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Development of Amenity Risk Assessments at Organic Waste Treatment Facilities

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Author(s):
Drew, G.H., Longhurst, P.J., Pollard, S.J.T., Smith, R. and Tyrrel, S.F.

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Research Contractor:
Centre for Resource Management and Efficiency
Sustainable Systems Department, School of Applied Sciences, Building 40, Cranfield University, Cranfield, Bedfordshire, MK43 0AL
01234 750111

Environment Agency's Project Manager:
Kerry Walsh
Human Health Science
Red Kite House
Wallingford
Oxon
OX10 8BD

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Steve Killeen

Head of Science

Executive summary

This report describes the objectives, achievements and programme of work for the Environment Agency's Post-doctoral Fellowship on amenity impacts from waste management. This three-year work programme started in January 2005 and set out to explore methods for the quantitative risk assessment of composting sites and other organic waste treatment facilities. The programme addressed a number of amenity impact issues common to waste processing operations, including odour and bioaerosols. Additionally, the potential impact of these on communities and their quality of life was assessed. One of the main tasks of this study was to provide scientific evidence to support the development of impact assessments. The results will be used to inform comparative health risk assessments for amenity risks for different waste.

The project:

- Demonstrated the ability to collect accurate source term data from compost windrows using the wind tunnel approach. This progress provides the potential to model downwind bioaerosol concentrations based on source data that are not contaminated by other bioaerosol sources.
- Showed that the highest bioaerosol emissions are related to compost agitation activities, such as turning, shredding and screening. This information allows us to focus on peak emissions for further studies and for risk mitigation measures.
- Improved enumeration of bioaerosols through the development of a new soil compost agar for actinomycetes.
- Undertook statistical analysis of replicated bioaerosol sampling, which has shown a high degree of variability, suggesting that caution should be exercised when interpreting the results of bioaerosol surveys with low levels of replication.
- Showed that variables including wind speed, processing activities, season and the type of facility influence bioaerosol concentration. In particular, high wind speeds and agitation activities are likely to result in higher concentrations of bioaerosols being detected further downwind. However, to date, there is still insufficient evidence to support a change to the current 250 m risk assessment limit.
- Showed that the current generation of air dispersion models offer a potentially valuable tool to model downwind concentrations of bioaerosols. In particular, the ADMS 3.3 provides a useful overview of emissions as it allows the incorporation of several different sources at the site and it has the ability to model intermittent sources, which closely resembles the true pattern of emissions from composting facilities.
- Demonstrated that the averaging time used in modelling studies can influence predicted concentrations, with shorter averaging times resulting in higher ground-level concentrations. Using hourly averaging times is less successful at capturing peak concentrations.
- Examined the quality of the bioaerosol risk assessments submitted to the Environment Agency and found the quality of these to be very variable. In particular, risk assessments tend not to be site-specific and lack bioaerosol monitoring data. Where bioaerosol concentrations have been sampled,

practitioners do not always follow the existing guidance, which complicates comparison with other studies.

The Fellowship produced outputs that go beyond pure scientific understanding. These include:

- Associated projects and collaborations to the value of £604,000.
- Five published journal papers, with a further four in preparation and three submitted for publication, as well as six conference papers and two published project reports.
- Training of 75 Environment Agency personnel in bioaerosol risk assessment and bioaerosol science at three workshops.
- Advice to Environment Agency officers in response to requests regarding bioaerosol risk assessments.
- Support for the development and training of both the Post-doctoral Fellow and four PhD students.
- Development of a network of contacts within waste operators, local authorities, government agencies and consultants.

Although a significant amount of progress and success has been achieved by the Fellowship and the associated work programme, the report suggests that further research is needed in the areas of bioaerosols monitoring, modelling, mitigation and health impacts and risk assessments.

Acknowledgements

The Fellow would like to acknowledge the support of all her colleagues at Cranfield University, including both staff and PhD students. In addition, the support of the Environment Agency project managers, Jan Gronow and Greg Jordinson, has been invaluable in developing both the work programme and the career of the Fellow. In addition, the support of other Environment Agency personnel is acknowledged, especially Alison Gowers, Rob Kinnersley, Mike Smith, Nina Sweet and Kerry Walsh.

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1 Introduction

This report describes the objectives, achievements and programme of work for the Environment Agency's Post-doctoral Fellowship on amenity impacts from waste management. The report starts with an introduction, aimed at providing all readers with a general introduction to the aims, objectives and different work programmes of the Fellowship. The second section provides a summary of all the scientific and research outputs from the Fellowship, and is primarily aimed at the Policy and Science teams. Section 3 describes a series of workshops focused on risk assessments. This section is aimed at Policy, Science and Operational teams. Section 4 focuses on dissemination, training and management activities, and is primarily aimed at those interested in the management of the Fellowship. The final section summarises all the activities and presents recommendations for future activities and further research.

1.1 Background

This three-year work programme started in January 2005 and set out to explore methods for the quantitative risk assessment of composting sites and other organic waste treatment facilities. The work programme addressed a number of amenity impact issues common to waste processing operations, including odour and bioaerosols. Additionally, the potential impact of these on communities and their quality of life was assessed. One of the main tasks of this study was to provide scientific evidence to support the development of impact assessments. The results will be used to inform comparative health risk assessments for amenity risks for different waste management processes, and will improve our understanding of bioaerosol dispersion around organic waste facilities.

1.2 Aim and objectives

The aim of this programme was to explore innovative risk and amenity impact science for waste management, to underpin policy development and improve process and operational decision-making within the Environment Agency.

The main objectives were to:

- develop risk science to support the development of amenity impact assessments for waste management facilities (particularly for organic waste treatment);
- interpret impact assessments in light of the supporting science (for example, bioaerosol exposure with distance from site, and interpretation of odour assessments in light of measurement uncertainty);
- inform the comparative health risk assessments of amenity risks;
- provide state-of-the-art reviews of available scientific evidence (such as dose–response relationships for main hazards of concern);
- expand research on methods of quantitative risk assessment at organic waste treatment facilities, particularly composting, to improve our understanding of bioaerosol monitoring and modelling;

- provide technical support to the Environment Agency's operational, policy, process and science staff; and
- disseminate information and knowledge on modelling and monitoring to the Environment Agency and other regulators, academia, consultants and industry.

1.3 Research programme

The Fellow was based at Cranfield University, within the Centre for Resource Management and Efficiency. The work programme and associated projects were directed by Prof. Simon Pollard, with significant input from Dr Richard Smith, Dr Phil Longhurst and Dr Sean Tyrrel and were managed by the Environment Agency.

The research programme aimed to share knowledge on amenity risk assessments with a wide audience, from academia to Environment Agency operational staff, to practitioners in the UK. A variety of methods were employed, for example by seeking external funding from research councils and industry. Where possible, projects were undertaken in collaboration with other universities and industry and involved multi-disciplinary researchers. This not only ensured wider dissemination, but also served as peer-review for the research in order to maintain a high quality of work. The findings were transferred to the Environment Agency through face-to-face meetings, workshops and through Environment Agency staff input into journal papers. Research projects were structured so as to increase the knowledge base and advance the development of amenity risk assessments, by addressing key areas in which knowledge is lacking.

1.3.1 Work programme I: Bioaerosols and composting

A risk management framework for composting facilities in England and Wales (Environment Agency, 2004) was developed for small and large sites and required underpinning by sound science.

To permit the installation of new composting facilities, the Environment Agency requires a site-specific risk assessment for any facility that has sensitive receptors (e.g. schools, homes or offices) within 250 m of the site boundary. The risk assessment should determine the concentrations of bioaerosols around the site and the potential risk to sensitive receptors. Although baseline monitoring can be carried out prior to installation, and programmes for routine monitoring can be arranged once a facility is operational, spot measurements only provide an indication of concentrations for the particular short-term measurement period. The ability to model bioaerosol emissions might allow a better prediction of impact prior to the facility becoming operational. Currently, however, there are several uncertainties associated with modelling the dispersion of bioaerosols around composting sites.

The Health and Safety Executive report (Health and Safety Executive, 2003) highlighted the importance of modelling bioaerosol viability and particle size distribution; these were not included in the Health and Safety Laboratories (HSL) modelling due to a lack of suitable data. Measuring the flux of bioaerosols rather than their concentration provides an insight into actual emissions and exposure. Such fluxes from composting processes are beginning to be quantified and understood (Taha et al., 2004). This work programme continued to develop these methods, focusing on generating, and collating, data to support research on dispersion modelling to estimate downwind concentrations of bioaerosols.

1.3.2 Work programme II: Odour

The reporting of odours by the general public is one of the most common causes of complaint recorded on public registers; these episodic nuisance events arise mainly from landfills, but increasingly from other waste treatment processes.

Odour control products are one reactive option to manage the impact of odour on local communities. While research into such products is ongoing in the water sciences area, limited data exists on the effectiveness of odour control products for waste management (Bouzalakos et al., 2004; Lewicki and Longhurst, 2000).

A more proactive approach would be to carry out modelling, with an element of on-site monitoring for validation. Limited dispersion modelling with the short-term mode of COMPLEX-I, software developed by the US Environmental Protection Agency (USEPA), has been used to quantify the potential odour strength causing an impact on the community around a municipal solid waste landfill site north of London. Further analysis of model calculations such as effects of wind direction, frequency of wind direction, stability of the atmosphere, selected odour threshold and integration time of the model would form a basis for calculating distances from the landfill site to impacts on the surrounding community (Sarkar et al., 2003).

Three areas of research have been identified as priorities for odour impact assessment:

- assessing existing sensitivities of different communities to actual odour impact;
- developing predictive emissions modelling combined with odour detection and odour complaint reporting; and
- understanding the implications of changing waste streams and future treatment and disposal requirements.

2 Scientific and research outputs

This section provides a summary of all the scientific and research outputs from the Fellowship, and is primarily aimed at the Policy and Science teams. Each of the key journal and conference papers are summarised below, separated into four key areas of research, namely bioaerosols, odour, literature reviews and waste collection schemes.

2.1 Bioaerosols

Bioaerosol is a general term used for micro-organisms suspended in air. Bioaerosols include allergens such as fungi, bacteria, actinomycetes, arthropods and protozoa, as well as microbial products such as mycotoxins, endotoxins and glucans (Millner et al., 1994). However, there are a number of uncertainties associated with bioaerosols, particularly relating to their emission and dispersion from composting facilities. Due to the numerous knowledge gaps in bioaerosol science, this became the focus of the work programme. Activities relating to bioaerosols undertaken during the Fellowship can be characterised into monitoring activities, method development and dispersion modelling. The outputs are described below under these topics.

2.1.1 Source term monitoring

Published as: Taha, M.P.M., Drew, G.H., Longhurst, P.J., Smith R. and Pollard S.J.T,, 2006. Bioaerosol releases from compost facilities: evaluating passive and active source terms at a green waste facility for improved risk assessments. Atmospheric Environment, 40(6), 1159–1169.

Concerns about the impact of compost operations on public health and amenity (dust, odour, traffic movements, and chemical and pathogen release) are frequently voiced when proposals are made for larger facilities in, or adjacent to, built-up areas (National Audit Office, 2002). Increasingly, public health concerns about composting focus on the potential release of, and exposure to, bioaerosols. Bioaerosols are airborne micro-organisms and their constituent parts, including fungi, bacteria and endotoxins. Bioaerosols are ubiquitous and associated with various sources, such as composting, agriculture and decomposing vegetation. It is therefore extremely difficult to associate concentrations measured downwind of a source to the correct source. Therefore, this research focuses on improving the quality of regulatory risk assessment for composting facilities by providing source term data at the point of release.

The sources of bioaerosols at a composting site can be classified as either static (area sources, e.g. windrow) or active (point sources, e.g. turning, screening or shredding). Due to the nature of the sources, two different sampling methodologies were employed. For the static sources, a wind tunnel, used previously for odour measurements, was tested and found to be useful in the collection of source term data. For the active sources, the SKC Universal dust and vapour sampling pump was connected to Institute of Occupational Medicine (IOM) sampling heads containing mixed cellulose ester filters (25 mm x 0.8 μm pore size). Simple source depletion curves were then constructed using the SCREEN3 (USEPA, 1995a, 1995b) screening level air dispersion model.

The results showed that these methods were capable of collecting source term data for bioaerosols released from composting facilities. Furthermore, the results revealed that agitation activities, such as screening, shredding and turning, release bioaerosol concentrations of the order of 2–3 log higher than from static compost windrows. This initial research highlighted several areas for further research, including the need for improved actinomycetes enumeration techniques and further development of air dispersion modelling methods.

In preparation: Drew, G.H., Nogami, A., Tamer Vestlund A., Pankhurst, L., Seymour, I., Batty, W., Pollard, S.J.T. and Tyrrel S.F., Monitoring and variation of bioaerosols at composting facilities using conventional and novel samplers.

The quality of any risk assessment is dependent on the availability and quality of the source term data (Pollard et al., 2006). For bioaerosol risk assessments, these data are frequently limited, in part because of the practical difficulties of microbiological sampling and analyses. As a result, statistics on the variability of bioaerosol concentrations are frequently absent and constrain the capacity of risk analysts to set confidence limits on bioaerosol source term concentrations. Numerous methods are available to capture bioaerosols (Nielsen et al., 1997; Stetzenbach et al., 2004), mostly based on culturing of micro-organisms, resulting in a delay between sample capture and bioaerosol enumeration. This may also result in underestimation compared to sampling methods that estimate total micro-organism counts (Karlsson and Malmberg, 1989).

A novel, porous polymer filter with a honeycomb structure has been developed for filtering of blood (Patent of Japan: 2005-152849, 2006; Tanaka, 2004; Tanaka et al., 2004; Tominaga et al., 2006). The honeycomb structure allows light to be transmitted through the filter, enabling filtered particles to be observed using a conventional light microscope. This experiment tested the ability of the novel filter with its associated sampler to collect bioaerosols. We also examined the variability between samples collected simultaneously, using both conventional samplers (SKC pump with IOM sampling heads) and the novel sampler and filter. Although the honeycomb filter was designed for analysis under optical microscopes, we used conventional culture methods here, in order to allow comparison with conventional methods. Furthermore, we illustrate the variability of replicated bioaerosol sampling, and offer statistical information for practitioners using these data for environmental risk assessments, data that are not currently available.

The actinomycetes concentrations captured were *ca.* 10^5 cfu/m^3 for both samplers. The *Aspergillus fumigatus* concentrations were *ca.* 10^4 cfu/m^3 for the SKC samplers, and *ca.* 10^3 cfu/m^3 for the novel samplers. The sampling head of the novel sampler is attached to the sampling device. In order to place the sampling head at the appropriate height (1.8 m) and still maintain access to the pump, it was necessary to fit tygon tubing to the novel sampler (Figure 2.1). This arrangement resulted in the sampling head being placed at the far end of the tube, with the filter located within the sampler (Figure 2.2). With the SKC sampler, the filter is placed within the sampling head located at the end of the tygon tube. This modification meant that micro-organisms captured would travel down the tube before being captured on the filter in the novel sampler, whereas for the SKC sampler the micro-organisms were captured directly onto the filter. This modification to the novel sampler may explain why fewer *A. fumigatus* spores were captured.

Figure 2.1 The two types of samplers with the pumps and sampling boxes on the lower platform for easy access, and the sampling heads at the end of the tygon tubing at a height of 1.8 m. The compost windrow can be seen in the background.

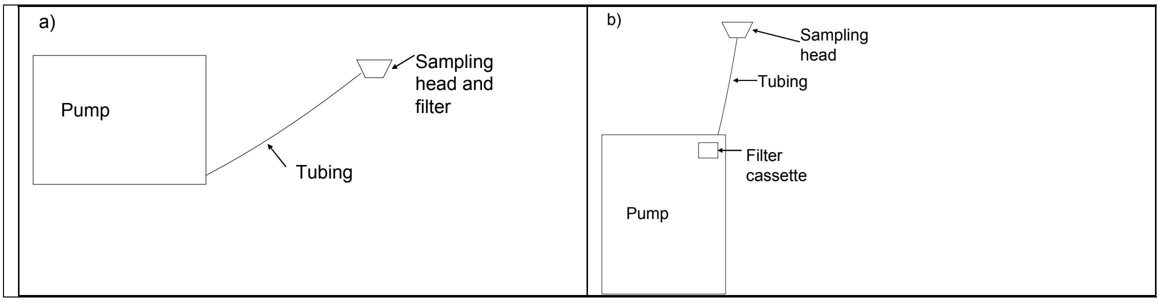


Figure 2.2 The schematic diagrams of a) the SKC sampling equipment, and b) the novel sampling equipment, showing the location of the pumps, tubing, filters and sampling heads.

The scattergram and error bars presented in Figures 2.3 and 2.4 indicate that the replicated measurements of *Aspergillus fumigatus* were more variable than for actinomycetes. Coefficients of variation for *A. fumigatus* ranged from 0.2 to 0.8, compared to 0.1 to 0.3 for actinomycetes. This degree of variability suggests that caution should be exercised when interpreting the results of bioaerosol surveys with low levels of replication.

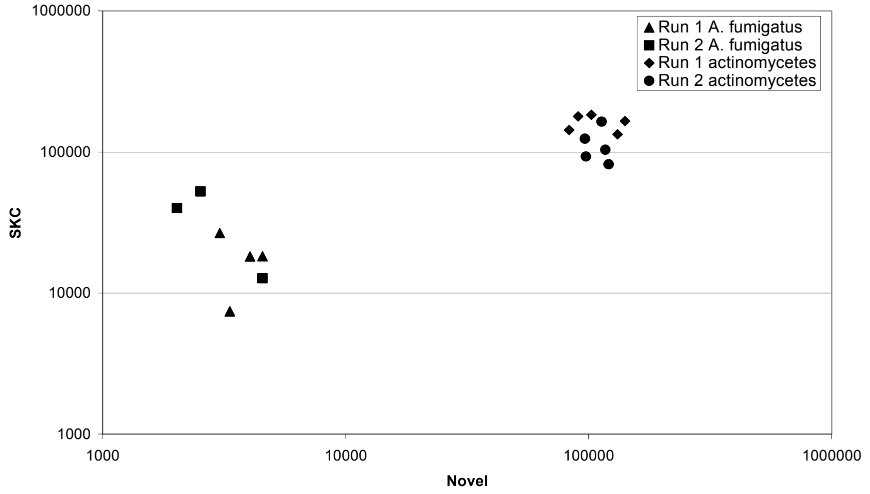
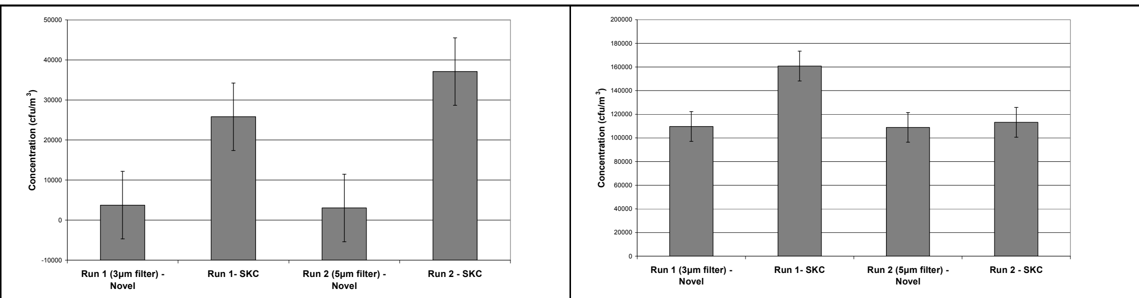


Figure 2.3 Scattergram comparing the results from the SKC sampler with the results from the novel particulate sampler (results are concentration in cfu/m^3). Run 1 tested the novel sampler with a 3 µm filter alongside the SKC samplers with a 0.8 µm polycarbonate filter



a) *Aspergillus fumigatus* b) Actinomycetes

Figure 2.4 The average results for each sampler for a) *Aspergillus fumigatus* and b) actinomycetes.

In preparation: Drew, G.H., Jordinson, G.M., Gladding, T.L., Pollard, S.J.T. and Tyrrel, S.F. Variability of monitored bioaerosols concentrations at composting facilities.

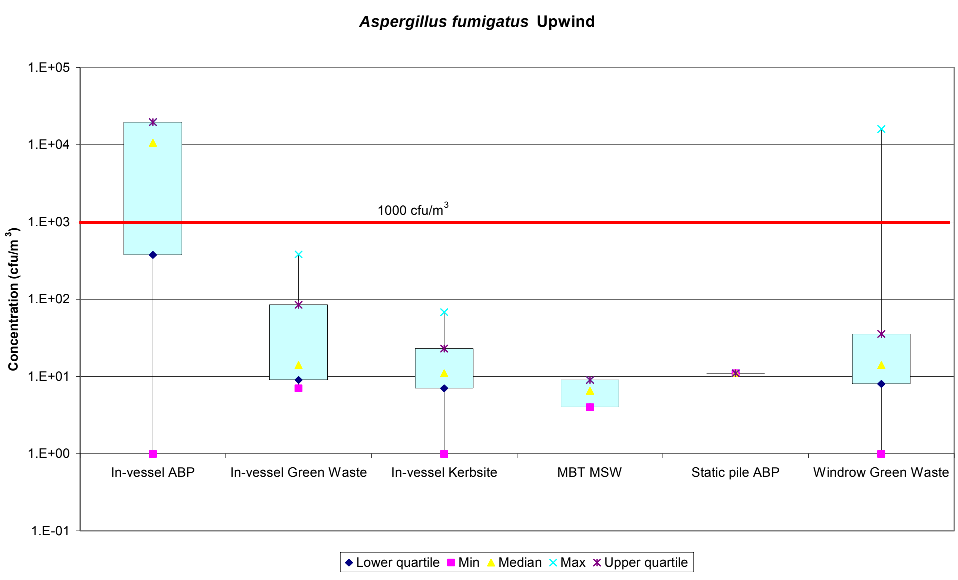
Our research to date suggests that bioaerosol concentrations are influenced by the sampling equipment used, the enumeration methods and the sampling locations. Other influences of variability include on-site activities during sampling, local weather conditions, topography, facility process and feedstock, compost age and moisture content. Despite our understanding that these variables are likely to influence bioaerosol concentrations we currently lack sufficient replicated data for detailed statistical analyses. This is because the practicalities of measurement and analysis limit the number of samples that can be taken. Therefore, we have chosen to collate a number of different datasets from different sources in order to undertake some analysis of the influence of these variables.

Six different datasets were combined into a database with common data categories. The data include unpublished and published information (ADAS/SWICEB, 2005; Drew et al., 2007; Environment Agency, 2008 (In preparation); SEPA/SNIFFER, 2007; Taha et al., 2005). A database was created for different micro-organisms, including actinomycetes, *Aspergillus fumigatus*, total fungi and total bacteria. Although other bioaerosols such as endotoxins were included, the number of data points was small and so these are not included in this analysis, due to the difficulties associated with examining the statistical significance of a small number of samples. The bioaerosol data were all collected at composting sites within the UK, and include upwind, downwind and at source measurements. The sampling methodologies and strategies are defined, as well as on-site activities occurring during sampling. The database includes information on the type of facility, the feedstock processed, the sampling date and local meteorological data from during the sampling period. Where possible, information on the age and moisture content of the compost is included.

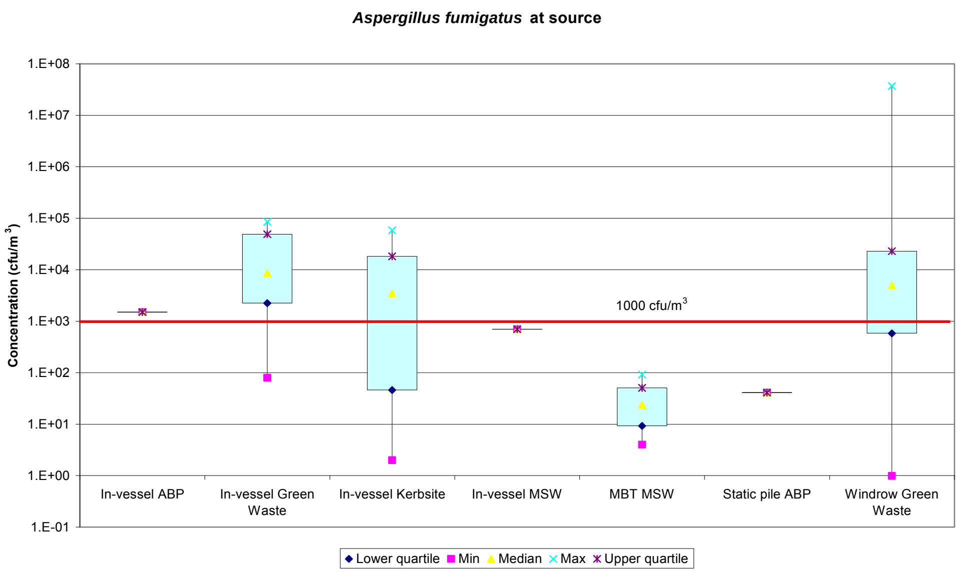
An initial analysis of the variation in bioaerosol concentration with different ambient temperature, wind speed, relative humidity, compost age and moisture content revealed no trends in the data. The analysis also suggests that at source bioaerosol concentrations may be higher during the spring, particularly for total bacteria and actinomycetes.

Processing activities on-site have been shown to emit the highest concentrations (Taha et al., 2006, 2007b) and this pattern is revealed in this analysis for most bioaerosols. However, for total fungi the highest mean concentrations were found for static conditions. The analysis also suggests that green waste windrow facilities emit the highest concentrations of *Aspergillus fumigatus* (Figure 2.5), actinomycetes and total bacteria. However, as most of the data were from these facilities, it is possible that this has biased the analysis.

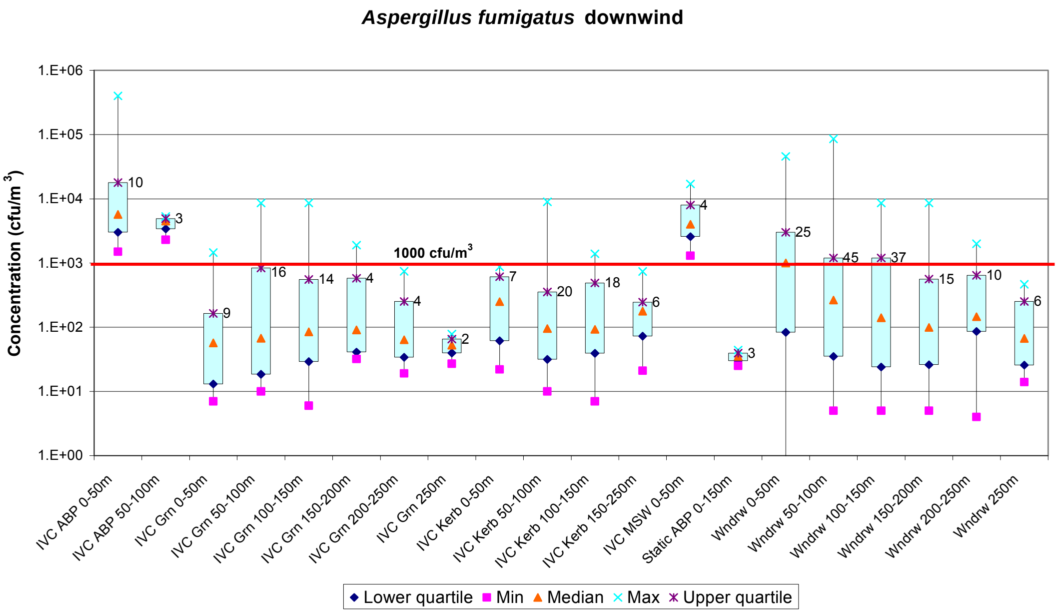
The initial analysis examined each of the variables that could affect the concentration independently of all the other variables, using simple descriptive statistics. This method provides an initial overview of the data, but should be interpreted with caution, as the variables are likely to have a combined influence on the bioaerosol concentration. Further detailed analysis of the data is planned.



a) Upwind



b) At source



c) Downwind

Figure 2.5 Variation in *Aspergillus fumigatus* concentration at different composting facilities for a) upwind, b) at source (0–10 m from source) and c) downwind (>10 m downwind).

2.1.2 Method development

Published as: Taha, M.P.M., Tamer, A., Aldred, D., Drew, G.H., Longhurst, P.J. and Pollard, S.J.T., 2007. Enumerating actinomycetes in compost bioaerosols at source – use of soil compost agar to address plate 'masking'. Atmospheric Environment, 41(22), 4759–4765.

Actinomycetes are a heterogeneous group of filamentous bacteria resembling fungi. They are a major component of bioaerosols emitted from composting facilities (Lacey, 1997; Niemi et al., 1982; Strom, 1985; Swan et al., 2003). Colony 'masking', where colonies overlap, is one of the problems associated with bioaerosol sampling based on the capture of culture methods (Chang et al., 1994, 1995; Chen et al., 1998; Kalogerakis et al., 2005). Masking impedes the visual enumeration of individual species, which may lead to colony counting errors. Lacey (1997) suggests that the method used to collect samples may influence the growth of other bacteria, and that this problem is particularly associated with isolating actinomycetes from compost samples. Researchers have commented that selecting the appropriate media for the environment in which the sample is collected may also improve the enumeration results (Balestra and Misaghi, 1997). Our own research revealed this to be a frequent occurrence and so we explored the use of an alternative media, soil compost agar, developed at Cranfield University.

The soil compost agar (SCA) is a supernatant of 100 g loam compost (John Innes™ No.1) with 1,000 ml deionised water, vigorously shaken for 2 minutes and centrifuged at 500 rpm for 5 minutes. The SCA agar was prepared using 7 g of agar-agar powder with 500 ml deionised water, with no need for pH adjustment. After preparation, the media were autoclaved (121°C for 15 minutes), left to cool to below 47°C and treated with 1% $^{w}/_{v}$ antifungal cycloheximide, dissolved in 2 ml of HPLC-grade ethanol. The method has proved to be cost effective and reduces analysis time.

Evidence from over 70 samples showed that the soil compost agar consistently improved actinomycetes enumeration when compared to half strength nutrient agar. Repeatable and reliable actinomycetes growth was best achieved at an incubation temperature of 44°C after 7 days' incubation.

2.1.3 Bioaerosol dispersion modelling

Presented as: Drew, G.H., Smith, R., Pollard, S.J.T., Longhurst, P.J. and Kinnersley R., 2005. Amenity impacts of episodic emissions from composting facilities. Paper presented at the 10th European Biosolids and Biowastes Conference Workshop and Exhibition, Wakefield, 13–16 November 2005.

Due to the ubiquitous nature of most bioaerosols, it can be difficult to determine the exact source of the micro-organisms. Sampling at distance from a source may therefore result in erroneous results. This has led to the use of models to predict downwind concentrations based on at- or near-source concentration measurements, as reviewed by Swan et al. (2003). Most mathematical models were developed to simulate dispersion over the medium to long range, not short ranges (<1 km). For bioaerosols in the UK, the range of interest is up to 250 m as this is the trigger distance for a risk assessment, as required by the Environment Agency.

This paper builds on previous work (Taha et al., 2006), which showed that bioaerosol emissions are episodic. Here we explored the potential for using an advanced steady-state Gaussian-like dispersion model, ADMS 3.3 (CERC, 2003), for modelling bioaerosol concentrations downwind of composting facilities. In particular, this paper focused on the impact of different averaging times, and became the precursor to further work on modelling of odours and bioaerosols (Drew et al., 2007; Taha et al., 2007b). Using previously monitored bioaerosol data (Taha et al., 2006), bioaerosols were modelled using the Pasquill stability classes and short-term fluctuations of 60, 900, 1,800 and 3,600 seconds, in an attempt to model short-term emission peaks.

The results showed that under both neutral and convective conditions, high concentrations of bioaerosols are predicted to still be present at 200 m from the facility, with fluctuation times of less than 3,600 seconds. With the shortest fluctuation time of 1 minute, modelled high concentrations were still detected at 400 m from source. This study highlighted the importance of collecting appropriate data that can be used to correlate modelled predictions and observed concentrations. Furthermore, monitoring regimes should take into account the occurrence of peak emissions and aim to sample these.

Presented as: Drew, G.H., Tamer, A., Taha, M.P.M., Smith, R., Longhurst, P.J., Kinnersley, R. and Pollard, S.J.T., 2006. Dispersion of bioaerosol from composting facilities. Paper presented at the Waste 2006 Conference, Stratford, 19–21 September 2006.

Bioaerosol dispersion will be influenced by the particle size, the emission rate, buoyancy effects, atmospheric effects and local topography. Bioaerosols range in size from 10 nm to 100 µm and have a small mass, which means that they do not settle quickly and have the potential to disperse on wind and thermal currents (Swan et al., 2003). Most of the current models do not take into account buoyancy effects of hot releases into cold air. In addition, recent studies (Taha et al., 2006 have shown that bioaerosol releases from composting are likely to be episodic and related to agitation activities on site. Most studies so far have failed to take this into account when modelling dispersion.

Several authors (e.g. ADAS/SWICEB, 2005; Millner et al., 1980; Wheeler et al., 2001) have assumed that bioaerosol spores are sufficiently small to allow for the use of Gaussian dispersion models, such as the Pasquill dispersion model (Pasquill, 1961), SCREEN3 (USEPA, 1995b) and ADMS (Carruthers et al., 1994; CERC, 2003). These methods model bioaerosols as a gas, while Fitt et al. (1987) used the power law and an exponential model, both of which are capable of taking the particle size into account. Furthermore, most of these studies use the Pasquill stability classes and not measured meteorological data. Despite this, there is still debate about the usefulness of any of these methods in predicting downwind concentrations of bioaerosols.

This study aimed to reveal the impacts of using measured meteorological data and of defining bioaerosols as particles (not as a gas). The results showed that the use of the hourly meteorological data provided less conservative estimates of downwind bioaerosol concentrations. We have previously shown that models can predict bioaerosol concentrations above 1,000 cfu/m^3 beyond the 250 m trigger limit for Environment Agency bioaerosol risk assessments. However, these results showed that the use of the hourly meteorological data resulted in enhanced drop-out of the plume and so lower downwind ground-level concentrations (Figure 2.6). Under very stable conditions, the model assumes low turbulence, and therefore emissions downwind remain concentrated. This results in model predictions showing higher downwind concentrations under these conditions. However, on-site sampling has shown that high wind speeds (more often associated with unstable conditions) are likely to result in higher downwind concentrations. This anomaly in the model predictions currently requires further study.

To date, there is still little information available regarding bioaerosol particle size and their tendency to clump or form aggregates. This study was an attempt to examine model sensitivity to depicting bioaerosols as particles. As was expected, modelling bioaerosols as particles resulted in an increased drop out from the plume and lower ground-level concentrations, particularly for *Aspergillus fumigatus*. However the results for actinomycetes were less conclusive, which is likely to be due to the very small terminal velocity and particle size used to represent actinomycetes (based on data from Lacey and Dutkiewicz, 1976).

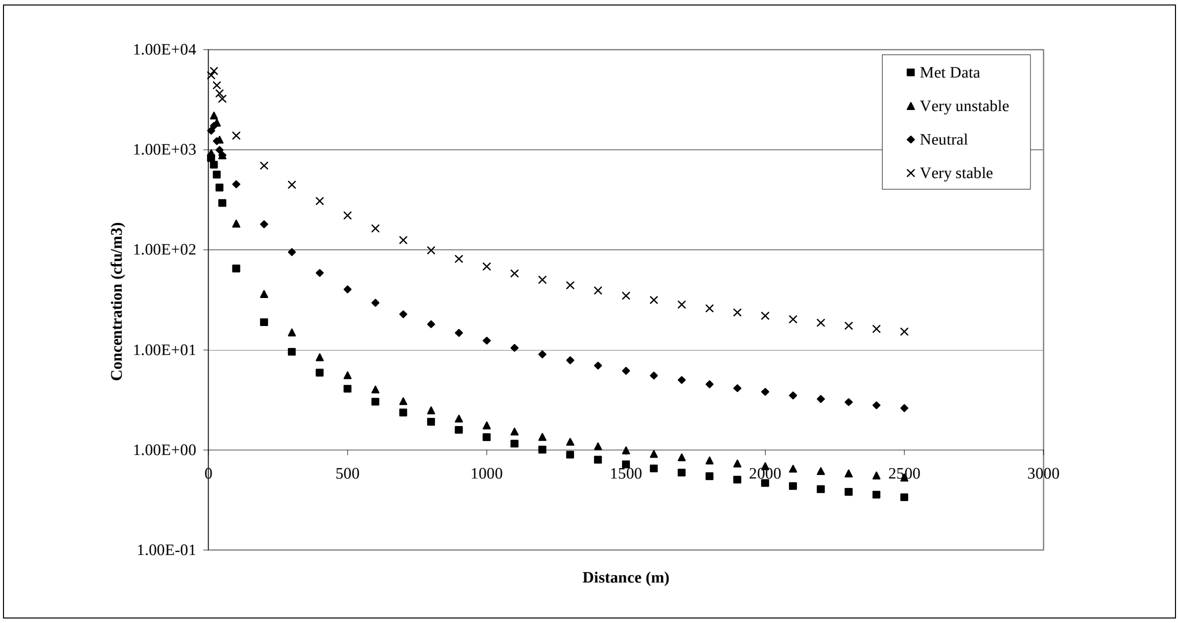


Figure 2.6 The modelled impact of using hourly meteorological data on downwind dispersal of *Aspergillus fumigatus*.

Published as: Taha, M.P.M., Drew, G.H., Tamer, A., Hewings, G., Jordinson, G., Longhurst, P.J. and Pollard, S.J.T., 2007. Improving bioaerosol exposure assessments of composting facilities – comparative modelling of emissions from different compost ages and processing activities. Atmospheric Environment, 41(21), 4504–4519.

Having examined the impact of compost agitation activities (Taha et al., 2006), the focus of the research moved on to examine the impact of compost age on bioaerosol emissions. However, the bioaerosol concentrations measured with the wind tunnel for static windrows did not reveal a distinct trend as the compost aged.

The results for agitation activities show that *Aspergillus fumigatus* emissions may differ depending on the age of the compost. During turning of one-week-old compost, the average *A. fumigatus* concentration was up to 2-log higher than turning of compost age from 4 weeks to 16 weeks. For actinomycetes, the average concentrations from turning of one- and four-week-old compost were 1-log higher than for 12- and 16-week-old compost. This is evidence that the stage of the composting process may influence the concentrations of bioaerosols released. In addition, emissions from shredding (1 x 10^5 cfu/s and 8 x 10^4 cfu/s, for *A. fumigatus* and actinomycetes respectively) and screening (1 x 10^5 cfu/s for both *A. fumigatus* and actinomycetes) tended to be slightly lower than from turning activities.

These concentrations were converted into emission rates and modelled using both ADMS 3.3 and SCREEN3 dispersion models. The SCREEN3 predictions show that most concentrations reduce to below background (494 cfu/m^3) by 200 m for *A. fumigatus* and actinomycetes, except for emissions from turning of two-week-old compost, which only reduces to below background by 500m. The ADMS 3.3 predictions suggest that the majority of emissions will have reduced to below background by 40 m, again apart from turning of two-week-old compost, which reduces to below background by 100 m.

The Environment Agency requires a risk assessment to be undertaken for any composting facility that has a sensitive receptor within 250 m of its boundary. The results presented here suggest that bioaerosol concentrations from both active and passive emissions reduce to below typical background levels before reaching the 250 m risk assessment requirement threshold, when modelled by the more advanced ADMS dispersion model.

SCREEN3 is designed for scoping studies and therefore has a tendency to overstate concentrations, taking a more precautionary approach in its estimation than the advanced ADMS dispersion model. This is most likely due to the inclusion of an alternative mixing height algorithm (Brode, 1991), which uses the maximum of a predetermined mixing height or a value adjusted slightly higher than the plume height, based on stability class. The use of this alternative algorithm results in overstated concentrations in comparison to those predicted by the USEPA's full Gaussian dispersion model, ISCST3 (USEPA, 1996). We therefore expect SCREEN3 results to be more precautionary when compared with another advanced Gaussian-like model such as ADMS 3.3, because SCREEN3 is designed to predict the worst case scenario. The source depletion curves estimated by both models can still be considered as only preliminary estimates of bioaerosol dispersal, as both models are currently not able to take into account bioaerosol properties such as clumping and inactivation. Future work will focus on improving measurement techniques for monitoring bioaerosol emissions, focusing on the clumping and inactivation properties.

In addition, the ADMS 3.3 model was used to predict the combined emissions from more than one source. This is a more realistic representation of dispersion from the facility, as composting facilities tend to have several sources of bioaerosols, including static compost windrows and agitation activities, such as shredding, screening and turning of the compost. This study showed that modelling the combined active and passive sources together resulted in predictions that were closer to background concentrations in comparison to modelling the passive sources alone. This suggests that the major contribution to bioaerosol emissions from composting facilities is from agitation activities (i.e. active sources), which by their nature are episodic.

Published as: SEPA/SNIFFER, 2007. Bioaerosol and Odour Monitoring from Three Composting Sites. Prepared by Drew, G.H., Tamer Vestlund, A., Tyrrel, S.F., Longhurst, P.J. and Pollard, S.J.T. SNIFFER Research Project UKPIR12. Available online at http://www.sniffer.org.uk.

Presented as: Tamer Vestlund, A., Drew, G.H., Jehlickova, B., Olsen, P., Sneath, R., Tyrrel, S., Longhurst, P.J., Jordinson, G. and Pollard, S.J.T., 2007. Bioaerosol and odour emissions: a comparison of three composting sites in Scotland. Eleventh International Waste Management and Landfill Symposium, Sardinia, 1–5 October 2007.

This research was a project funded by SEPA and SNIFFER in support of the Environment Agency Fellowship work programme. The research was undertaken by Asli Tamer Vestlund and managed by the Fellow. The aim of the research was to examine bioaerosol emissions from three different composting facilities. The three facilities used different technologies to process different feedstock, namely:

- an open windrow processing green waste;
- a vertical, continuous-flow silo cage composting facility processing animal by-products waste;
- a thermally insulated in-vessel composting system processing municipal solid waste.

This study also collected a limited number of odour samples taken in conjunction with the bioaerosol samples. The odour samples were taken during the summer and were used to calibrate the air dispersion models, as the models tested have been used for many years to model odour.

The bioaerosol concentrations measured were within the same range as previously reported results (Taha et al., 2006, 2007b) and showed that in-vessel composting facilities emitted higher concentrations of both odour and bioaerosols than the green waste windrow facility. This is an expected result due to the nature of the feedstock. In addition, the biofilters and air management systems are likely to reduce the odour impact on the surrounding area. To date, there is little information on the ability of biofilters to reduce bioaerosol emissions, and this is highlighted as an area for further research.

The modelling studies undertaken from these results revealed that the dispersion models underestimate downwind bioaerosol concentrations (in comparison to sampled concentrations) by 1- to 3-log (Figure 2.7), although other influences, such as alternative sources of bioaerosols, could account for these differences. The results, in contrast to previous studies, also indicate no differences in ADMS 3.3 source depletion curves when bioaerosols are modelled as a gas or as particles. These results were the major justification for a further research study, which is currently ongoing. The ongoing research is examining bioaerosol particle size and aggregation mechanisms, and aims to incorporate the results into more advanced modelling options (particle modelling) within ADMS 3.3 to improve the current dispersion modelling techniques.

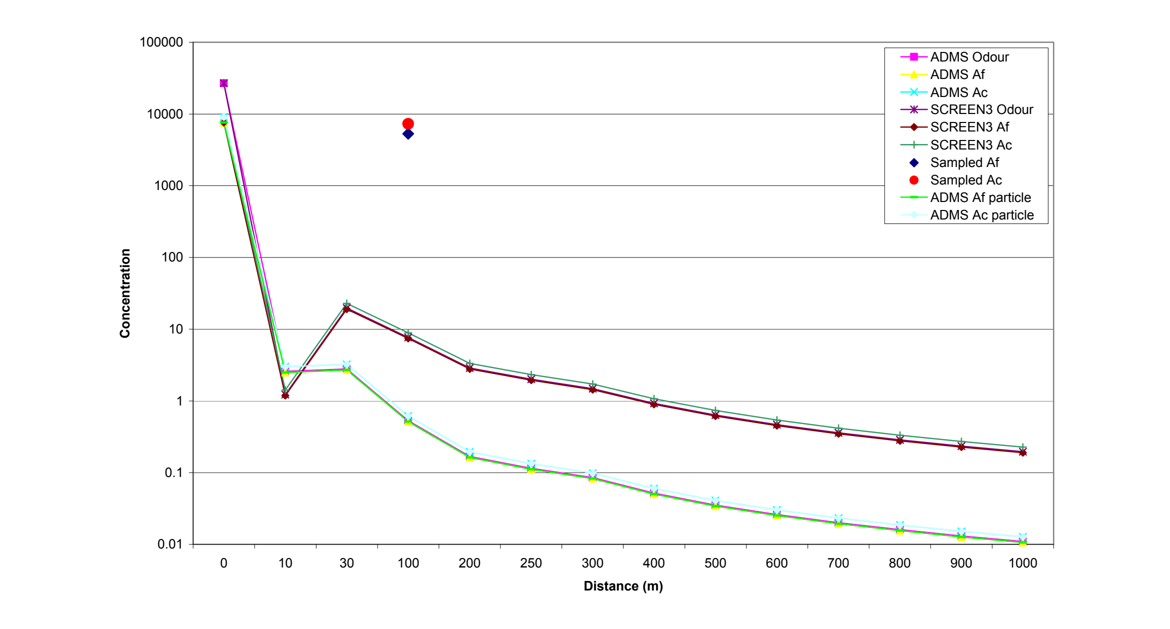


Figure 2.7 Downwind SCREEN3 and ADMS 3.3 predicted concentrations of odour, *Aspergillus fumigatus* and actinomycetes for Site B. Note: Bioaerosol concentrations are in cfu/m^3 and odour concentrations are in ou$_E$/m^3. The x axis is on a nonlinear scale.

Presented as: Drew, G.H., Tamer Vestlund, A., Jordinson, G., Smith, R., Tyrrel, S., Longhurst, P.J. and Pollard, S.J.T., 2007. Progress towards a best practice method for modelling dispersion of bioaerosols from composting facilities. Eleventh International Waste Management and Landfill Symposium, Sardinia, 1–5 October 2007.

This conference paper was an opportunity to summarise the results of our bioaerosol monitoring modelling to date and to highlight areas for future research. Our initial studies focused on collecting authentic source term data. This was achieved using a wind tunnel and personal aerosol samplers to collect bioaerosol emissions from static compost windrows and two in-vessel composting facilities. In addition, bioaerosol samples were taken as close as practically possible to compost agitation activities, such as turning, screening and shredding. The proximity of sampling to the activities was determined with consideration for the safety of the sampling team. Our initial modelling activities were based on several simplifying and limiting assumptions:

- the particles displayed a Gaussian distribution in both lateral (crosswind) and vertical directions;
- no gravitation deposition was assumed;
- only one source was modelled;
- the source was assumed to be continuous;
- the wind velocity and direction were assumed to be constant over modelled time and distance;
- the modelled surface was relatively flat;
- the particle and wind velocity were assumed to be the same; and
- microbial inactivation and aggregation were not considered.

These assumptions were initially decided upon, based on the limitations of the SCREEN3 dispersion model. By using the more advanced ADMS 3.3 model, we began to examine the influences of each of these assumptions. In addition to examining the differences between the SCREEN3 and ADMS 3.3 models, our studies to date have examined the impact of:

- agitation activities in comparison to static sources;
- compost age on downwind concentrations;
- single sources in comparison to combined sources;
- using hourly monitored meteorological data in comparison to the Pasquill stability classes;
- modelling bioaerosols as particles; and
- continuous sources compared to intermittent sources.

Our results to date have shown that the more advanced modelling options tend to result in lower downwind bioaerosol concentrations than when these factors are not considered. This suggests that current methods may overestimate downwind receptor exposure to bioaerosols. The results presented here provide us with more questions than answers. In particular, how do we validate the model results? Sampling downwind of a facility may capture emissions from that facility, but these sampled concentrations may also be contaminated by other sources of bioaerosols, due to their ubiquitous nature. We therefore need to find a method to determine the true emissions from different sources downwind of composting facilities, in order to estimate the contribution of each source to the ambient bioaerosol concentration.

2.2 Odour

Waste management facilities, such as landfill and composting, are odorous activities, due to the nature of the material processed. Odour from these facilities is primarily related to the decomposition of organic material and the emission of various odorous gases. Although residents living near such facilities may find the visual aspects unpleasant, it is primarily the odours emitted that influence their living conditions and it is therefore the emitted odours that will lead to complaints about waste management facilities. Due to the focus on bioaerosols, activities relating to odour assessment and measurement became a secondary focus of the Fellowship. The outputs described below focus on dispersion modelling and on amenity assessment. The methods used for modelling odour dispersion were also useful in developing the bioaerosol modelling research described earlier.

2.2.1 Odour dispersion modelling and averaging times

Published as: Drew, G.H., Smith, R., Gerard, V., Burge, C., Lowe, M., Kinnersley, R., Sneath, R. and Longhurst, P.J., 2007. Appropriateness of selecting different averaging times for modelling chronic and acute exposure to environmental odours. Atmospheric Environment, 41(13), 2870–2880.

Odour emissions from landfill and composting sites tend to be episodic, characterised by periods of high emissions associated with on-site activities, and periods of low emissions when no activity occurs. Assessing the impact of odours on communities is a complex process, due to the very complex nature of odours. Most odours are the result of a number of different substances, which can make analysing the source difficult. Factors such as the intensity and hedonic tone (the pleasantness of the odour) will influence how people react to it. The way the odour is perceived by the population is also highly dependent on the receptors. Characteristics of the population will also determine how likely they are to complain, such as previous exposure to the odour and the receptor's personality. The olfactory sense is able to adapt to persistent odours, thereby reducing annoyance (GOAA, 1999). However, short-term, high peak concentrations may still be detected and considered an annoyance (Miedema et al., 2000). In other words, it is frequently the fluctuations from the mean concentration, and not the actual mean itself, that determine how the odour is perceived (Best et al., 2001).

The techniques used for odour assessment include olfactometry, dispersion modelling and the sniffing method. Olfactometry is a frequently used technique to determine the concentration of odour, and employs preselected panellists to assess the concentration at which they can reliably detect an odour sample. The procedure for this assessment is defined in an EU standard (CEN, 2003) and this method is now generally adopted in Western Europe, with the unit referred to as an odour unit (ou_E). The laboratory technique employed uses a dynamic dilution olfactometer. This is a gas diluter specifically designed to present controlled samples of odour to panellists. Panellists are required to smell air being delivered from a 'horn' and state when they can detect an odour. The number of odour units for a sample is calculated by the number of times the air is diluted before being detectable by only 50% of the panellists. This method currently gives the most useful indicator of smell for the purposes of research and evaluation, but it is very expensive and difficult to undertake.

Dispersion modelling has frequently been used to assess the potential dispersion of odour from industrial sources (Sheridan et al., 2004). Our research has focused on the ability of these models to predict chronic and acute exposures to odour. The models have typically been used to determine chronic exposures, where concentrations are averaged over a set time period, usually one hour. This effectively smoothes out any high concentration peaks and short-term fluctuations, but it is useful in defining a 'tolerable' level of exposure. An alternative to this method is to use short averaging times that do not filter out the concentration peaks, which can be achieved using new generation dispersion models.

In this project, a series of experiments was designed to compare the results of using different averaging times in a dispersion model (ADMS 3.1) with odour complaints recorded around a landfill site in a community monitoring database. The results show that using hourly averaging times is less successful at capturing peak concentrations, and does not capture the pattern of odour emission as indicated by the community monitoring database. The use of short averaging times produces a modelled pattern of dispersal that more closely matches the observed database. This approach is therefore of greater value in predicting the likely nuisance impact of an odour source and in framing appropriate regulatory controls.

2.2.2 Odour annoyance and amenity

Submitted as: Jehlickova, B., Longhurst, P.J. and Drew, G.H., 2008. Assessing effects of odour: a critical review of assessing annoyance and impact on amenity. Third IWA Odour and VOCs Conference, Barcelona, 8–10 October 2008, submitted.

Odour emissions from industries such as landfills can result in complaints from the public. In the UK, these emissions are described as having an impact on amenity. In order to achieve a balance between the often conflicting interests of industry and the public, odour emissions are quantified and attempts are made to assess the annoyance caused and the impact on amenity. However, the assessment of odour comprises both objective and subjective assessments. Furthermore, the term amenity is a vague and contested concept that lacks a legal definition. This paper reviews the concept of amenity from a historical and planning perspective.

The term amenity initially denoted an aesthetically pleasing quality that came under threat from some form of a new development. This suggests that it was related to early nature conservation concerns, as it was evoked when technical development encroached on visually harmonious and aesthetically highly valued tracts of landscape. Its use was gradually extended beyond the original concern and has increasingly been used in the context of odour annoyance. In particular, the concept of amenity is used by planners to grant or refuse permission for potentially odorous industries. The concept is therefore of paramount importance to operators of waste treatment facilities, such as landfill and composting sites.

In contrast to the ambiguities surrounding the concept of amenity, the definitions of annoyance in the literature are robust. Annoyance is a negative emotional response to a stimulus that is believed to have a negative impact (Lindvall and Radford, 1973). The loss of amenity resulting from odorous incidents can give rise to annoyance, while annoyance caused by odour can lead to the sense of the loss of amenity. Despite the conceptual differences between annoyance and the loss of amenity caused by the impact of odour, they also share certain aspects. Both are responses to odour as a stimulus, and both can be described by a mixture of quantitative and qualitative parameters. Some of these parameters are common to both, and enable evaluation of both the degree of annoyance and the loss of amenity. The quantitative parameters are clearly defined, while there is less consensus on the latter, qualitative parameters. However, due to the subjective nature of odour response, both quantitative and qualitative methods for assessing odour annoyance and loss of amenity need to be used and further developed.

2.3 Literature reviews

One of the objectives of the Fellowship was to provide state-of-the-art reviews of available scientific evidence. To this end, three literature reviews were undertaken, focusing on bioaerosols and mechanical biological treatment. These reviews are summarised below.

In preparation: Tamer Vestlund, A., Drew, G.H., Tyrrel, S.F., Jordinson, G.M. and Pollard, S.J.T. A critical review of current issues in composting bioaerosol risk assessments.

This paper provides a critical and comprehensive review of current issues in composting bioaerosol risk assessments. Although many reviews currently exist focusing on bioaerosols, they do not focus on the bioaerosol properties that influence dispersion downwind of composting facilities. This review focuses on the gaps in our understanding of the factors influencing bioaerosol behaviour after release. These include the episodic nature of their release, bioaerosol viability and inactivation, bioaerosol aggregation and dose–response relationships. The implications of these knowledge gaps are the possible inaccurate estimations of risks associated with bioaerosols released from composting facilities.

The review highlights the lack of comparability between different bioaerosol studies, due to different sampling strategies and sampling methodologies, including enumeration techniques. Government guidance on these issues is limited and outdated. Furthermore, the lack of dose–response relationships complicates estimates of the risks. However, determining dose–response relationships to bioaerosols is complicated due to the large number of different micro-organisms and the differences in human responses to different concentrations.

This paper concludes by highlighting several areas for future research, including:

- improvements in the quality of source term data;
- the use of bioaerosol sampling methods that allow for sampling over longer time periods; and
- improving our understanding of bioaerosol properties, such as aggregation, which will influence dispersion.

It also concludes that other factors, such as environment variables, should be considered when bioaerosols are studied.

In preparation: Pankhurst, L., Drew, G.H., Pollard, S.J.T. and Tyrrel, S.F. Quantifying receptor exposure to bioaerosols from composting facilities: a critical review.

This review takes a novel approach by analysing the change in the focus of bioaerosol research over the last 20 years. The review highlights the many advances in monitoring methods and the lack of sufficient data to support current monitoring guidelines. Further research into novel and alternative methods is needed to support a change to current monitoring guidelines. In addition, there is still insufficient evidence regarding bioaerosol dispersal and fate in the environment to allow for concrete conclusions to be drawn regarding exposure of sensitive receptors. Most studies to date have focused on sampling and method development, sources and emissions, indoor bioaerosols and health, with very few attempting true exposure assessments at receptor. Due to the lack of validated modelling techniques and the complexities of microbiological sampling, the best available technique for exposure assessment at the moment is intensive sampling strategies. Through repeated sampling, variables such as meteorology, season and local geographical variables can be taken into account. This strategy would allow for the creation of a comparable dataset of bioaerosol concentrations, from both composting and other sources, which would aid in both model validation and future exposure assessments.

Submitted as: Velis, C.A., Pollard, S.J.T., Longhurst, P.J., Drew, G.H. and Smith, R. The mechanical biological treatment (MBT) of waste: a review. Critical Reviews in Environmental Science and Technology, submitted.

This journal paper critically reviews the performance of mechanical–biological treatment (MBT) plants producing refuse-derived fuel or solid recovered fuel (SRF). The paper focuses on the shift from waste to resource management, and the ability of MBT plants to contribute to more sustainable waste/resource management solutions. We assess both the management of material flows through MBT plants as well as the quality management initiatives for SRF. The analysis reveals that insufficient scientifically derived data are available in the public domain on the performance of individual process unit operations that would inform the design of MBT plants to meet the needs of the modern sustainable resource management agenda. However, MBT plants are generally energy intensive mechanised processes and therefore a wider sustainability appraisal of MBT performance, compared with alternative technologies such as anaerobic digestion, should be undertaken. Additional data on specific material properties (e.g. physical properties) are needed to build confidence on MBT-derived SRF as a viable alternative to fossil fuels. The performance of MBT systems requires continued scrutiny to establish a viable waste treatment technology for improved handling of material flows in accordance with sustainable resource management.

2.4 Health impact assessment of alternate week waste collections

This study was commissioned by Wycombe District Council and funded by the Department for Environment, Food and Rural Affairs (Defra) Waste Implementation Programme (WIP). It reviewed the potential health impacts from alternate week waste collection schemes, with particular focus on separate biodegradable waste collection.

Published as: Defra, 2007. Health Impact Assessment of Alternate Week Collections of Biodegradable Waste. Prepared by Drew, G.H., Tamer, A., Hough, R., Chackiath, S., Longhurst, P.J., Broomfield, M., Bellamy, N. and Davies, J. Defra Waste Implementation Programme Report.

Presented as: Drew, G.H., Tamer, A., Hough, R.L., Chakiath, S.J., Broomfield, M., and Longhurst, P.J., 2007. Health Impact Assessment of Alternate Week Waste Collections. The Chartered Institution of Wastes Management Conference and Exhibition, Torbay, 12–15 June 2007.

Wycombe District Council currently operates an alternate week waste collection under its Get Recycling Organic Waste (GROW) scheme. The scheme has been trialled over a 10-year period and currently serves about half the area. Residents are provided with a green bin for cooked and uncooked food waste and garden waste, a paper recycling box and a grey waste bin for residual waste. In addition, since November 2005 around 15,000 residents have also been provided with a can and plastic recycling box.

Although overall reactions among residents have been positive, this study was carried out to investigate any issues relating to odours, insects, rodents and the risks of disease.

This first task in the study compiled a review of evidence on the extent to which health impacts can occur from alternate week waste collection. A limited number of documents cite health concerns with this collection method, but these are not supported by direct evidence of health impacts. This study considered whether lessons could be learned from research on the health impacts of waste management in a wider context, including waste collection, storage and processing. Waste management operations demonstrate continuing improvement in compliance and generally acceptable impacts on human health and the environment. The research literature provided no evidence that alternate week waste collection can cause health impacts. This is consistent with wider studies of the health effects of waste management, which indicate that waste management has at most a minor effect on health.

The literature review was supported by three surveys. The first survey was used to determine whether other local authorities have recorded significantly more health impacts from alternate week waste collection schemes compared to weekly ones. This survey was designed for local authorities on both weekly collection schemes and alternate week collection schemes. During the winter survey, 11 out of 31 local authorities contacted for the survey participated, giving a response rate of 36%. A further 15 different authorities responded during the summer survey, yielding a response rate of 46.8% for the summer survey. Sixteen (62%) of them use an alternate week collection scheme and the remaining ten use a weekly collection scheme.

The second survey asked Wycombe District Council waste operatives to compare the alternate week collection scheme with the previously operated weekly one. The aim of this survey was to determine whether the waste collection operatives noticed an increase in problems that may lead to health impacts since the introduction of the alternate week scheme.

Thirdly, structured questioning of a representative sample of residents was used to collect information on residents' bin management strategies and any self-reported health impacts associated with their household waste. The residents' survey was undertaken in two phases, one in the winter (32.7% response rate; 143 responses) and one in the summer (27.1% response rate; 144 responses), to capture any seasonal differences in their responses.

The results from the local authority survey reveal that, although complaints were received regarding odours, vermin and insects, no local authority found evidence of health impacts associated with alternate week waste collection schemes. Furthermore, the key elements of a successful scheme were communication with the residents, education of the residents, and political support for the scheme.

As waste operatives are a visible presence among residents, they frequently receive complaints from the residents. They were therefore asked if they had noticed any problems since the introduction of the alternate week waste collection scheme. The survey results show that although operatives do receive complaints from residents, they did not report any complaints of health impacts associated with the waste collection scheme.

The results from the residents' survey reveal that while residents on the alternate week collection scheme may experience more amenity impacts, such as odours and insects, the evidence does not allow us to say whether this is linked to the scheme, or whether it is due to a bias in the data. The evidence suggests that no adverse health effects are associated with the alternate week collection scheme, consistent with findings that waste management generally has a low or non-existent effect on health.

Most amenity impact issues can be managed by taking some common-sense steps set out in advice provided by Wycombe District Council:

- keep the waste containers clean, for example by washing and disinfecting between collections;
- keep moisture in waste containers to a minimum;
- put waste into the bin in larger pieces – that is, do not shred or chop kitchen waste;
- keep the waste container outdoors and out of direct sunlight where possible;
- avoid giving shelter opportunities for rodents;
- keep all waste tightly wrapped or in containers; and
- avoid using open compost piles in the garden.

Our research indicates that no significant adverse health effects are likely to be caused by alternate week waste collections. Provided the above steps are taken, amenity impact issues can also be managed.

3 Bioaerosol risk assessments

The Environment Agency requires risk assessments for composting facilities that have a sensitive receptor within 250 m of the facility boundary. The responsibility for interpreting site-specific risk assessments currently falls to Environment Agency regulatory staff, who are not necessarily expert in risk assessment interpretation, although interpretation will move to national teams in the future. At a recent Environment Agency sponsored bioaerosol workshop (Environment Agency, 2006), the lack of inter-comparability between risk assessments was highlighted as a potential influence on the consistency of regulatory decisions. It was therefore decided to undertake a review and critical analysis of bioaerosol risk assessments, in order to highlight good practice and areas for improvement.

In addition, one of the objectives of the Fellowship was to provide technical support to the Environment Agency's operational, policy, process and science staff. A further objective was to transfer knowledge developed during the Fellowship to the Environment Agency. In order to achieve these objectives, a series of workshops were held for Environment Agency operational staff to provide training on bioaerosol risk assessments. Three workshops have been held in Leeds, Birmingham and Swindon, with between 20 and 25 attendees at each. The workshops commenced with an initial introduction to risk assessments, aimed at ensuring all attendees have the same basic understanding of risk assessments. This was followed by an exercise where the attendees were asked to develop a conceptual model of a theoretical composting site. The afternoon of the first day focused on the key aspects of a risk assessment, namely problem definition and risk screening and prioritisation. Examples of risk assessments were used in exercise sessions to demonstrate both good and bad practice.

The second day of the workshops focused specifically on bioaerosols and covered topics such as sampling strategies and methods, and health impacts of bioaerosols, as well as providing data on the range of bioaerosol concentrations that could be found at different composting facilities.

This section describes the results from reviewing these risk assessments and the content from the workshops. The outputs described in this section are:

Submitted as: Drew, G.H., Jordinson, G.M., Smith, M.A. and Pollard, S.J.T. An evaluation of composting and bioaerosol risk assessments: insights for UK best practice. Resources, Conservation and Recycling, submitted.

Presented as: Drew, G.H., Pollard, S.J.T. and Jordinson, G. Bioaerosol and composting risk assessments. Workshop presented to Environment Agency officers September 2007 and January 2008 (Leeds 25 delegates; Swindon 25 delegates; Birmingham 25 delegates). External audience March 2008 (Cranfield 20 delegates).

3.1 Introduction to risk assessments

Risk assessment examines the probability that harm may occur as a consequence of a hazard. A hazard is a substance or situation with the potential to cause harm. The essential questions to ask when undertaking a risk assessment are what is at risk, and what is it at risk from. Specifically, one needs to examine the risk of an initiating event (e.g. major plant failure or collapse of flood defence), the risk of exposure and the risk of harm occurring.

The key stages in a risk assessment are:

- Identify the problem and define the scope of the risk assessment.
- Identify the hazards and characterise the contaminant.
- Identify the pathways through an exposure assessment. In order for a risk to exist, there must be a pathway or exposure mechanism between the hazard and the receptor.
- Estimate the magnitude of the risk and the potential significance or consequences.

Risk assessments provide a basis for management decisions regarding mitigation of potential hazards. They also provide reassurance to both regulators and the local population that facilities are safely operated with consideration of the health and wellbeing of staff, the public and the local environment. Specifically, risk assessments allow the prioritisation of resources in order to support regulatory and operational decisions.

There are a number of key elements to a risk assessment. Table 3.1 provides a description of these, in the context of bioaerosol risk assessments, and potentially serves as a checklist for those assessing risk assessments for completeness. The description of each attribute is framed as a question to assist with assessing the quality of a risk assessment.

Table 3.1 Key components of a bioaerosol or composting risk assessment

Attribute	Description
Problem definition	Have they examined the composting process and Environment Agency policy? Do they state why the risk assessment is being done?
Limitations/uncertainties	Do they state what was not done and why?
Stakeholder involvement	Have any stakeholders been contacted?
Logical/transparent	Does it make sense? Can it be followed easily?
Risk screening and prioritisation	Are all possible risks listed and ranked appropriately?
Magnitude of consequences	Have all these been examined appropriately?
Probability of consequences	Likelihood of consequences occurring? Has this been examined correctly?
Diagrams	Are they present? Are they useful?
Effort related to risks	Has enough work been done to adequately assess the risks?
Options appraisal	Have potential mitigation options been listed and evaluated?
Identification of other emissions	Have they recognised that bioaerosols are not the only problem associated with composting sites?
Process description	Do they provide a site-specific process description that includes all sources, pathways and receptors?
Sampling description	Have they provided full details of sampling techniques, and included activities on-site during sampling, sampling times, sampling locations, equipment used and environmental conditions?
Organisms sampled	Have they stated the organisms sampled for?
Culture techniques	Have they stated details such as media used, incubation temperature and length of incubation?
Assumptions	Have they justified their sampling techniques, organisms sampled and culture techniques?
Appreciation of health risks	Have they shown an understanding of the health

Attribute	Description
	risk associated with this particular site?
Plans to re-visit risk assessment	Do they intend to re-assess the risks regularly, taking into account any changes?
Relevance of information	Is the information site-specific?
Background information	Have background bioaerosols been sampled?
Identification of sensitive receptors	Have they shown type of receptor, distance from site and dominant wind directions?
Identification of other sources	Have they examined other potential influences on bioaerosol concentrations (especially upwind and downwind)?

3.2 Risk assessment evaluation

In this section, we provide a constructive critique of bioaerosol risk assessments submitted to the Environment Agency in support of permitting decisions. This provides valuable insight into the qualities of existing assessments, where opportunities for improvement exist and important input to forthcoming regulatory guidance.

The results of the analysis revealed that the majority of composting risk assessments adequately cover generic risk assessment attributes. However, the majority of the risk assessments do not adequately examine the specific risks associated with bioaerosols and are frequently not based on site-specific monitored data. Given that bioaerosol concentrations vary greatly, depending on local conditions, sampling methods and on-site activities, it is difficult to justify using data from a site that is unlikely to have similar bioaerosol sources. However, where sites are not yet operational, it is still useful to monitor for bioaerosols to gain an understanding of the baseline data associated with other activities in the area. Admittedly, this would probably only be a single snapshot, but in the absence of more advanced methods for monitoring bioaerosols this would be the best available background data for a new composting facility. Furthermore, practitioners need to follow the existing guidance in terms of sampling procedures at the very minimum, and clearly describe their practice, including any assumptions and limitations within the risk assessment. The data and information presented should be relevant and concise; for example, describing the general process of undertaking a risk assessment is not necessary, as this is provided in the guidance documents.

Although the aim of this exercise was to identify good and bad practice, no ideal examples were identified. Instead we found that the majority of risk assessments consisted of both good and bad components, with the whole scoring rather poorly. In particular, the aspects of the regulatory risk assessments requiring attention include (i) descriptions of the limitations and uncertainties within risk analyses; (ii) presentation of methodological details of sampling and analysis; and (iii) the provision of background information. Sections of the risk assessments that display good practice have been highlighted for the Environment Agency personnel in the workshops.

3.3 Impact of workshops

Overall, the response to the workshops was extremely positive. In particular, the second day and the information on bioaerosols was considered to be the most useful by the attendees. The workshop focused on providing the latest scientific information, combined with hands-on exercises, for example, planning a sampling strategy for a theoretical composting facility. This exercise in particular, was useful in providing Environment Agency employees with an alternative view, as they were examining the problem from the perspective of a consultant or operator undertaking the risk assessment. In addition, the exercises were designed to highlight the key attributes that should be included in a risk assessment and provided checklists that could be used by Environment Agency staff after the workshops.

The workshops provided Environment Agency staff with detailed scientific knowledge of bioaerosols, which they were unfamiliar with before the workshops. Without an understanding of the complexities of bioaerosol science, staff may not be fully aware of all the issues and may therefore not have made the correct regulatory decisions. The workshops have allowed Environment Agency permitting and operational staff to make more informed decisions on the quality of risk assessments presented to them.

A further, unexpected benefit, was the sharing of knowledge and experience between Environment Agency operational and science staff. A few members of the Science Team attended the workshop and found learning about the real, practical issues faced by the Environment Agency operational staff enlightening.

4 Dissemination, training and management

This section focuses on dissemination, training and management activities, and is primarily aimed at those interested in the management of the Fellowship.

4.1 Dissemination activities

One of the objectives of this programme was to disseminate information on modelling and monitoring to the Environment Agency and other regulators, academia, consultants and industry. Five journal papers have been published or accepted by international journals with impact factors greater than 2.5, with three manuscripts currently under review. All manuscripts are co-authored with an input of expertise from at least one Environment Agency staff member. A full list of all the outputs can be found in Table 4.1.

The number of citations of a journal paper provides an indication of the impact of the research. To date (August 2008), the Taha et al. (2006) paper has been cited 11 times, with the Drew et al. (2007) being cited once.

In additional to the journal papers, the Fellow has co-authored two project reports and presented at major waste-related international conferences to raise the profile of the work programme. These include the 10th European Biosolids and Biowastes Conference (Wakefield, 2005, approximately 200 delegates) and the Waste 2006 Conference (Stratford, 2006), both on modelling of downwind dispersion of bioaerosols. A paper on the health impacts of alternate week waste collections was presented by the Fellow at the Chartered Institution of Wastes Management (CIWM) Conference in Torbay, June 2007 (approximately 6,000 delegates). In addition, two papers were presented at the Eleventh International Waste Management and Landfill Symposium held in Sardinia in October 2007 (approximately 1,200 delegates). In total, the conferences papers have been distributed to approximately 8,000 people.

Table 4.1 Publications associated with the Fellowship

Published journal papers
Taha, M.P.M., Tamer, A., Aldred, D., Drew, G.H., Longhurst, P.J. and Pollard, S.J.T., 2007. Enumerating actinomycetes in compost bioaerosols at source – use of soil compost agar to address plate 'masking'. *Atmospheric Environment,* 41(22), 4759–4765.
Taha, M.P.M., Drew, G.H., Tamer, A., Hewings, G., Jordinson, G., Longhurst, P.J. and Pollard, S.J.T., 2007. Improving bioaerosol exposure assessments of composting facilities – comparative modelling of emissions from different compost ages and processing activities. *Atmospheric Environment,* 41(21), 4504–4519.
Drew, G.H., Smith, R., Gerard, V., Burge, C., Lowe, M., Kinnersley, R., Sneath, R., and Longhurst, P.J., 2007. Appropriateness of selecting different averaging times for modelling chronic and acute exposure to environmental odours. *Atmospheric Environment,* 41(13), 2870–2880.
Macleod, C.J., Duarte-Davidson, R., Fisher, B.E.A., Ng, B., Willey, D., Shi, J.P., Martin, I., Drew, G. and Pollard, S., 2006. Modelling human exposures to air pollution control

(APC) residues released from landfills in England and Wales. *Environment International*, 32, 500–509.

Taha, M.P.M., Drew, G.H., Longhurst, P.J., Smith, R. and Pollard, S.J.T, 2006. Bioaerosol releases from compost facilities: evaluating passive and active source terms at a green waste facility for improved risk assessments. *Atmospheric Environment*, 40(6), 1159–1169.

Journal papers submitted

Velis, C.A., Pollard, S.J.T., Longhurst, P.J., Drew, G.H. and Smith, R., The mechanical biological treatment (MBT) of waste: a review. *Critical Reviews in Environmental Science and Technology,* submitted.

Jehlickova, B., Longhurst, P.J. and Drew, G.H., 2008. Assessing effects of odour: a critical review of assessing annoyance and impact on amenity. Third IWA Odour and VOCs Conference, Barcelona, 8–10 October 2008.

Drew, G.H., Pollard, S.J.T. and Jordinson, G.M. An evaluation of composting and bioaerosol risk assessments: insights for UK best practice. *Resources, Conservation, Recycling,* submitted.

Journal papers in preparation

Drew, G.H., Jordinson, G.M., Gladding, T.L., Pollard, S.J.T. and Tyrrel, S.F. Variability of monitored bioaerosols concentrations at composting facilities.

Drew, G.H., Nogami, A., Tamer Vestlund A., Pankhurst, L., Seymour, I., Batty, W., Pollard, S.J.T. and Tyrrel S.F., Monitoring and variation of bioaerosols at composting facilities using conventional and novel samplers.

Pankhurst, L., Drew, G.H., Pollard, S.J.T. and Tyrrel, S.F. Quantifying receptor exposure to bioaerosols from composting facilities: a critical review.

Tamer Vestlund, A., Drew, G.H., Tyrrel, S.F., Jordinson, G.M. and Pollard, S.J.T. A critical review of current issues in composting bioaerosol risk assessments.

Conferences and workshops

Drew, G.H., Pollard, S.J.T. and Jordinson, G. Bioaerosol and composting risk assessments. Workshop presented to Environment Agency officers September 2007 and January 2008 (Leeds 25 delegates; Swindon 25 delegates; Birmingham 25 delegates). External audience March 2008 (Cranfield 20 delegates).

Tamer Vestlund, A., Drew, G.H., Jehlickova, B., Olsen, P., Sneath, R., Tyrrel, S., Longhurst, P.J., Jordinson, G. and Pollard, S.J.T., 2007. Bioaerosol and odour emissions: a comparison of three composting sites in Scotland. Eleventh International Waste Management and Landfill Symposium, Sardinia, 1–5 October 2007.

Drew, G.H., Tamer Vestlund, A., Jordinson, G., Smith, R., Tyrrel, S., Longhurst, P.J. and Pollard, S.J.T., 2007. Progress towards a Best Practice Method for Modelling Dispersion of Bioaerosols from Composting Facilities. Eleventh International Waste Management and Landfill Symposium, Sardinia, 1–5 October 2007.

Drew, G.H., Tamer, A., Hough, R.L., Chakiath, S.J., Broomfield, M. and Longhurst, P.J., 2007. Health impact assessment of alternate week waste collections. The Chartered Institution of Wastes Management Conference and Exhibition, Torbay, 12–15 June 2007.

Drew, G.H., Tamer, A., Taha, M.P.M., Smith, R., Longhurst, P.J., Kinnersley, R. and Pollard, S.J.T., 2006. Dispersion of bioaerosol from composting facilities. Paper

presented at the Waste 2006 Conference, Stratford, 19–21 September 2006.

Drew, G.H., Smith, R., Pollard, S.J.T., Longhurst, P.J. and Kinnersley, R., 2005. Amenity impacts of episodic emissions from composting facilities. Paper presented at the 10th European Biosolids and Biowastes Conference Workshop and Exhibition, Wakefield, 13–16 November 2005.

Reports

SEPA/SNIFFER, 2007. Bioaerosol and Odour Monitoring from Three Composting Sites. Prepared by Drew, G.H., Tamer Vestlund, A., Tyrrel, S.F., Longhurst, P.J. and Pollard, S.J.T. SNIFFER Research Project UKPIR12. Available online at http://www.sniffer.org.uk.

Defra, 2007. Health Impact Assessment of Alternate Week Collections of Biodegradable Waste. Prepared by Drew, G.H., Tamer, A., Hough, R., Chackiath, S., Longhurst, P.J., Broomfield, M., Bellamy, N. and Davies, J. Defra Waste Implementation Programme Report.

In addition to the reports, journal and conference papers described in this report, the Fellow has also published trade articles on bioaerosols in the Environmental KTN newsletter (audience approximately 5,000) and was invited to author the Composting Association's 'Buyer's Guide to Odour and Bioaerosols' (Summer 2008 issue).

The Fellow has also attended and presented at the Environment Agency's workshop on bioaerosols associated with green waste composting, held in February 2006, and the Environment Agency's Biowaste Network meeting held in Birmingham in June 2006.

As a direct result of the Fellowship, Cranfield University was invited to participate in a CEN working group on bioaerosol monitoring methods. Cranfield University is represented by Dr Sean Tyrrel. The CEN working group (CEN/TC264/WG28) aims to produce a suite of standard methods for measuring micro-organisms in ambient air. The first method to be standardised is a filtration method based on the authoritative German VDI guidance.

The Fellow has also begun to develop a network of contacts through collaborative projects (see Table 4.2). These include other regulators, policy makers and lead organisations (Scottish Environmental Protection Agency, Scottish and Northern Ireland Forum For Environmental Research, Defra and South East Waste Advisory Group, and Waste and Resources Action Programme), academia (e.g. the University of Kitakyushu in Japan, the Open University and University of the West of England, Bristol), industry (e.g. SITA UK, TEG and Donarbon Waste Management) and consultants (e.g. Enviros Consulting Ltd and SLR Consulting).

Table 4.2 Contacts and associations developed by the Fellowship

Name	Organisation	Role/specialism
Alison Gowers	Environment Agency Health Science Team	Fellowship Project Manager: August – December 2007
Greg Jordinson	Environment Agency Health Science Team (moved to GSK)	Senior Scientist – Human Health Fellowship Project Manager: October 2005 – August 2007
Jan Gronow	Environment Agency (retired)	Fellowship Project Manager: January – October 2005
Rob Kinnersley	Environment Agency	Principal Scientist – Air Quality
Mike Smith	Environment Agency	Biowaste Technical Adviser
Nina Sweet	Environment Agency	Policy Advisor biological

		treatment (secondment to WRAP as the Anaerobic Digestion Technical Specialist)
Dr Peter Olsen	Scottish Environmental Protection Agency (SEPA)	Senior Policy Officer, Biowaste
Gina Martin	SNIFFER	Research co-ordinator
Dr Robert Sneath	Silsoe Odours Ltd	Managing Director
Dr Brian Crook	HSL	Principal Occupational and Environmental Microbiologist
Dr Stephen Wise-Merry	Shanks (ex-SITA UK)	Composting and biowaste
Dr Philippa Yates	SITA UK	Operations Manager – South
Andrew Finney	SITA UK	Operations Manager – North
Emily Nichols	Composting Association	Technical Manager
Dr Angela Cronje	TEG Environmental plc	Technical Manager
Prof. Ian Pepper	University of Arizona	Environmental microbiologist specialising in the molecular ecology of the environment
Dr Caroline Herr	Institute of Hygiene and Environmental Medicine, Giessen, Germany	Senior Registrar
Dr Inge Wouters	Institute of Risk Assessment Science University of Utrecht	
Simon Parker	Porton Down	
Dr Toni Gladding	Open University	Lecturer – Occupational exposure to bioaerosols
Prof. Simon Jackson	University of the West of England, Bristol	Molecular immunology – endotoxin expert
Dr Mark Broomfield	Enviros Consulting Ltd	Technical Director
Jonathon Davies	Enviros Consulting Ltd	Commercial Director
John Enright	Defra WIP	Head of Local Authority Support Unit
Ian Paton	Paton & Associates Ltd	Composting consultant
Sarah Clover	Donarbon Waste Management	Planning Manager
Dr Enda Hayes	Air Quality Management Resource Centre, University of the West of England, Bristol	Research Associate
Dr Phil Hobbs	Institute of Grassland and Environmental Research	
Prof. A Nogami	University of Kitakyushu, Japan	
Sally Gordon	Wycombe District Council	Waste & Recycling Services Manager
Sarah Wilkinson	CERC	Senior Consultant
Richmond Kingsbury	SLR Consulting	
Elaine Malarky	South Bedfordshire District Council	
Peter Sykes	Cardiff School of Health Sciences, University of Wales Institute Cardiff	Senior Lecturer
John Allen	Cardiff School of Health Sciences, University of Wales Institute Cardiff	Consultancy & Training Officer
Rhys Sherman	Cardiff School of Health	Consultancy & Training Officer

	Sciences, University of Wales Institute Cardiff	
Sandra Davies	D & F Associates	Consultant
Andrew Goddard	Viridor Waste Management	Technical Manager
David Willay	RPS Consultancy	Consultant

4.2 Associated projects

The Environment Agency invested £189,000 in the Fellowship. Financial leverage has been gained to the value of £604,000 through additional funding and associated projects secured by the Fellow (Table 4.3). Although it is difficult to estimate the costs that could have been incurred if this research had not been undertaken, it is possible to examine the impact of some of the activities.

For example, the cost of a two-day training course similar to the risk assessment workshops, could be within the region of £550 per delegate. Overall, 75 Environment Agency personnel attended the workshops, which would have cost £41,250 in fees alone. In addition, if each workshop attendee were to transfer the knowledge gained to just five of their colleagues, then a total of 375 personnel would have benefited from these workshops.

Table 4.3 Projects that have supported and contributed to the Fellowship work programme

Title	Funders	Financial contribution
Doctoral Training Account (PhD student: Asli Tamer)	EPSRC	£60,000
Student top-up funding (PhD student: Asli Tamer)	SEPA	£15,000
Student top-up funding (PhD student: Asli Tamer)	SNIFFER	£20,000
Continued professional development studentship (PhD student: M.P.M. Taha, completed)	Malaysian Department of Health	£45,000
Community odour modelling (PhD student: Mirka Jehlickova)	WRG	£170,000
Health impacts of alternate week waste collections (with Wycombe District Council)	Defra WIP	£25,000
CASE Award (PhD student: Louise Pankhurst)	IPM-Net	£45,000
Student top-up funding (PhD student: Louise Pankhurst)	SITA UK	£20,000
Testing of innovative aerosol samplers	City of Kitakyushu, Japan	£15,000

Title	Funders	Financial contribution
In kind contribution for testing of innovative aerosol samplers	University of Kitakyushu, Japan	£4,000
Consultancy projects, including bioaerosol and odour risk assessments	Various	£35,000
Environmental exposure to endotoxin emissions from commercial composting activities	NERC Environment and Human Health Programme	£150,000

The Fellow had the responsibility for day-to-day supervision of four PhD candidates, whose projects fall within the remit of the programme. These are:

- Mohamad Pauze Taha – Bioaerosol releases from composting facilities (completed).
- Asli Tamer Vestlund – Incorporating bioaerosol properties in regulatory risk assessments.
- Mirka Jehlickova – Developing existing relationships that define amenity impacts from landfill odour emission and community monitoring.
- Louise Pankhurst – Improving best practice methods for regulatory risk assessments at organic waste treatment facilities.

In addition to the above, the training and research linked to the Fellowship programme will continue through ongoing training and research activities. The training activities include:

- development of the bioaerosol risk assessment workshops into a short course to be offered annually;
- incorporation of the bioaerosol risk assessment workshops into the Environmental Diagnostics MSc programme; and
- development of industrial short courses on odour.

The ongoing research activities include:

- Two PhD student projects (Asli Tamer Vestlund and Louise Pankhurst).
- The NERC funded project on environmental exposure to endotoxin emissions from commercial composting facilities.
- Publication of at least two further journal papers relating to bioaerosol risk assessments and modelling.

The results of these research activities will be communicated to the Environment Agency through the links established by the Fellowship.

5 Conclusions and recommendations

5.1 Scientific and research outputs

This section summarises the knowledge developed, published and disseminated to Environment Agency staff. In particular, our understanding of bioaerosols emitted from composting facilities has been improved. We have:

- Demonstrated the ability to collect accurate source term data from compost windrows using the wind tunnel approach. This progress provides the potential to model downwind bioaerosol concentrations based on source data that are not contaminated by other bioaerosol sources.
- Shown that the highest bioaerosol emissions are related to compost agitation activities, such as turning, shredding and screening. This information allows us to focus on peak emissions for further studies and for risk mitigation measures.
- Improved enumeration of bioaerosols through the development of a new soil compost agar for actinomycetes.
- Undertaken statistical analysis of replicated bioaerosol sampling, which has shown a high degree of variability, suggesting that caution should be exercised when interpreting the results of bioaerosol surveys with low levels of replication.
- Shown that variables including wind speed, processing activities, season and the type of facility influence bioaerosol concentration. In particular, high wind speeds and agitation activities are likely to result in higher concentrations of bioaerosols being detected further downwind during on-site monitoring. However, to date, there is still insufficient evidence to support a change to the current 250 m risk assessment limit.
- Shown that the current generation of air dispersion models offer a potentially valuable tool to model downwind concentrations of bioaerosols. In particular, the ADMS 3.3 provides a useful overview of emissions as it allows the incorporation of several different sources at the site and it has the ability to model intermittent sources, which closely resembles the true pattern of emissions from composting facilities.
- Demonstrated that the averaging time used in modelling studies can influence predicted concentrations, with shorter averaging times resulting in higher ground-level concentrations. Using hourly averaging times is less successful at capturing peak concentrations.
- Examined the quality of the bioaerosol risk assessments submitted to the Environment Agency and found the quality of these to be very variable. In particular, risk assessments tend not to be site-specific and lack bioaerosol monitoring data. Where bioaerosol concentrations have been sampled, practitioners do not always follow the existing guidance, which complicates comparison with other studies.

5.2 Dissemination, training and management

The Fellowship has produced outputs that go beyond pure scientific understanding. These include:

- Associated projects and collaborations to the value of £604,000 have contributed to the success of the work programme undertaken by the Fellowship.
- Five published journal papers, with a further four in preparation and three submitted for publication, as well as six conference papers and two published project reports.
- 75 Environment Agency personnel have been trained in bioaerosol risk assessment and bioaerosol science at three workshops (Leeds, Swindon and Birmingham).
- Advice to Environment Agency officers has been provided in response to requests regarding bioaerosol risk assessments.
- The Fellowship has supported the development and training of both the Post-doctoral Fellow and four PhD students. This has established the Fellow's academic career and resulted in the promotion of the Fellow to Lecturer at Cranfield University. This permanent appointment of the Fellow will allow the existing relationship between the Environment Agency and Cranfield University to continue.
- The work programme of the Fellow has developed a network of contacts within waste operators, local authorities, government agencies and consultants. This has raised the profile of the Environment Agency, the Fellowship, and the confidence in the scientific basis for outputs that underpin and provide scientific evidence for regulatory decisions.

5.3 Impact of the Fellowship

By providing a significant number of peer reviewed scientific papers, this Fellowship has helped to develop a credible scientific base from which the Environment Agency can develop its policies with regard to human health, bioaerosols and odour. The scientific insights gained during the Fellowship have been communicated to Environment Agency staff and stakeholders and one area where this will have an immediate impact is through improvements to the interpretation and development of bioaerosol risk assessments. A willingness to engage with both industry and academia has given the Environment Agency credibility in an area where this has been lacking and has demonstrated the Environment Agency's commitment to developing this science area.

5.4 Recommendations

Although a significant amount of progress and success has been achieved by the Fellowship and the associated work programme, several areas for further research can be suggested in the areas of bioaerosols monitoring, modelling, mitigation, health impacts and risk assessments.

5.4.1 Monitoring guidance

The existing bioaerosol sampling guidance (Composting Association, 1999) represented the state-of-the-art when it was compiled. However, recent advances in bioaerosol science suggest that it is now time to review and update this guidance to reflect these new findings. This should include a reference to the new CEN/ISO standardisation initiatives in this and related fields. Furthermore, the variability between samples and the exact relationship between bioaerosol concentration and variables such as weather conditions, sampling methods and facility characteristics requires further research. This could be achieved through replicated sampling strategies associated with the sampling details described below. The detailed sampling strategies suggested above should be supported by exploration of novel sampling methods, particularly those that go beyond just culturable organisms. This information could be used to support a change to existing, outdated guidance on bioaerosol monitoring. The Environment Agency, in association with the Composting Association (now The Association for Organics Recycling), should consider reviewing the existing monitoring guidance.

5.4.2 Bioaerosol modelling

Although progress has been made in modelling downwind dispersion of bioaerosols, we are currently not in a position to recommend the use of models as tools in regulatory risk assessment. Further research is needed and should focus on:

- Obtaining detailed, accurate data to validate current bioaerosols dispersion modelling techniques. This should include samples taken upwind, at source, at agitation activities and downwind. In addition, detailed information on local conditions during sampling should be noted.
- Obtaining more information on bioaerosol properties, especially particle size and aggregation (work under way: Asli Tamer Vestlund PhD project). This will assist in the calibration and validation of dispersion models, which will give us confidence in their ability to model downwind dispersion of bioaerosols.

Dispersion modelling of bioaerosols could be used to support on-site monitoring by providing further information on downwind exposure of receptors to bioaerosols. This information would assist operators in completing risk assessments for composting facilities and assist Environment Agency personnel in assessing the risks. It is therefore recommended that the Environment Agency supports further research into the development of dispersion modelling techniques for bioaerosols. In addition, this research should be supported by compost facility operators.

5.4.3 Bioaerosol mitigation

The composting process relies on micro-organisms and so will always produce a certain level of bioaerosol emissions. This research programme has identified conditions that result in higher releases of bioaerosols, such as during agitation activities (screening, shredding and turning). Despite not focusing on mitigation methods, this research programme has demonstrated the lack of detailed statistical data on the efficacy of bioaerosol mitigation methods. In particular, there is little information on the ability of biofilters to reduce bioaerosol emissions, and this is therefore highlighted as an area for further research. As operators are required to show that bioaerosol emissions can be mitigated or minimised through their risk assessments, this issue is within the permitting functions of the Environment Agency. It is therefore recommended that the Environment Agency undertake or support further research into this area.

5.4.4 Bioaerosol health impacts

Although not specifically covered within the work programme of this Fellowship, the health impacts and dose–response relationships of bioaerosols remains a large knowledge gap within bioaerosol science. Risk assessments are hampered by a lack of knowledge of the health significance of measured bioaerosol concentrations. Work on standardised methods and dose–response relationships is needed as a precursor to the development of threshold values. As this is a significant piece of research, it is recommended that a consortium of partners undertake this research, including bioaerosol scientists and medical health practitioners, with support from the appropriate Research Councils.

5.4.5 Risk assessment guidance

The Environment Agency should encourage practitioners submitting bioaerosol risk assessments to undertake site-specific bioaerosol monitoring, in order to more accurately assess the risks associated with individual sites. In the absence of new monitoring guidance, practitioners should be encouraged to closely follow existing guidance on bioaerosol monitoring. The Environment Agency should consider publishing guidance on bioaerosol risk assessment aimed at both its personnel who review the risk assessments, and practitioners undertaking risk assessments.

References

ADAS/SWICEB, 2005. *Bioaerosol Monitoring and Dispersion from Composting Sites.* SWICEB report, August 2005.

Balestra, G.M., and Misaghi, I.J., 1997. Increasing the efficiency of the plate counting method for estimating bacterial diversity. Journal of Microbiological Methods, 30, 111-117.

Best, P.R., Lunney, K.E. and Killip, C.A., 2001. Statistical elements of predicting the impact of a variety of odour sources. *Water Science and Technology,* 44(9), 157–164.

Bouzalakos, S., Jefferson, B., Longhurst, P.J. and Stuetz, R.M., 2004. Developing methods to evaluate odour control products. *Water, Science and Technology*, 50(4), 225–232.

Brode, R.W., 1991. A comparison of SCREEN model dispersion estimates with estimates from a refined dispersion model. *Seventh Joint Conference on Applications of Air Pollution Meteorology with A&WMA*, 93–96.

Carruthers, D.J., Holroyd, R.J., Hunt, J.C.R., Weng, W.S., Robins, A.G., Apsley, D.D., Thompson, D.J. and Smith, F.B., 1994. UK-ADMS: a new approach to modelling dispersion in the earth's atmospheric boundary layer. *Wind Engineering and Industrial Aerodynamics*, 52, 139–153.

CEN, 2003. *Air Quality—Determination of Odour Concentration by Dynamic Olfactometry*. CEN EN 13725: 2003.

CERC, 2003. *ADMS 3 Technical Specification*. Cambridge Environmental Research Consultants.

Chang, C.W., Hwang, Y.H., Grinshpun, S.A., Macher, J.A. and Willeke, K., 1994. Evaluation of counting error due to colony masking in bioaerosol sampling. *Applied and Environmental Microbiology*, 60(10), 3732–3738.

Chang, C.W., Grinshpun, S.A., Willeke, K., Macher, J.A., Donnelly, J., Clark, S. and Juozaitis, A., 1995. Factors affecting microbiological colony count accuracy for bioaerosol sampling and analysis. *American Industrial Hygiene Association Journal,* 56(10), 979–986.

Chen, C.C., Yu, T.S., Chang, J.Y., Chang, C.W., Shih, T.S. and Hwang, J.S., 1998. A computer simulation study on bioaerosol colony counting error due to masking effect. *Annals of Occupational Hygiene*, 41(7), 501–510.

Composting Association, 1999. *Standardised Protocol for the Sampling and Enumeration of Airborne Micro-Organisms at Composting Facilities*. ISBN 0 9532546 2 3, 30 pp.

Defra, 2007. *Health Impact Assessment of Alternate Week Collections of Biodegradable Waste*. Prepared by Drew, G.H., Tamer, A., Hough, R., Chackiath, S., Longhurst, P.J., Broomfield, M., Bellamy, N. and Davies, J. Defra Waste Implementation Programme Report.

Drew, G.H., Smith, R., Gerard, V., Burge, C., Lowe, M., Kinnersley, R., Sneath, R. and Longhurst, P.J., 2007. Appropriateness of selecting different averaging times for modelling chronic and acute exposure to environmental odours. *Atmospheric Environment*, 41(13), 2870–2880.

Environment Agency, 2004. *An Environmental Risk Management Framework for Composting Facilities in England and Wales*. Environment Agency internal guidance prepared by Pollard, S., Tyrrel, S. and Longhurst, P. (Cranfield University), Version 1.0, October 2004, Environment Agency, Bristol, 41 pp.

Environment Agency, 2006. *International Workshop on Bioaerosols from Green Waste Composting*. Available online at http://www.environment-agency.gov.uk.

Environment Agency, 2008. Bioaerosols in waste composting: deriving source terms and characterising profiles. Prepared by Crook B, Stagg S and Uwagboe UC. In preparation.

Fitt, B.D.L., Gregory, P.H., Todd, A.D., McCartney, H.A. and Macdonald, O.C., 1987. Spore dispersal and plant disease gradients: a comparison between two empirical models. *Journal of Phytopathology*, 117, 227–242.

GOAA, 1999. *Guideline on Odour in Ambient Air – Determination and Assessment of Odour in Ambient Air* (1994). (Feststellung und Beurteilung von Geruchsimmissionen – Geruchsimmiions-Richtlinie) Länderausschuss für Immissionsschutz, LAI-Schriftenreihe No. 5, Berlin; revised version 1999 (available in English). Available online at http://www.lua.nrw.de/luft/gerueche/infos.htm.

Health and Safety Executive, 2003. *Occupational and Environmental Exposure to Bioaerosols from Composts and Potential Health Effects – A Critical Review of Published Data*. The Composting Association and Health and Safety Laboratory, Research Report 130.

Kalogerakis, N., Paschali, D., Lekaditis, V., Pantidou, A., Eleftheriadis, K. and Lazaridis, M., 2005. Indoor air quality – bioaerosol measurements in domestic and office premises. *Aerosol Science*, 36, 751–761.

Karlsson K, Malmberg P. Characterization of exposure to molds and actinomycetes in agricultural dusts by scanning electron microscopy, fluorescence microscopy and the culture method. Scand. J. Work. Environ. Health 1989; 15: 353-359

Lacey, J., 1997. Actinomycetes in compost. *Annals of Agricultural and Environmental Medicine*, 4, 113–121.

Lacey, J. and Dutkiewicz, J., 1976. Isolation of actinomycetes and fungi from mouldy hay using a sedimentation chamber. *Journal of Applied Bacteriology*, 41, 315–319.

Lewicki, R.A. and Longhurst, P.J., 2000. Evaluation of odour control methods for landfill and waste management facilities. *Proc. Waste 2000: Waste Management at the Dawn of the Third Millennium*, Stratford-upon-Avon, UK, 2–4 October 2000, pp. 515–524.

Lindvall T. and Radford, E.P., 1973. Measurement of annoyance due to exposure to environmental factors. In: *The Fourth Karolinska Institute Symposium on Environmental Health*, Environmental Research, pp. 1–36.

Macleod, C.J., Duarte-Davidson, R., Fisher, B.E.A., Ng, B., Willey, D., Shi, J.P., Martin, I., Drew, G. and Pollard, S., 2006. Modelling human exposures to air pollution control (APC) residues released from landfills in England and Wales. *Environment International*, 32, 500–509.

Miedema, H.M.E., Walpot, J.I., Vos, H. and Steunenberg, C.F., 2000. Exposure–annoyance relationships for odour from industrial sources. *Atmospheric Environment*, 34, 2927–2936.

Millner, P.D., Bassett, D.A. and Marsh, P.B., 1980. Dispersal of Aspergillus fumigatus from sewage sludge compost windrows subjected to mechanical agitation in open air. Applied and Environmental Microbiology, 39(5), 1000–1009.

Millner, P.D., Olenchock, S.A., Epstein, E., Rylander, R., Haines, J., Ooi, B.L., Horne, E. and Maritato, M. (1994) Bioaerosols associated with composting facilites. *Compost Science and Utilization*, 2(4), 8-57.

National Audit Office, 2002. *Environment Agency, Protecting the Public from Waste*. Report by the Comptroller and Auditor General, The Stationery Office, London, 60 pp.

Nielsen EM, Breum NO, Nielsen BH, Würtz H, Poulsen OM, Midtgaard U. Bioaerosol exposure in waste collection: a comparative study on the significance of collection equipment; type of waste and seasonal variation. Ann. Occ. Hyg. 1997; 41:325-344.

Niemi, R.M., Knuth, S. and Lundström, K., 1982. Actinomycetes and fungi in surface waters and in potable water. *Applied and Environmental Microbiology*, 43(2), 378–388.

Patent of Japan Publication number: 2005-152849. Filter for catching floating particulate, method of catching floating particulate using the same, method of analyzing floating particulate, and catching apparatus of floating particulate. Date of request for examination: 31.10.2006 (under examination).

Pasquill, F., 1961. The estimation of the dispersion of windborne material. *Meteorological Magazine*, 90, 33–49.

Pollard SJT, Smith R, Longhurst PJ, Eduljee G, Hall, D. Recent developments in the application of risk analysis to waste technologies. Environ. International 2006; 32(8): 1010-1020.

Sarkar, U., Hobbs, S.E. and Longhurst, P.J., 2003. Dispersion of odour: a case study with a municipal solid waste site in North London, United Kingdom. *Journal of Environmental Management*, 68(2), 153–160.

SEPA/SNIFFER, 2007. *Bioaerosol and Odour Monitoring from Three Composting Sites*. Prepared by Drew, G.H., Tamer Vestlund, A., Tyrrel, S.F., Longhurst, P.J. and Pollard, S.J.T. SNIFFER Research Project UKPIR12. Available online at http://www.sniffer.org.uk.

Sheridan, B.A., Hayes, E.T., Curran, T.P. and Dodd, V.A., 2004. A dispersion modelling approach to determining the odour impact of intensive pig production units in Ireland. *Bioresource Technology*, 91, 145–152.

Stetzenbach LD, Buttner MP, Cruz P. Detection and enumeration of airborne biocontaminants. Current Opin. Biotechnol. 2004; 15: 170-174.

Strom, P.F., 1985. Identification of thermophilic bacteria in solid-waste composting. *Applied and Environmental Microbiology*, 50(4), 906–913.

Swan, J.R.M., Kelsey, A., Crook, B. and Gilbert, E.J., 2003. Bioaerosol components and hazard to human health. In: *Occupational and Environmental Exposure to Bioaerosols from Composts and Potential Health Effects – A Critical Review of Published Data*, Research report 130, HSE Books, pp. 15–20.

Taha, M.P.M., Pollard, S.J.T., Sarkar, U. and Longhurst, P.J., 2004. The influence of process variables on bioaerosol emission flux and exposure – estimating fugitive bioaerosol releases from static compost windrows. *Proc. Biodegradable and Residual Waste Management*, Harrogate, UK, 18–19 February 2004, pp. 268–275.

Taha, M.P.M., Pollard, S.J.T., Sarkar, U. and Longhurst, P.J, 2005. Estimating fugitive bioaerosol releases from static compost windrows: feasibility of a portable wind tunnel approach. *Waste Management*, 25, 445–450.

Taha, M.P.M., Drew, G.H., Longhurst, P.J., Smith, R. and Pollard, S.J.T., 2006. Bioaerosol releases from compost facilities: evaluating passive and active source terms at a green waste facility for improved risk assessments. *Atmospheric Environment*, 40(6), 1159–1169.

Taha, M.P.M., Tamer, A., Aldred, D., Drew, G.H., Longhurst, P.J. and Pollard, S.J.T., 2007a. Enumerating actinomycetes in compost bioaerosols at source – use of soil compost agar to address plate 'masking'. *Atmospheric Environment*, 41(22), 4759–4765.

Taha, M.P.M., Drew, G.H., Tamer, A., Hewings, G., Jordinson, G., Longhurst, P.J. and Pollard, S.J.T., 2007b. Improving bioaerosol exposure assessments of composting facilities – comparative modelling of emissions from different compost ages and processing activities. *Atmospheric Environment*, 41(21), 4504–4519.

Tanaka, M. Design of novel biointerfaces (I). Blood compatibility of poly(2-methoxyethyl acrylate). Bio-Medical Materials and Engineering, 2004, 14, 427-438.

Tanaka, M., Takebayashi, M., Miyama, M., Nishida and J., Shimomura, M. Design of novel biointerfaces (II). Fabrication of self-organized porous polymer film with highly uniform pores. Bio-Medical Materials and Engineering, 2004, 14, 439-446.

Tominaga E., Nogami A. ,Sawa Y. ,Kakimoto K. ,Kudo Y.,Tanaka M. and Shimomura M. Individual capture and quick analyze of SPM by using honeycomb polymer film –an application to fiber-shaped fine particles. The 23nd Symposium on Aerosol Science & Technology, 2006, 205-206 (in Japanese).

USEPA, 1995a. *User's Guide to the Industrial Source Complex (ISC3) Dispersion Models (Revised). Volume 1 – User Instructions*. EPA-454/B-95–003a. US Environmental Protection Agency, Research Triangle Park, NC.

USEPA, 1995b. *SCREEN3 Model User's Guide.* EPA-454/B-95-004. US Environmental Protection Agency, Research Triangle Park, NC.

USEPA, 1996. *SCREEN3 Model Change Bulletin.* 12 February 1996. US Environmental Protection Agency, Research Triangle Park, NC. Available online at http://www.epa.gov/scram001/mcbs/scrz2.txt.

Wheeler P.A., Stewart, I., Dumitrean, P. and Donovan, B., 2001. *Health Effects of Composting: A Study of Three Compost Sites and Review of Past Data*. R&D Technical Report P1-315/TR, Environmental Agency, Bristol.

List of abbreviations

ADMS – Atmospheric Dispersion Modelling System

CEN – European Committee for Standardisation

CERC – Cambridge Environmental Research Consultants

cfu – colony forming units

cfu/m^3 – colony forming units per metre squared

cfu/s – colony forming units per second

CIWM – Chartered Institute of Wastes Management

COMPLEX-I – a screening level air dispersion model from the USEPA

Defra – Department for Environment, Food and Rural Affairs

GOAA – Guideline on odour in ambient air

GROW – Get Recycling Organic Waste

IOM – Institute of Occupational Medicine

ISCST3 – Industrial Source Complex (ISC3) Short Term Dispersion Model

MBT – mechanical biological treatment

ou_E – European odour units

SCA – soil compost agar

SCREEN3 – a single-source Gaussian plume dispersion model

SEPA – Scottish Environment Protection Agency

SNIFFER – Scotland and Northern Ireland Forum For Environmental Research

SRF – solid recovered fuel

SWICEB – South West Industrial Crops Ltd

USEPA – US Environmental Protection Agency

WIP – Waste Implementation Programme

Glossary

Actinomycetes – A specific group of bacteria that are capable of forming very small spores.

Acute – referring to exposures and effects occurring on a relatively short timescale (e.g. hours or days).

Aerobic – An organism or process that requires oxygen.

Aerosol – A suspension in a gaseous medium of solid particles, liquid particles or solid and liquid particles having a negligible falling velocity.

Agar – A gelatinous material derived from marine algae, used as a base for bacterial culture media and as a stabiliser and thickener in food.

Anaerobic – A metabolic process occurring in the absence of oxygen.

Aspergillus fumigatus – Species of fungus with spores that can cause allergic reactions in some people.

Bacteria – A group of micro-organisms with a primitive cellular structure, in which the genetic material is not retained within an internal membrane (nucleus).

Bioaerosols – Micro-organisms suspended in air.

Chronic – Refers to exposures and effects occurring on a relatively long timescale, typically years.

Colony forming units (cfu) – Unit of measure for micro-organism numbers that relies on bacteria to grow to form colonies on nutrient plates that can be subsequently counted.

Dose–response relationship – The characterisation of the effect of an agent or substance with increasing exposure.

Exposure – Exposure to a chemical is the contact of that chemical with the outer boundary of the human body, including the skin and openings of the body such as the mouth, nostrils, and punctures and lesions in the skin.

Fungi – A group of micro-organisms with a more complicated cellular structure than bacteria, in which the hereditary genetic material is retained within an internal membrane, forming a nucleus.

Gaussian – Exhibiting properties that follow the statistical distributions developed by the German mathematician Gauss.

Hazard – The potential of an activity, object or exposure to cause harm.

Impact – A measure of the effect of an activity, object or exposure upon a receptor.

Moisture content – Percentage of a substance comprised of water. Moisture content equals the mass of the water portion divided by the total mass.

Odour units (OU) – Odour units are the unit of measuring the strength of odours. They are the number of dilutions required for 50% of the population to detect the odour.

ou_E – Odour units measured using methods conforming to the European Standard for Olfactometry

Pasquill stability classes – Stability classes are defined for different meteorological situations, characterised by wind speed and solar radiation (during the day) and cloud cover during the night.

Pathogen – Any organism capable of producing disease through infection.

Receptor – Components of the environment one wishes to protect.

Risk – The likelihood that a hazard will actually cause harm.

Risk assessment – An evaluation, often quantitative in nature, of the level of risk associated with an activity, object or exposure.

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Environment Agency
Rio House
Waterside Drive, Aztec West
Almondsbury, Bristol BS32 4UD
Tel: 0870 8506506
Email: enquiries@environment-agency.gov.uk
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