should be limited to the nursery stage. European studies on an antibiotic ban have not found a measurable effect on pig health at the growing and finishing stages. However, a negative effect, increased prevalence of diarrhea, was observed in weanling pigs.