# APPENDIX A

Risk Assessment Report by Dr. Toni Gladding

# A REPORT ON THE DOWNWIND CONCENTRATIONS OF DUST AND BIOAEROSOLS FROM OPERATIONAL COVERED COMPOSTING AND THE LIKELY IMPACT AT THE SHANNON VERMICOMPOSTING SITE AFTER THE DEVELOPMENT OF SIMILAR COMPOSTING OPERATIONS



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## 1.0 INTRODUCTION

This report examines the Shannon Vermicomposting site and compares the scale of this proposed site to results from environmental air quality sampling undertaken at a similar site during 2003, carried out by Dr Toni Gladding. This environmental monitoring was carried out at a site with covered bays and maturation windrows specifically for dust and bioaerosols.

The following report should be considered as an outline of the type of concentrations it can be expected that a site of the proposed size of the Shannon Vermicomposting site may generate, and is designed to give an idea of the potential for future distribution downwind of the site once composting is put into operation. The report also illustrates risk to sensitive receptors in the locality based on results expected from such sites and a literature review of similar studies.

Roffco Environmental Monitoring Services (REMS) staff have previously been involved on a number of projects concerning airborne contaminants that present a risk to health and have extensive experience in the measurement of personal and environmental exposures to dust and bioaerosols in a variety of environments.

## 2.0 THE SITE

The Shannon Vermicomposting site comprises a site specifically for composting with a proposed capacity of approximately 20,000 tonnes p.a.. This will consist of 10,800 tonnes of green waste, 2,700 tonnes of (wet) sewage sludge, 4,500 tonnes of commercial green wastes and 2,000 tonnes of wood chippings. Composting is proposed using a 5 stage process (waste reception, pre-vermicomposting aeration, screening, vermicomposting, product utilisation) with aeration, the exhaust air being fed through vermicomposting tunnels, tanks, an ozone disinfection defuser and finally an outdoor biofilter. All of the processing is to be carried out within structures on site, with the exception of screening. The immediate area surrounding the site has several potential sensitive receptors, and the distances of the nearest sensitive receptors from the site boundary and the composting operation itself are shown in Table 1.1:



| Sensitive Receptor | Distance from proposed boundary |
|---|---|
| Home of owner | Within boundary |
| Offices | Within boundary |
| Nearest house to site | 25m north |
| House | 350m north |
| House | 400m south-east |
| Surrounding farmland | various |

**Table 1.1:** Nearest sensitive receptors to the Shannon Vermicomposting site

The Environment Agency for England and Wales currently operate a policy of requiring a risk assessment if sensitive receptors are within a 250m guideline from the site boundary, as first suggested by (Wheeler *et al* 2001). As can be seen in table 1.1, there are a number of potential sensitive receptors within this guideline at the Shannon Vermicomposting site.

A paper-based risk assessment is possible for this site as REMS staff have monitored a large number of composting operations over the past three years, and it is possible to demonstrate concentrations generated by broadly comparative sites. For this report the comparative site utilised covered bays for composting and has a capacity of 25,000 tonnes per annum but had in the region of 20,000 tonnes on-site during sampling and hence is very similar to the tonnage

proposed by Shannon Vermicomposting. This site also pumped air through the material for aeration purposes that exited to the environment via a biofilter. As Shannon Vermicomposting are proposing to use similar equipment it is reported here. It should be noted however that the sample site does not deal with sewage sludge. Air sampling was carried out upwind and downwind of the plants to quantify the presence or absence of dust and bioaerosols. Bioaerosols are airborne solid or liquid particles, which may contain microorganisms, ranging in size from 0.5 to 100+ microns. For the purposes of this investigation, bioaerosols were detected by monitoring for the presence of viable microorganisms (bacteria and fungi) that were quantified as colony forming units based on their ability to grow in the laboratory.

## 3.0 METHODOLOGY

The methodology used for collecting data from the example site on all occasions is based on a number of existing protocols. These include Composting Association guidance (Gilbert *et al* 1999), research taken from an Environment Agency report (Gladding *et al* 2001), and research for the Environment Agency on composting sites (Wheeler *et al* 2001).

The protocol developed by Gilbert *et al* (1999) was based upon the following statement in Waste Management Paper 4 (section 5.93) which specifies:

*'Turning of windrows leads to the emission of ...aerosols that may contain pathogenic microorganisms. Such emissions are particularly difficult to control. Hence, unless the site is distant from sensitive receptors, the licensee should:*

- *undertake background sampling for some time before operations begin;*
- *monitor for airborne microorganisms around the site.*



The protocol recommended a practical standardised approach to sampling comparable throughout the country. It is this protocol that is utilised for this investigation.

### 3.1 Dust (Total Suspended Particulates and $PM_{10}$)

Environmental sampling of particulates included sampling for total suspended particulates (TSP) of 10 microns or over, particulate matter with an aerodynamic diameter less than or equal to a nominal ten micrometers ($PM_{10}$), particulate matter with an aerodynamic diameter less than or equal to a nominal two point five micrometers ($PM_{2.5}$) and particulate matter with an aerodynamic diameter less than or equal to a nominal one micrometer ($PM_{1.0}$). This was undertaken to ascertain the amount of fugitive dust (any visible emission, other than water droplets, issuing from any source other than through a stack) emitted from the site.

Monitoring for TSP and $PM_{10}$ was undertaken with a direct reading instrument, the LN5 (Munroe Environmental, Reading). This instrument makes optical dust measurements and is capable of datalogging and providing instantaneous and long-term results. The advantages are that it allows 24 hour sampling times, peak exposures to be detected during operations and periods of inactivity; it can be placed anywhere at a site; it is battery charged and does not require electrical power; it enables simultaneous measurement of many particulate sizes in real-time; and it incorporates logging of weather data. The following is taken into consideration when placing a sampler:

- the site should be in an open setting in relation to surrounding buildings (5-10m from

nearest);

- the site should be open to the sky, with no overhanging trees or buildings;
- the sample intake should be max. 10m above ground level, and ideally less than 5m;
- there should be no major sources of pollution within 50m, and no intermediate sources within 20m;
- vehicles should not be left running within 5m of the sample inlet;
- There should be no major redevelopment within 100 m of the surrounding area.

In addition the Composting Association recommend a sampling height of 1.5m to reflect the human breathing zone (Gilbert *et al* 1999). Environmental sampling of particulates followed these guidelines as far as possible. Results were downloaded onto a PC laptop using 'AirQ16' software.

### 3.2 Viable Counts

Prior to visiting the site, the two media were prepared as recommended in the Composting Association protocol (Gilbert *et al* 1999) (Table 3.1). Growth temperatures were chosen to reflect both environmental and human source organisms, nutrient agar (NA) plates were incubated at 37°C that supports growth of a range bacteria including potential pathogens. The Composting Association protocol is specifically designed to quantify airborne *Aspergillus fumigatus* propagules, as these can be released in large numbers as a result of composting operations and the fungus is a potential human pathogen. Malt extract agar (ME) plates were incubated at 40°C that favours the growth of *A. fumigatus* over that of other common airborne fungi and thus facilitates its detection. *A. fumigatus* colonies were identified on the basis of morphology. Total numbers of fungal colonies present were also recorded, although these represent an underestimate of the total number of viable fungal propagules present in the air as the method is primarily designed to detect *A. fumigatus*.



| Media | Temp (°C) | Incubation | Species Expected |
|---|---|---|---|
| Half strength Nutrient Agar (NA) (14g nutrient, 10g agar to 1L distilled water, 100mg Cyclohexamide dissolved in acetone <2ml) | 37 | 2 days | Bacteria e.g. *Bacillus* sp., *Actinomycetes, Streptomyces* and 'total remaining species' |
| Malt Extract Agar (20g and 20g Agar No.3 to 1L distilled water, incorporating 20 units/ml Penicillin & 40 units/ml Streptomycin) | 40 | 2 days | Fungi. Growth conditions favour *Aspergillus fumigatus*, but other species such as *Penicillium sp.*, *Cladosporium sp.* and yeasts may also grow. |

**Table 3.1:** Media Used and Species Expected for Viable Counts

Single stage Andersen microbial samplers operated at 28.3 l/min were used to collect airborne particles directly onto agar plates by impaction as specified by Gilbert *et al* (1999). Each sampler was fitted with a hemi-cylindrical baffle extending in height at least 15cm above the top of the inlet of the cone, to ensure stagnation point sampling. Samplers were mounted in pairs for simultaneous sampling on tripods at approximately 1.5m above the ground, with baffles placed at the downwind edge of the sampler. Samplers were connected to vacuum pumps with in-line flow meters for calibration purposes. Pumps were run for at least 10 minutes prior to each sampling period to ensure that the flow rate had stabilised.

Samplers were loaded with agar plates on a plastic-covered table within the mobile laboratory on site. The surface of the table and the samplers themselves were disinfected with a 70% aqueous solution of ethanol between each sampling run. Duplicate samplings onto NA plates were taken at each sampling location followed by duplicate samplings onto ME plates. After incubation in the laboratory, emerging colonies on agar plates were counted, positive hole correlation applied where needed and the total colony count calculated and expressed as colony-forming units (cfu/$m^3$ air sampled). Controls comprised agar plates loaded into Andersen Samplers then unloaded without exposure, to determine any residual contamination introduced by the sample handling process in field conditions. Blank plates were also left in sealed bags taken on site, to ascertain the purity of the medium. Plates were kept at 4°C until use. It was planned for any NA plates on which more than 399 colonies grew would be classified TNTC (too numerous to count), as the number of colonies present on such plates cannot be determined accurately. In such cases, the concentration of airborne bacteria that had been exceeded to give >399 colonies can be calculated and would be reported. A similar approach was planned for ME plates which contain too many colonies to count, which would also be recorded as TNTC; due to the morphology of fungal colonies, this can occur when fewer than 399 colonies are present. As for bacteria, a minimum concentration exceeded would be reported.

### 3.2.1 Sample Locations

Sampling was undertaken at the example site three times during 10 months, each taking one day to represent summer, autumn and winter. Between six and nine sampling points were chosen upwind, downwind and adjacent to the composting site, adjacent to the biofilter and during operations such as shredding and adding of material to the covered system. For all sampling locations, Andersen samplers were run in duplicate with NA plates exposed for 2 minutes and ME for 10 minutes. Plates were transported at ambient temperatures and incubated later in the same day after sampling for a period of 48 hours.



### 3.3 Meteorological Conditions and Measurements

The LN5 monitor was used to automatically log temperature, relative humidity, windspeed and wind direction every minute for the duration of both sampling periods. This equipment was placed away from intervening structures or buildings, in accordance with supplier and protocol advice. Cloud cover and general weather conditions were recorded manually on both occasions.

## 4.0 Results

The average environmental conditions during the first (prior to operations) and second (during operations) sampling days are summarised in Table 4.1 (range in brackets) followed by mean:

| Date | Weather/Rain | Cloud Cover | T (°C) | RH (%) | Windspeed (mps) |
|---|---|---|---|---|---|
| Summer | Dry and warm | (0/8-7/8)<br>4/8 | (16-26)<br>23 | (42-57)<br>50 | 0.28 average, gusts to 0.7 |
| Autumn | Damp, rain in | (4/8-7/8) | (9-14) | (81.7-90.1) | 0.3 average, gusts |

| | | | | | |
|---|---|---|---|---|---|
| | the days before | 5/8 | 11 | 88.2 | to 0.6 |
| Winter | Dry and sunny, breezy | (3/8-6/8) 4/8 | (8-10) 9 | (92.9-90.1) 85 | 0.65 average, gusts to 1.1 |

**Table 4.1:** Environmental Conditions During Air Sampling
T=Temperature; RH=Relative Humidity; mps=meters per second

Temperatures ranged from 9°C in winter, to 23°C in summer, relative humidity averaged between 50 to 80%. Windspeed was relatively low on all occasions. These sampling periods represent a good variety of weather conditions that might occur at an operational covered composting site. (Note: sampling is only carried out on dry days, and when there is activity such as shredding, loading and unloading on site. During periods of rain bioaerosols and dust are effectively damped down, and during inactive periods they are not disturbed hence a true measurement is not recorded).

## 4.1 Particulates

The sample site was in the vicinity of a landfill site, though this was relatively inactive during the sampling periods. Sampling results for particulates are shown Table 4.2:

| Position | Details of Siting | Duration of LN5 Monitoring | Mean TSP ($\mu g/m^3$) | Mean $PM_{10}$ ($\mu g/m^3$) | Mean $PM_{2.5}$ ($\mu g/m^3$) |
|---|---|---|---|---|---|
| **Summer** | | | | | |
| Upwind | Site boundary but downwind of landfill | 4hrs 50mins | 239.69 | 122.03 | 7.24 |
| Downwind | 50m from shredding | 4hrs 21mins | 482.47 | 207.25 | 8.10 |
| **Autumn** | | | | | |
| Upwind | 15m from site boundary | 3hrs 30mins | 57.1 | 39.2 | 20.69 |
| Downwind | 30m downwind | 3hrs 47mins | 913.4 | 1027.4 | 243.89 |
| **Winter** | | | | | |
| Upwind | Site boundary to landfill | 3hrs 45mins | 11.03 | 8.06 | 4.38 |

**Table 4.2:** Location of particulate samplers



It should be recognised that operational sites will generate particulates in excess of background concentrations, hence downwind concentrations are significantly higher than upwind (background) concentrations. During summer in particular sampling results show a raised background particulate concentration (typically $PM_{10}$ where background studies are normally below 50 $\mu g/m^3$), potentially as a result of vehicle movements on dry hard standing in conjunction with various site activities. Recommended concentrations limits are to prevent health effects are outlined in section 5.4.

## 4.2 Viable Counts

Tables 4.3 to 4.5 show the number of viable airborne microorganisms collected at the site in summer, autumn and winter. Average $cfu/m^3$ from sample duplicates are shown. Full results for sampling prior and during operations are displayed in Appendices 1 to 3.

| Details of Siting | $cfu/m^3$ summer | $cfu/m^3$ autumn | $cfu/m^3$ winter |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Directly in vicinity of biofilter within 1m | 3074 | - | - |
| Mid-site | 42880* | 10495 | - |
| Upwind | 6890 | 203 | 274 |
| 40/50m downwind | 3949 | 42880* | 8375 |
| 100m downwind | 6511 | 6519 | 1193 |
| 150m downwind | 2102 | 353 | 2155 |
| 180-200m downwind | 309 | 133 | 4602 |
| 230-250m downwind | 822 | 159 | 1493 |

**Table 4.3:** Bacteria exposure time 2 minutes unless indicated (*plates overloaded, indicative only)

Two duplicates were loaded but not exposed throughout the sampling period to act as controls, e.g. to ensure contamination of plates was not occurring. Mid-site in summer and immediately downwind in autumn samples were too numerous to count (TNTC) due to overloading of plates, hence concentrations only represent a threshold of that which was exceeded. All fungi were also sampled:

| Details of Siting | cfu/m$^3$ summer | cfu/m$^3$ autumn | cfu/m$^3$ winter |
|---|---|---|---|
| Directly in vicinity of biofilter within 1m | 80 | - | - |
| Mid-site | 4196 | 8576* | - |
| Upwind | 380 | 113 | 23 |
| 40/50m downwind | 6306 | 8576* | 2534 |
| 100m downwind | 2505 | 8576* | 2507 |
| 150m downwind | 32 | 1894 | 2951 |
| 180-200m downwind | 13 | 39 | 3058 |
| 230-250m downwind | 0 | 78 | 4023 |
| 300m downwind | - | - | 3131 |

**Table 4.4:** All fungi exposure time 10 minutes (*plates overloaded, indicative only)



Only autumn showed some TNTC samples. Again winter shows generally higher concentrations downwind, but lower at the initial source. These results indicate that the majority of the fungi collected on the plates at most of the sampling sites are presumptive *Aspergillus fumigatus* colonies (broadly identified as this species), this is because the methodology favours growth of *A. fumigatus*, hence it represents some 90% of the fungi sampled.

Appendices1 to 3 display the full results and show the number of viable airborne microorganisms collected at a working covered site of the type planned by Shannon Vermicomposting. Duplicates are shown together. Colonies below 20 on a plate are not corrected, as it is unlikely multiple deposition took place (as recommended by Andersen 1984). During sampling plates loaded/not exposed showed little contamination for bacteria (3 colonies on one plate) but not for fungi (0 colonies). Blank unexposed media did not grow any colonies. Therefore results for controls on all of these sampling occasions were insignificant.

## 5.0 Discussion

The study at the existing covered site is a good representation of what concentrations of on site particulates and bioaerosols might be found at the Shannon Vermicomposting site. They are evaluated in more detail in the context of the situation at the Shannon Vermicomposting site below.

5.1 Sources and Hazards

Particulates and bioaerosols are evaluated separately below.

5.1.1 Particulates

This study represented an investigation into the concentrations of particulates on site during a period of busy vehicular activity and during shredding of material, hence represents the 'worst case' scenario. Airborne dusts are likely to be liberated by the handling of the waste materials accepted on site, their storage and movement and by meteorological conditions (presence or absence of precipitation, wind, etc.). Vehicles on site may exacerbate this situation at the Shannon Vermicomposting site due to the hard standing in some areas of the site. The example site was dusty during sampling and was not damped down during the morning of the sampling. The monitoring equipment for particulates detected the transport of larger particles from vehicle movements and from the shredding operations.

Many particles generated on site are in the coarse size-range and become deposited immediately, e.g. TSP (total suspended particulates above ten microns in size). However, respirable dusts (especially those below 10 microns, e.g. $PM_{10}$ (particulate matter of ten microns or under)) may remain airborne for longer periods, e.g. they can take several minutes to settle (longer if they are re-aerosolised via gusts of wind) and can settle at distances of 500m or more downwind. Hence measurements of particulates on-site are important in determining likely spread off-site.



Background concentrations of TSP tend to be under 70 $\mu g/m^3$ and $PM_{10}$ under 50 $\mu g/m^3$. It could be expected that a covered site would display background concentrations during much of its operation as the material is enclosed. However, during 'worst case' operations such as shredding, screening, loading and unloading when there is no damping of dust (such as when the samples at the example site in this study were taken) concentrations will be significantly higher. Larger particles are likely to settle relatively rapidly, i.e. within a minute or so and within 100m or so of the point of generation. Finer particles can be more adequately controlled with dust suppression techniques (such as water spraying), therefore the concentrations seen in table 4.2 show a 'worst case' scenario.

Environment Agency research in England (Wheeler *et al* 2001) found some difficulties in modelling particle deposition and recommended good housekeeping and dust suppression by keeping site surfaces damp. Although some authors have argued this does not remove the finest particles (Robert Long Consultancy Ltd 1999) research by Epstein (2001) found that the effective management of dust significantly reduced the release of dust and so *Aspergillus fumigatus* from a composting facility during the construction of windrows, turning and screening processes. It is for this reason that dust suppression is recommended on-site, particularly as the covered tunnels are surrounded by hard standing which tends to aid generation of dust in warm dry weather, and at the exit of the screening conveyor which can generate large amounts of fine dust elevated from ground level. The close monitoring of the moisture levels in the compost could also minimise generation of dusts.

5.1.2 Bioaerosols

The example study investigated the concentrations of bioaerosols on a covered site and their transport downwind. It is clear from the literature that the potential for particulates to be liberated from composting sites does exist. Within a mix of airborne dust and particulates it is

likely bioaerosols are present. They may be present as clumps, aggregates or as single cells, all of which may or may not be attached to particles of other material. Airborne bioaerosols are likely to be liberated by the handling of the waste materials accepted on site, their storage and movement and by meteorological conditions (presence or absence of precipitation, wind, etc.).

Many bioaerosols would be expected to be in the smaller size ranges, e.g. $PM_{10}$ and below, and therefore could potentially travel substantial distances. However, in reality bioaerosols are aerosolised as clumps, aggregates and attached to larger mineral particles (also noted by Wheeler *et al* 2001). Weather conditions can also affect generation and aerosolisation of bioaerosols, therefore estimating distances travelled can be difficult. Viability can deteriorate according to temperature, humidity and sunlight. Die off is generally exponential, although non-viable (dead) microorganisms may still be able to cause health effects (from the action of endotoxin and glucan, both respiratory sensitisers). However, the majority of data at present utilises numbers of viable microorganisms. Wheeler *et al* (2001) utilised a 'straight line fit' for estimating dispersion, which may over-estimate numbers and distance travelled.

As bioaerosols are often in clumps and irregular chains they are more likely to be associated with the heavier particles that would settle more rapidly, i.e. particles in the TSP size range (total suspended particulates above ten microns in size). They could settle fairly rapidly, i.e. within a minute or two and within 100m or so of the point of generation.

During the example site sampling visits all measurements were taken during shredding operations to represent a 'worst case' scenario, this measured the highest concentrations of bacteria mid-site during summer, with a concentration in excess of $4.2 \times 10^4$ cfu/m$^3$. Fungi peaked at concentrations in excess of $8.5 \times 10^3$ cfu/m$^3$, during autumn. These results are not unusual for a site shredding, based on similar studies undertaken previously using the same equipment and protocols. It is also worth noting that concentrations of bioaerosols directly at the exhaust port of the biofilter were very low ($3.1 \times 10^3$ cfu/m$^3$ for bacteria, 80 cfu/m$^3$ for fungi), demonstrating the effectiveness of this method of controlling bioaerosol release. The other notable point is that concentrations of both bacteria and fungi remained higher further downwind in the winter despite lower on-site concentrations. There are many possible reasons for this. It is generally a sheltered feedstock being fed through the shredder, but in winter less multiplication has occurred due to lower ambient temperatures. However, less die-off has also probably occurred, due to less sunlight and generally higher humidity.



## 5.2 Pathways and Potential Receptors

For both sampling periods, the main consideration was to investigate dusts and their potential liberation off-site. This necessarily requires the consideration of potential routes of exposure of individuals to such dusts should they escape from the site and the potential health effects. These pathways of exposure are:

- inhalation – breathing via nose or mouth;
- ingestion – eating or swallowing;
- absorption – through skin or via the eyes (directly or via contaminated surfaces/clothing);
- contact – with the surface of the skin or eyes;
- injection – by high pressure equipment/contaminated sharp objects

For each route of exposure a number of factors will need to be considered: e.g. whether effects are likely to be acute (short-term) or chronic (long-term); whether there is a risk of sensitisation (of respiratory tract if inhaled, or skin if contact occurs) or allergic reaction; whether it could be harmful to the reproductive process; or whether infection could be caused (such as in the case of microorganisms).

Concerning particulates, guidelines outlining $PM_{10}$ limits exist, but only guidance concerning TSP and nuisance levels (outlined in section 5.4). Also, as there is a lack of dose-response data for viable bioaerosols it is difficult to make an accurate assessment of potential effects on sensitive receptors off-site. However, it is assumed the most important potential route of any exposure will be airborne inhalation or ingestion. Section 5.4 deals with recommended exposure limits for these routes of exposure.

Identification of potential sensitive receptors is also important. There are several categories of sensitive receptor that could include:

- houses and residents nearby;
- trade premises;
- factories;
- public footpaths;
- other amenities;
- crops and livestock



It is important to consider that potential effects on a sensitive receptor need not be limited in definition to direct impacts on individuals, but that crops and livestock are also significant. Farmer (1993) outlined the potential impacts on vegetation from such operations as open-cast mining and road traffic, and concluded that effects of such dusts could affect plants in many ways, e.g. photosynthesis, respiration and transpiration can all be affected. Of equal importance are the potential effects on crops and livestock meant for human consumption. However, as crops are washed many times prior to consumption this is extremely unlikely to become an issue.

Taking these issues into account, and considering the Environment Agency for England and Wales's guidelines of 250m, the nearest sensitive receptors from the edge of the application boundary for the Shannon Vermicomposting site are shown in table 1.1 of section 2. The nearest buildings are the house of the owner on-site, offices on-site and the house to the north of the site. However, as most of the operations are to be carried out under cover much of the material will be contained. Hence the risk to the sensitive receptors, providing active dust suppression on roadways and at the screening conveyor are carried out, and monitoring management practices are regularly reviewed, potentially remains very low.

### 5.3 Potential Scale of Exposure and Background/Reference values

Concentrations measured in comparison to 'normal' background concentrations are discussed below.

5.3.1 Particulates

As reported in section 5.1.1 particulates concentrations measured at the example may have been affected by movement of vehicles as the site. In general, background concentrations reveal an average of TSP below 70 $\mu g/m^3$ and $PM_{10}$ below 50 $\mu g/m^3$. Operational sites will generate particulate levels in excess of background values. During operations particulates averaged at 483 $\mu g/m^3$ 50m downwind in summer during open shredding, with no damping, and this is mainly generated by vehicular disturbance on roadways. At the Shannon Vermicomposting site the screening equipment will also generate dusts, hence water spraying is recommended to reduce concentrations of dusts for nuisance reasons.

5.3.2 Bioaerosols

At the example site samples taken during shredding for bacteria peaked in excess of $4.2 \times 10^4$ $cfu/m^3$, but were generally below $6 \times 10^3$ $cfu/m^3$. Regarding fungi/*A. fumigatus* at the example site, the highest concentration was found to be approximately $8.5 \times 10^3$ $cfu/m^3$ directly in the vicinity of the shredder. As the method is designed the majority of the fungi sampled at most of the sites were broadly identified as *A. fumigatus*. In autumn and summer, these concentrations declined rapidly. In winter they were maintained at $10^3$ $cfu/m^3$ to 300m, potentially due to the nature of the shredded material and weather conditions. However, $10^3$ $cfu/m^3$ is much lower than levels thought to cause health effects (see section 5.4).

In terms of published scientific literature, other authors report natural concentrations of bacteria and fungi routinely range from 1000 to 100,000 ($10^3$ to $10^5$) $cfu/m^3$ air (Cox & Wathes 1995). Hryhorczuk *et al* (2001) in an investigation of a windrow composting site, reported high measurements of fungi off-site in wet woodland comparable to on-site. Additionally, it was reported that mowing a nearby meadow also significantly affected results of viable fungi and bacteria (160 and 480 respectively prior to mowing, $15.0 \times 10^3$ $cfu/m^3$ and $17.6 \times 10^3$ $cfu/m^3$ after). This shows how other activities and environments can affect results obtained from composting facilities. Indeed, there is the potential that any existing farming activities in the vicinity of the Shannon Vermicomposting site will already be generating bioaerosols.



5.4 Thresholds and Acceptable Levels of Exposure

Recommended exposure concentrations for bioaerosols and particulates are outlined below.

5.4.1 Particulates

There are no standards for concentrations of total suspended particulates (TSP), although a guideline was recently investigated for nuisance purposes and Wheeler *et al* (2001) suggested concentration guidelines at 10% and 2.5% of the occupational exposure limit for inhalable dust in England and Wales (10 $mg/m^3$), i.e. 1000$\mu g/m^3$ and 250 $\mu g/m^3$ respectively.

Concentrations measured at the example site were well below 10% of inhalable dust concentrations (demonstrated by TSP). They exceeded the 2.5% suggested limit, but these were taken at 30 to 50m from the actual shredding operation. Current guidance by The Composting Association (Gilbert and Gladding 2004) recommend that offices and other structures with workers in are not situated within 30m of such operations for health reasons (unless there are intervening structures or other physical barriers such as trees) and this should be taken into account on this site.

Taking into account particulate settling rates it is expected that concentrations will decrease rapidly, particularly of heavier particles. Any dust generation from roads and hardstanding should be mitigated with dust suppression techniques. Wheeler *et al* (2001) concluded that particulates should not be a cause for concern for general public health, the example site results however should be used to recommend dust suppression to avoid nuisance.

### 5.4.2 Bioaerosols

Very little research has been carried out on what constitutes 'safe' levels of bioaerosols to which an individual can be exposed with respect to biodegradable wastes, either in terms of occupational or environmental exposures. This general lack of data also means it is very difficult to draw on past studies and provide definitive conclusions. The sampling protocol undertaken will not enable detailed assessments to be made of whether the example facility presents a risk to the health, as satisfactory dose-response data are not available. Therefore, related legislation and guidance, and research from a variety of workers are used as a guideline for exposure, as seen in table 5.1:

| **Element** | **Known sources of emissions** | **Agency** | **Description** | **Recommended Limit** | **Sizes** | **Potential Health Effects** | **Notes** |
|---|---|---|---|---|---|---|---|
| $PM_{10}$ | Natural (sea salt), industrial and traffic sources | UKNAQS<br><br>USANAAQS | 24 hour running mean<br>24 hour mean | 50 ug/$m^3$<br><br>150 ug/$m^3$ | >10um | Irritation to respiratory tract, implicated in asthma | Diesel exhaust particulates |
| Viable Micro-organisms | Natural, industrial and farming, putrescible biodegradation, compost | Lavoie *et al* (1991) (USA) Breum *et al* (1999) (DK) Rao *et al* (1996) (various standards reviewed) | No legal standards – only for guidance From reviews, consensus & surveys in non-contaminated indoor environments | $10^4$ cfu (colony forming units)/$m^3$<br><br>100-1000 cfu/$m^3$ (non-contaminated indoor environment) | All: coarse (10+ug) to ultra-fines (<2.5 µg) | $10^{6-8}$ and above known to cause allergic alveolitis. Other health effects depend on particular micro-organisms present | Research based effects and limits at present, absence of standard protocols, little data on human dose-response relationship |

**Table 5.1:** Recommended exposure limits

There are no recognised exposure limits for bioaerosols, and as stated earlier no dose-response data. Lavoie *et al* (1991) states a conservative $10^4$ cfu/$m^3$ as an occupational guidance level for waste management facilities based on work by a variety of authors, but this is an approach based on a review of the literature and is not supported by dose-response data. The Danish Working Environment Service propose that levels in excess of 1 x $10^6$-$10^9$ cfu/$m^3$ could cause respiratory problems (Wurtz 1996). Lacey *et al* (1994) report concentrations of viable microorganisms above $10^6$ cfu/$m^3$ have been linked to hypersensitivity pneumonitis (allergic alveolitis) complaints, e.g. Farmers' Lung. Concentrations measured in this study are significantly below that reported as causing health effects by Wurtz (1996) and Lacey *et al* (1994). Wheeler *et al* (2001) uses a very conservative concentration of 1000 cfu/$m^3$ for bacteria and fungi, effectively a no-observed effect level. However, given that natural

concentrations could be regularly expected to exceed this (section 5.3.2), and that farming regularly generates concentrations in excess of this (Swan *et al* 2003) and again it is not supported by dose-response data, this can serve as a guideline only.

As might be expected, concentrations found in this report are well below those which research has demonstrated can cause health effects - indeed all of the concentrations measured in this investigation are substantially below those which have previously been shown to cause health effects e.g. allergic alveolitis. However, they are in excess of the 'no effect' guideline concentrations. The higher concentrations measured ($10^4$ for bacteria, $10^3$ for fungi) are 'on-site' samples, and it is reasonable to expect these will decrease further downwind.

## 5.5 Control Measures and Evaluation of Risk

Many studies outlined have investigated occupational exposures to dusts during various types of waste handling. There are few studies that have measured environmental exposures of particulates/dust downwind from waste facilities, though these are expanding.

Crook *et al* (1987) measured microorganisms downwind of transfer stations, and found that although there were increases in numbers downwind compared to upwind (7.4 times more bacteria, 5.6 times more fungi), concentrations were only 10% of those found in the tipping halls of transfer stations within 50m of source. They concluded that the large concentrations of microorganisms found in tipping halls rapidly dispersed when released into the atmosphere and that they were unlikely to cause problems for residents downwind of the sites. At other older traditional waste sites, Lembke *et al* (1980) looked at plants which also processed sewage sludge, and found that at 100 to 300m downwind of a solid waste recovery plant, coliform densities were at ambient concentrations (however it should be noted that coliforms die very rapidly in air). Kothery *et al* (1984) monitored *A. fumigatus* from a sewage sludge composting site and found they were 4000 cfu/$m^3$ 1m from piles, but had fallen to only 1000 cfu/$m^3$ 50m downwind. Pahren (1987) concluded from a review of the literature that waste sites were unlikely to cause a public health problem, except when high densities of microorganisms were present, which was more likely to be an occupational health concern. However, it must also be noted that suppression measures are not always successful. Both Crook *et al* (1987) and Rahkonen (1987) found concentrations of bacteria increased with spray irrigation of water onto the waste, probably due to their ability to associate with water droplets. However, it was still thought useful as a dust suppression method on roadways (Rahkonen *et al* 1990).



Epstein (1994) reviewed studies concerning sludge composting and concluded microorganisms returned to background concentrations at approximately 1000 to 1500m downwind of site, much higher than other studies. Also previously, Cronholm (1980) found enteric bacteria at three different sewage plants up to 930m downwind of the sites. However, Epstein (1994) concluded that the predominant amount of data from sewage sludge and solid waste composting facilities indicated that the dispersion of bioaerosols is primarily within the confines of the facility, at approximately 153m. This is supported by Anon (1996) who found no impact on the residents of a community surrounding a compost site. Lavoie *et al* (1997) found the quality of air 100m downwind did not seem affected by recycling/composting operations.

Gilbert *et al* (1999) investigated downwind measurements of bioaerosols at two composting

facilities in the UK. In publishing a standardised protocol for measuring sites, it was determined that sensitive receptors were within 200m of the boundary of the operational area of a composting site, unless complaints about emissions were located beyond this limit or local factors e.g. local meteorological conditions dictated otherwise. The 200m figure was based on experience of dispersal monitoring during 1998. In an Environment Agency for England and Wales report Wheeler *et al* (2001) recommends a conservative limit of 250m based on dispersal monitoring during 1999 and 2000, which was further agreed with by Swan *et al* (2003) in a report for the Health and Safety Executive. However, these are very conservative as they rely on straight line modelling of bioaerosols (when die off leads to an exponential decrease) and conservative exposure values. Wheeler also measured concentrations up to $10^7$, much higher than found during the course of this study.

Déportes *et al* (1995) reported that aerial contamination may be ignored due to the relatively low exposure, and that compost dispersed in the air was mainly due to manipulation and so was an occupational problem only. This paper considered that application of composts by individuals to foodstuffs or application in public fields might pose a risk to health, with the most prominent risks being from hand-mouth contact by children. As there are crops in the vicinity of the proposed composting plant this aspect should be considered, however it is expected any crops will be subject to washing before consumption it is not expected this will become a problem.

Schilling *et al* (1999) reported concentrations of fungi and *Aspergillus fumigatus* from an enclosed composting site were returned to background within 200 m, but that an open site showed levels in excess of background to 500 m. Neef *et al* (1999) also reported excess concentrations to distances of 500 m. However, this study measured much higher concentrations generally ($10^6$ cfu/m$^3$) on site and so cannot be directly compared to the example site that recorded concentrations to a maximum of $10^4$ cfu/m$^3$ (consisting of bacteria). Also reporting of concentrations in excess of background does not directly relate to health effects, and as has been reported by Cox & Wathes (1995) many different background concentrations are possible.



Hryhorczuk *et al* (2001) found that on-site concentrations of total bacteria ($7.9 \times 10^4$ cfu/m$^3$) demonstrated a statistically significant pattern of decreasing concentration with distance from pile and higher downwind vs. upwind concentrations. Concentrations were higher during activity on-site. The most common species of fungi recorded were *Aspergillus, Penicillium and Cladosporium.* Masks were recommended for workers, with wetting of the compost to reduce dust generated.

Many studies examining open facilities generally emphasise concentrations of bioaerosols returning to background within 200 m. Although presence of microorganisms from a site may be reported as possible up to 1000 m downwind, the concentrations generally reported are below that thought to have adverse health effects, and the above studies emphasize how quickly and widely bioaerosols are dispersed back to background concentrations. It is therefore expected that a facility such as the Shannon Vermicomposting site would present little risk to the local community in terms of bioaerosol dispersion. Consideration could also be given to planting natural breaks such as trees which will significantly reduce the amount of bioaerosols dispersed - enclosing operations such as has been planned at Shannon Vermicomposting will have the same effect.

Regarding the sensitive receptors within 100m, water suppression significantly reduces bioaerosols released, it is recommended that Shannon Vermicomposting take heed of Epstein (2001) who found that the effective management of dust significantly reduced the release of *Aspergillus fumigatus* from a composting facility and employ an effective dust suppression programme. Finally it should be noted that the composting operation itself does not release significant amounts only the treatment and movement of material. Monitoring of the wind direction should also be undertaken, and turning and moving large amounts of material should be avoided during southerly winds (as this blows towards the nearest sensitive receptor off-site).

### 5.6 Contingency and Further Actions Required

The protocol used for this investigation relies on selected indicator microorganisms indicative of the composting process. It relies on 'grab sampling', and therefore only provides an estimate to be made of the concentration of culturable microorganisms at specified sampling intervals.

Concentrations on-site are likely to be higher with more site activity, particularly after a dry spell where the dirt roads of the site may cause further dust. Wheeler *et al* (2001) also recommends that compost be kept moist to reduce production of bioaerosols, and that operations should be enclosed if possible, which Shannon Vermicomposting are carrying out by using a covered approach. However, it is recommended that dust suppression of roadways be monitored during warm dry spells to ensure effective reduction of the particulates leaving the site, which have the potential to cause nuisance.



#### 5.6.1 Potential Sampling Frequencies

As the Shannon Vermicomposting site has several sensitive receptors in the vicinity, monitoring of the potential dust nuisance is recommended during the summer months, with the ability to receive reports of dust nuisance particularly after long dry periods. However, frequency may need to be reviewed if substantially different or increased amounts of material were planned for the site, or if a different (open) composting system were considered for the site.

## 6.0 Conclusions

Due to the lack of studies concerning fugitive dust emissions and bioaerosols from enclosed composting operations, it is difficult to draw any definitive conclusions regarding the risks to the surrounding population from such sites (Wheeler *et al* 2001 also commented on this problem). However, research has outlined guidelines in terms of potential effects on health. Therefore, control measures can be implemented in the interim. Sites can measure their emissions and ensure that the health of potential sensitive receptors is protected. Lack of standards in this area should not necessarily preclude this precautionary approach.

Sampling at the example site showed elevated background particulate and bioaerosol concentrations due to operations such as shredding. The following conclusions are made:

- Particulates are increased in summer during activities such as shredding and screening, but also potentially due to hard standing and dusty roads. Shannon Vermicomposting should address this by either enclosing the screening equipment or employing dust suppression at the conveyor exit to prevent finer particles being dispersed widely, and by using a bowser

for dust suppression on roadways, it is expected that these two measures will significantly reduce particulates generated on site to acceptable levels and that very little egress of particulates will occur to sensitive receptors in the area;

- At the example site, during shredding operations, bacteria peaked at mid-site and dropped rapidly. Lower on-site concentrations were seen in winter, but bacteria travelled for longer distances. Again enclosing or carrying out dust suppression with such operations would be expected to significantly reduce the concentrations of bacteria downwind on site;
- Fungi including *A. fumigatus* were higher on the example site during autumn up to 150m downwind and again were lower in winter but survived for a longer distance. Again enclosed operations and dust suppression would be expected to significantly reduce the concentrations of fungi downwind on and off site;
- It is expected that use of a biofilter will greatly reduce the egress of bioaerosols from any operations on-site, sampling at the example site and experience elsewhere for REMS staff has demonstrated this to be a very effective and simple technology;
- Sewage sludge was not present during sampling at the sample site shown here. However, the bioaerosols generated will behave in very similar ways, and reviewed studies(section 5.5) show sewage sludge sites to have a similarly rapid dispersion of bioaerosols downwind. Since this material arrives on site and is processed in an enclosed building it is not expected any additional hazards will be created by handling this material;
- Consideration should be given to the wind direction when moving material, and a basic weather vane put up on site to monitor this. The prevailing winds are from the south-west or west. The latter are most frequent in July, the former in December (generally away from the nearest sensitive receptor). Potentially screening should be carried out with care during southerly winds as this blows towards the nearest sensitive receptor off-site.



In conclusion a variety of studies have shown different dispersal distances and has used differing reference values for estimating effects on health to local populations. At this time no significant health effects have reported in relation to an operational site in the UK. The results in this report indicate that the example site based on the information available to date, generates bacteria in the range of $10^{3-4}$ cfu/m$^3$ and fungi $10^3$ cfu/m$^3$ environmentally on site when not enclosed. However, good practice, taking care regarding wind direction and regular dust suppression of roadways and at the exit of the screening conveyor belt will all minimise generation of dust and bioaerosols and transport off site. It can be concluded therefore, that if effective management of the site and the compost is maintained that the risk to sensitive receptors remains very small.

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## 8.0 APPENDICES

### Appendix 1: Summer Sampling at Covered Facility

| Sample No. | Details of Siting | No. colonies | Corrected colonies[1] | cfu/m$^3$ | Average of counts |
|---|---|---|---|---|---|
| 1 | Nr to air handling unit within 1m | 141 | 174 | 3074 | 3074 |
| 1a | | 141 | 174 | 3074 | |
| 2 | Upwind Site Boundary (d/w landfill site) | 262 | 426 | 7527 | 6890 |
| 2a | | 235 | 354 | 6254 | |
| 3 | Mid-site (d/w bay unloading) | TNTC | 2427 | 42880 | 42880* |
| 3a | | TNTC | 2427 | 42880 | |
| 4 | 50m d/w whilst screening in operation | 132 | 160 | 2827 | 3949 |
| 4a | | 205 | 287 | 5071 | |
| 5 | 100m d/w whilst screening in operation | 196 | 269 | 4753 | 6511 |
| 5a | | 276 | 468 | 8269 | |
| 6 | 150m d/w whilst screening in operation | 84 | 94 | 1661 | 2102 |
| 6a | | 121 | 144 | 2544 | |
| 7 | 200m downwind | 20 | 21 | 371 | 309 |
| 7a | | 14 | 14 | 247 | |
| 8 | 250m downwind | 58 | 63 | 1113 | 822 |
| 8a | | 29 | 30 | 530 | |
| 9 | Off-site (u/w landfill/composting | 150 | 188 | 3322 | 3180 |
| 9a | operations, i.e. background) | 140 | 172 | 3039 | |

**Table 1.1:** Bacteria Summer exposure time 2 minutes positive hole correlation



| Sample No. | Details of Siting | No. colonies | Corrected colonies | cfu/m$^3$ | Average of counts |
|---|---|---|---|---|---|
| 1 | Nr to air handling unit within 1m | 17 | 17 | 60 | 80 |
| 1a | | 27 | 28 | 99 | |
| 2 | Upwind Site Boundary (d/w landfill site) | 96 | 110 | 389 | 380 |
| 2a | | 92 | 105 | 371 | |
| 3 | Mid-site (d/w bay unloading) | 391 | 1518 | 5364 | 4196 |
| 3a | | 353 | 857 | 3028 | |
| 4 | 50m d/w whilst screening in operation | 377 | 1142 | 4035 | 6306 |
| 4a | | 417 | 2427 | 8576 | |
| 5 | 100m d/w whilst screening in operation | 332 | 709 | 2505 | 2505 |
| 5a | | 332 | 709 | 2505 | |
| 6 | 150m d/w whilst screening in operation | 10 | 10 | 35 | 32 |
| 6a | | 8 | 8 | 28 | |
| 7 | 200m downwind | 5 | 5 | 18 | 13 |
| 7a | | 2 | 2 | 7 | |
| 8 | 250m downwind | 0 | 0 | 0 | 0 |
| 8a | | 0 | 0 | 0 | |
| 9 | Off-site (u/w landfill/composting | 9 | 9 | 32 | 23 |
| 9a | operations, i.e. background) | 4 | 4 | 14 | |

**Table1.2:** Fungi Summer exposure time 10 minutes (E3+3a 5 minutes)

| Sample No. | Details of Siting | No. colonies | Corrected colonies | cfu/m$^3$ | Average of counts |
|---|---|---|---|---|---|
| 1 | Nr to air handling unit within 1m | 16 | 16 | 57 | 78 |
| 1a | | 27 | 28 | 99 | |
| 2 | Upwind Site Boundary (d/w landfill site) | 81 | 91 | 322 | 314 |
| 2a | | 78 | 87 | 307 | |
| 3 | Mid-site (d/w bay unloading) | 380 | 1198 | 4233 | 3532 |
| 3a | | 346 | 801 | 2830 | |
| 4 | 50m d/w whilst screening in operation | 370 | 1036 | 3661 | 6118 |
| 4a | | 414 | 2427 | 8576 | |
| 5 | 100m d/w whilst screening in operation | 337 | 739 | 2611 | 2470 |
| 5a | | 323 | 659 | 2329 | |
| 6 | 150m d/w whilst screening in operation | 6 | 6 | 21 | 23 |
| 6a | | 7 | 7 | 25 | |
| 7 | 200m downwind | 8 | 8 | 28 | 20 |
| 7a | | 3 | 3 | 11 | |
| 8 | 250m downwind | 7 | 7 | 25 | 37 |
| 8a | | 14 | 14 | 49 | |
| 9 | Off-site (u/w landfill/composting | 9 | 9 | 32 | 21 |
| 9a | operations, i.e. background) | 3 | 3 | 11 | |

**Table 1.3:** Presumptive *Aspergillus fumigatus* Summer exposure time 10 minutes (E3+3a 5 mins)

Appendix 2: Autumn Sampling at Covered Facility

| Sample No. | Details of Siting | No. colonies | Corrected colonies[1] | cfu/m$^3$ | Average of counts |
|---|---|---|---|---|---|
| 1 | Mid-site adjacent operational shredder | 301 | 559 | 9876 | |
| 1a | | 317 | 629 | 11113 | 10495 |
| 2 | 40m Downwind of operational shredder | 412 | 2427 | 42880 | |
| 2a | | 416 | 2427 | 42880 | 42880** |
| 3 | 100m Downwind of operational shredder | 247 | 384 | 6784 | |
| 3a | | 235 | 354 | 6254 | 6519 |
| 4 | 150m Downwind of operational shredder | 26 | 27 | 477 | |
| 4a | | 13 | 13 | 230 | 353 |
| 5 | 15m Upwind of site (but downwind of | 12 | 12 | 212 | |
| 5a | landfill site by 80m) | 11 | 11 | 194 | 203 |
| 6 | 230m Downwind of site | 9 | 9 | 159 | |
| 6a | | 9 | 9 | 159 | 159 |
| 7 | 180m Downwind of site | 5 | 5 | 88 | |
| 7a | | 10 | 10 | 177 | 133 |

**Table 2.1:** Bacteria Autumn exposure time 2 minutes [1]positive hole correlation.

| Sample No. | Details of Siting | No. colonies | Corrected colonies | cfu/m$^3$ | Average of counts |
|---|---|---|---|---|---|
| 1 | Mid-site adjacent operational shredder | TNTC | 2427 | 8576 | |
| 1a | | | 2427 | 8576 | 8576** |
| 2 | 40m Downwind of operational shredder | TNTC | 2427 | 8576 | |
| 2a | | | 2427 | 8576 | 8576** |
| 3 | 100m Downwind of operational shredder | TNTC | 2427 | 8576 | |
| 3a | | | 2427 | 8576 | 8576** |
| 4 | 150m Downwind of operational shredder | 310 | 597 | 2110 | |
| 4a | | 278 | 475 | 1678 | 1894 |
| 5 | 15m Upwind of site (but downwind of | 20 | 21 | 74 | |
| 5a | landfill site by 80m) | 41 | 43 | 152 | 113 |
| 6 | 230m Downwind of site | 19 | 19 | 67 | |
| 6a | | 24 | 25 | 88 | 78 |
| 7 | 180m Downwind of site | 12 | 12 | 42 | |
| 7a | | 10 | 10 | 35 | 39 |

**Table 2.2:** Fungi Autumn exposure time 10 minutes



| Sample No. | Details of Siting | No. colonies | Corrected colonies | Cfu/m$^3$ | Average of counts |
|---|---|---|---|---|---|
| 1 | Mid-site adjacent operational shredder | TNTC | 2427 | 8576 | |
| 1a | | | 2427 | 8576 | 8576** |
| 2 | 40m Downwind of operational shredder | TNTC | 2427 | 8576 | |
| 2a | | | 2427 | 8576 | 8576** |
| 3 | 100m Downwind of operational shredder | TNTC | 2427 | 8576 | |
| 3a | | | 2427 | 8576 | 8576** |
| 4 | 150m Downwind of operational shredder | 291 | 520 | 1837 | |
| 4a | | 270 | 450 | 1590 | 1714 |
| 5 | 15m Upwind of site (but downwind of | 20 | 21 | 74 | |
| 5a | landfill site by 80m) | 41 | 43 | 152 | 113 |
| 6 | 230m Downwind of site | 17 | 17 | 60 | |
| 6a | | 23 | 24 | 85 | 72 |
| 7 | 180m Downwind of site | 11 | 11 | 39 | |
| 7a | | 10 | 10 | 35 | 37 |

**Table 2.3:** Presumptive *Aspergillus fumigatus* Autumn exposure time 10 minutes

Appendix 3: Winter Sampling at Covered Facility

| Sample No. | Details of Siting | No. colonies | Corrected colonies[1] | cfu/m$^3$ | Average of counts |
|---|---|---|---|---|---|
| 1 | Upwind site boundary | 20 | 20 | 353 | |
| 1a | | 11 | 11 | 194 | 274 |
| 2 | 50m downwind shredding | 259 | 417 | 7367 | |
| 2a | | 294 | 531 | 9382 | 8375 |
| 3 | 100m downwind shredding | 53 | 57 | 1007 | |
| 3a | | 71 | 78 | 1378 | 1193 |
| 4 | 150m downwind shredding | 97 | 111 | 1961 | |
| 4a | | 113 | 133 | 2350 | 2155 |
| 5 | 200m downwind shredding | 189 | 256 | 4523 | |
| 5a | | 194 | 265 | 4682 | 4602 |
| 6 | 250m downwind shredding | 84 | 94 | 1661 | |
| 6a | | 68 | 75 | 1325 | 1493 |
| 7 | 300m downwind shredding | 4 | 4 | 71 | |
| 7a | | 49 | 52 | 919 | 495 |

**Table 3.1:** Bacteria Winter exposure time 2 minutes [1]positive hole correlation.

| Sample No. | Details of Siting | No. colonies | Corrected colonies | cfu/m$^3$ | Average of counts |
|---|---|---|---|---|---|
| 1 | Upwind site boundary | 4 | 4 | 14 | 23 |
| 1a | | 9 | 9 | 32 | |
| 2 | 50m downwind shredding | 340 | 759 | 2682 | |
| 2a | | 326 | 675 | 2385 | 2534 |
| 3 | 100m downwind shredding | 304 | 571 | 2018 | |
| 3a | | 352 | 848 | 2996 | 2507 |
| 4 | 150m downwind shredding | 340 | 759 | 2682 | |
| 4a | | 359 | 911 | 3219 | 2951 |
| 5 | 200m downwind shredding | 343 | 779 | 2753 | |
| 5a | | 363 | 952 | 3364 | 3058 |
| 6 | 250m downwind shredding | 390 | 1476 | 5216 | |
| 6a | | 346 | 801 | 2830 | 4023 |
| 7 | 300m downwind shredding | 366 | 986 | 3484 | |
| 7a | | 344 | 786 | 2777 | 3131 |

**Table 3.2:** Fungi Winter exposure time 10 minutes

| Sample No. | Details of Siting | No. colonies | Corrected colonies | Cfu/m$^3$ | Average of counts |
|---|---|---|---|---|---|
| 1 | Upwind site boundary | 4 | 4 | 14 | 23 |
| 1a | | 9 | 9 | 32 | |
| 2 | 50m downwind shredding | 340 | 759 | 2682 | |
| 2a | | 326 | 675 | 2385 | 2534 |
| 3 | 100m downwind shredding | 304 | 571 | 2018 | |
| 3a | | 352 | 848 | 2996 | 2507 |
| 4 | 150m downwind shredding | 330 | 697 | 2682 | |
| 4a | | 355 | 874 | 3219 | 2776 |
| 5 | 200m downwind shredding | 328 | 686 | 2753 | |
| 5a | | 356 | 883 | 3364 | 2772 |
| 6 | 250m downwind shredding | 390 | 1476 | 5216 | |
| 6a | | 346 | 801 | 2830 | 4023 |
| 7 | 300m downwind shredding | 366 | 986 | 3484 | |
| 7a | | 344 | 786 | 2777 | 3131 |

**Table 3.3:** Presumptive *Aspergillus fumigatus* Winter exposure time 10 minutes