REPORT

BEST PRACTICE GUIDANCE FOR THE QUEENSLAND POULTRY INDUSTRY – PLUME DISPERSION MODELLING AND METEOROLOGICAL PROCESSING

DEEDI

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

PAEHolmes was engaged by the Queensland Department of Employment, Economic Development and Innovation (DEEDI) to develop a best practice guidance document for meat chicken farm odour modelling, as part of a broader engagement to review existing methods for separation distance determination.

The approach to assessing new meat chicken farms in Queensland allows for either a readily-applied separation distance formula approach (the so-called 'S Factor' method) for simpler cases or detailed plume dispersion modelling, primarily focused on odour, for larger farms and more complex cases where the S Factor method is not adequate.

This document sets out recommended approaches to odour dispersion modelling in an attempt to ensure that important decisions about meat chicken farm development approval are consistently based on appropriate and transparent practices and data.

This document is designed primarily to guide modellers in the process of conducting an odour assessment for meat chicken farms.

1.1 Purpose of this Document

This document reviews current odour modelling practices in the meat chicken industry and provides recommendations on a best practice approach in the Queensland context. Modelling practices and recommendations from regulatory and advisory bodies are reviewed, although the scope is not to comprehensively review all available models or guidance documents. Rather, the focus is on models that are already widely used and accepted in Queensland and on guidance that is either Queensland-based or directly relevant to Queensland meat chicken farm odour assessment. The optimum use of models is discussed in relation to tunnel-ventilated meat chicken farms. Much of the guidance can be readily adapted to other poultry operations including breeder and breeder-rearer farms, the main difference being odour emission rates and batch cycles.

In addition to model guidance, the document also considers odour impact assessment criteria that are considered to be appropriate for newly developed meat chicken farms in southeast Queensland.

The document is intended for use by consultants, regulators and researchers with experience in odour modelling and assessment. It is not intended to give detailed technical descriptions of the available models or to be used as a prescriptive modelling tutorial.

2 BACKGROUND TO AIR QUALITY ASSESSMENT FOR POULTRY FARMS

Air quality assessment is a routine requirement for many development applications across a broad spectrum of industries. In the case of the poultry industry, most particularly the meat chicken industry, odour has been long recognised as the limiting factor on farm size and siting in areas where land use conflicts can arise. In southeast Queensland, urban and rural residential populations are expanding rapidly in localities where poultry production has traditionally located close to processing plants. Increased production through larger and more numerous farms has been required to meet growing demand. Substantial pressures on both the industry and sensitive land uses have developed as available buffers have been eroded and demographic characteristics have changed.

Hence, the determination of suitable planning controls and approval mechanisms to strike a suitable balance between industry and community concerns has been a requirement for many years and is now in need of review as the science advances and issues affecting sound decision-making remain.

Odour tends to be the most restrictive of the air quality issues relating to meat chicken farms, although dust is recognised as a potentially significant issue as well. Attention to odour modelling is therefore somewhat greater.

Often, odour modelling and assessment is required for proposals involving new or expanded farms. A difficulty with this is that air quality modelling is technically specialised and complex, and consequently can be both difficult to do well and difficult to explain clearly to a diverse group of stakeholders.

A dispersion model takes information on emissions and the meteorological conditions that dictate how those emissions are dispersed in the atmosphere. Typically a full year of hourly data is used and, for each hour, the model calculates the plume concentrations at locations affected under the specific weather conditions at that time. The assessment of impacts uses statistical summaries of the hourly model calculations for the whole year.

There is no standard methodology for meat chicken farm odour modelling, so there can be confusing differences between one assessment and another. The main aspects of modelling and assessment are:

- selecting and applying a dispersion model;
- identifying and defining emission sources;
- estimating emission rates;
- defining the local terrain and ground cover;
- developing a meteorological dataset to use in the model; and
- comparing model results to assessment criteria, such as those set out in regulatory odour guidelines.

In relation to the first item above, **model selection** is an important and sometimes critical issue. The four dispersion models most commonly used in Australia – AUSPLUME (Lorimer 1986), CALPUFF (Scire, Strimaitis et al. 2000), TAPM (Hurley 2008) and AERMOD (Cimorelli, Perry et al. 2005) - have different methods of calculating plume behaviour. These differences become critically important in conditions of very light wind and temperature inversions, which

are common in most parts of southeast Queensland, particularly in differentiating AUSPLUME and AERMOD from the other two models.

Defining emission sources, i.e., poultry sheds, is not done uniformly by all consultants. Some modelling is based on a recommendation to model sheds as non-buoyant volume sources (Jiang and Sands 2000). Recent research based on measurements and modelling has demonstrated that under some conditions the plumes emitted from sheds can rise to some extent when they are warmer than the surrounding air (Dunlop, Duperouzel et al. 2010). Consequently, an odour modelling approach that takes plume buoyancy into account would be more realistic than the alternative approach which ignores this effect. Both approaches are in use at present.

The **estimation of emission rates** is done in a number of different ways, some of which attempt a more detailed simulation of the variations in emissions over the hours of the year than others. Although it is evident from recent research that some of the variation in emissions cannot be readily explained with current data, there is nevertheless a systematic and useful relationship between odour emissions and several key factors including bird mass, bird age, ambient temperature and shed ventilation rate (Dunlop, Gallagher et al. 2010). This is consistent with the general basis of some emissions estimation models in use (Ormerod and Holmes 2005), for example.

Terrain, land use and vegetation information is used in the two main models in different ways. The information is used to account for ways in which the land surface affects the behaviour of air flowing over it. Terrain features sufficient to steer the airflow, such as in valley cold air drainage conditions, cannot be simulated in AUSPLUME but can in CALPUFF. Although not critically important in every case, this is sometimes a factor in determining the magnitude and location of the highest odour impacts at sensitive receptors.

Meteorological data is a fundamental driver of a dispersion model and must be as accurate and representative as possible for best results. There are fundamental differences in the meteorological data requirements for AUSPLUME, CALPUFF and TAPM. AUSPLUME requires a relatively simple set of hourly data for a single site, representative of the area under consideration. On the other hand, CALPUFF[a] uses a 3-dimensional grid of data across the whole area under consideration, at levels ranging from the surface to thousands of metres above the ground. Clearly, such detailed data cannot be measured directly. Methods that blend data from measurements with those from sophisticated meteorological models, such as TAPM and WRF[b], are often used to generate the required data used in CALPUFF and AUSPLUME.

The odour assessment criteria used in Queensland are usually the default criteria set out in the DERM (formerly EPA) document *Odour Impact Assessment for Developments* (Queensland Environmental Protection Authority 2004). These default criteria are:

- 0.5 ou, 1-hour average, 99.5th percentile for tall stacks

[a] CALPUFF can be run in a mode which uses the simple (single-station) AUSPLUME meteorological file, but this mode is not used often and instead the 3-D capabilities of CALPUFF are usually employed.

[b] The Weather Research & Forecasting Model, http://www.wrf-model.org.

- 2.5 ou, 1-hour average, 99.5th percentile for ground-level sources and down-washed plumes from short stacks. This definition applies to poultry sheds.
- This modelling guidance document has taken this default position in the Queensland guideline and considered it alongside population-based criteria from New South Wales and South Australia as well as the approach to model uncertainty utilised in South Australia. The result is a recommendation to apply odour assessment criteria of 2.5 ou (1-hour average, 99.5th percentile) in areas with compatible land use zoning and 1.0 ou (1-hour average, 99.5th percentile) in areas with non-compatible land use zoning. The intention is to provide for model uncertainty and suspected increased community expectations of amenity in areas on the fringes of the growing south east Queensland metropolitan area.

3 DISPERSION MODELS

3.1 Background

Plume dispersion modelling is a form of applied meteorology, and is typically used to predict or simulate the ambient concentrations of air contaminants, including odour, emitted from a variety of source types. The dispersion of emissions from any source, once released from the source, is entirely controlled by the atmospheric conditions, which near the earth's surface are strongly influenced by surface characteristics. The ability of the model to represent the way in which emissions are released from the source is also highly important, as this affects the initial plume form as atmospheric processes take over.

Most modern air pollution models calculate the pollutant concentration downwind of a source or sources based on the following information:

- Pollutant emission rate;
- Emission source characteristics;
- Dimensions and locations of surrounding buildings;
- Local topography and land-use;
- Meteorology of the area; and
- Receptor network

A generic overview of how this information is used in a dispersion model is shown in Figure 3.1[c].

[c] This decision diagram is for general information only and does not necessarily apply in detail for any specific model or model application.

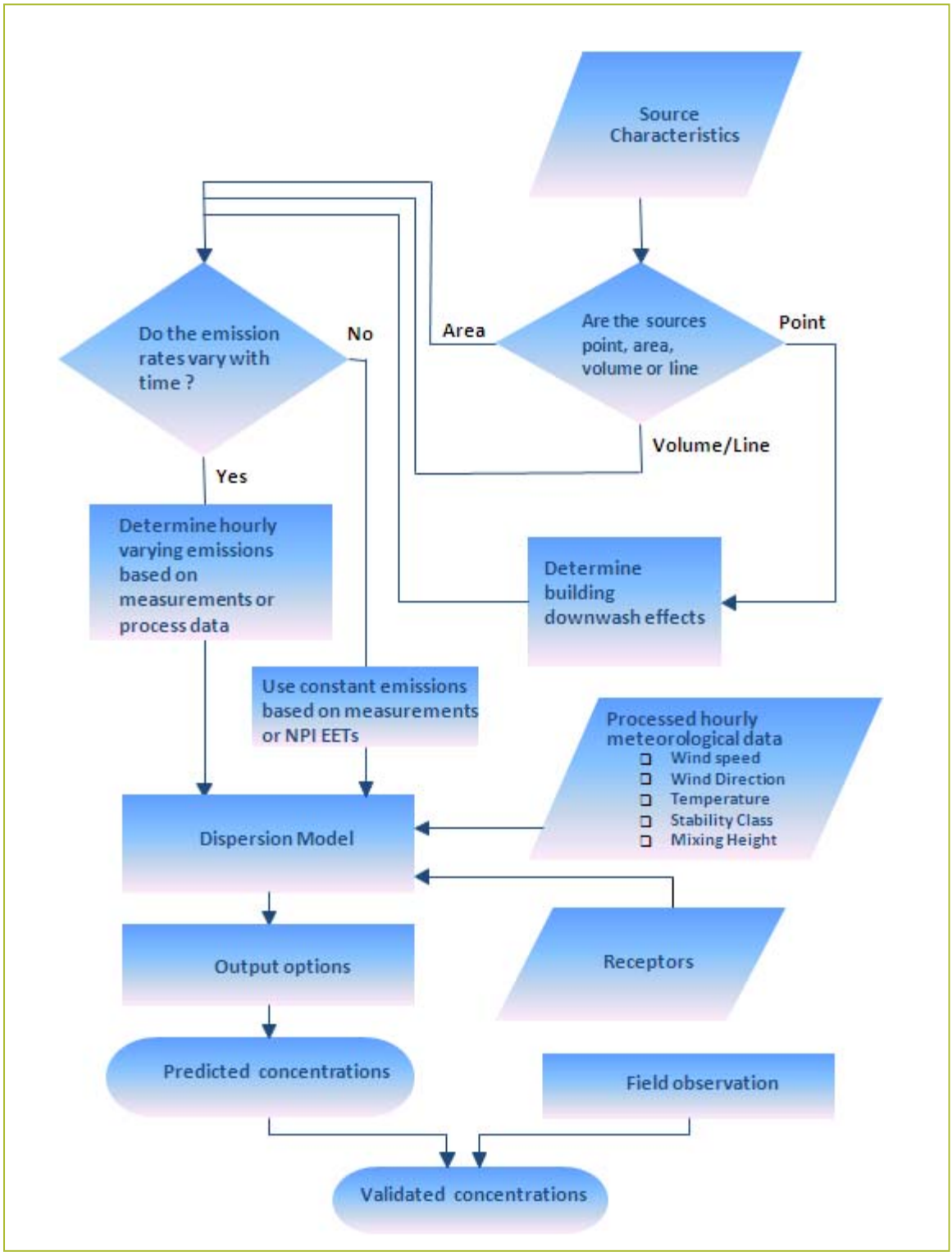

Figure 3.1: Generic dispersion modelling process.

The success of any dispersion model in predicting ground level concentrations is dependent not only on the quality of data being used, but also on the degree to which the mathematical basis of the model represents the real atmospheric and source characteristics. All dispersion models contain a variety of assumptions, which are necessary in order to simplify the model mathematics. In some cases, those assumptions can be satisfied within tolerable margins, leading to adequate model performance. In other cases, the complexities of the real world situation will be such that the assumptions are strongly violated, leading to inadequate model performance. In such cases, a more complex model with fewer simplifying assumptions will be necessary. For example, instead of using a model that assumes plumes travel in straight lines (e.g., AUSPLUME or AERMOD) it may be necessary to use one that allows plumes to follow cold air drainage or deviate around hills (e.g., CALPUFF or TAPM).

The potential for a model to perform adequately is bounded by the degree to which its assumptions are satisfied by actual real-world conditions. That potential can only be realised when the model is executed using the highest quality data. If appropriate data are unavailable or data quality is not optimised, then model performance will be subject to an additional layer of uncertainty, over and above the inherent uncertainty in predicting ground level concentrations that is caused by the turbulent nature of atmospheric dispersion. Models predict 'ensemble mean' concentrations (Chang and Hanna 2004): in any specific situation, the model result is the average of a range of possible outcomes.

The reliability of air dispersion modelling for evaluating impacts from poultry farm facilities is dependent upon a number of factors, most notably:

- Selection of an air dispersion model best suited to simulating dispersion from the type of emission source under consideration;
- The suitability and accuracy of the meteorological data used to drive the model;
- The accuracy of source information input to the model, including:
  - Facility layout and features (e.g., ventilation rate if a tunnel ventilated shed);
  - Odour and dust emission rates;
  - Source type:
    - Tunnel ventilated sheds (wake-affected point sources, usually with zero vertical momentum, or volume sources);
    - Naturally ventilated sheds (volume sources);
- Model receptor grid density; and
- Accuracy and resolution of terrain and land use data.

3.2 Common Model Types

3.2.1 Steady-State and Non-Steady State Models

3.2.1.1 Steady-State Models

Gaussian plume models assume that, over time, the average concentration distribution of the pollutant (or odour) plume follows a Gaussian (bell-shaped or normal) distribution vertically and horizontally about the centreline (Figure 3.2). They also assume instantaneous, straight-line transport between source and receptor based on hourly-averaged wind speed and direction data and for that reason are described as steady-state models: plume calculations for one hour contain no memory of what happened in previous hours.

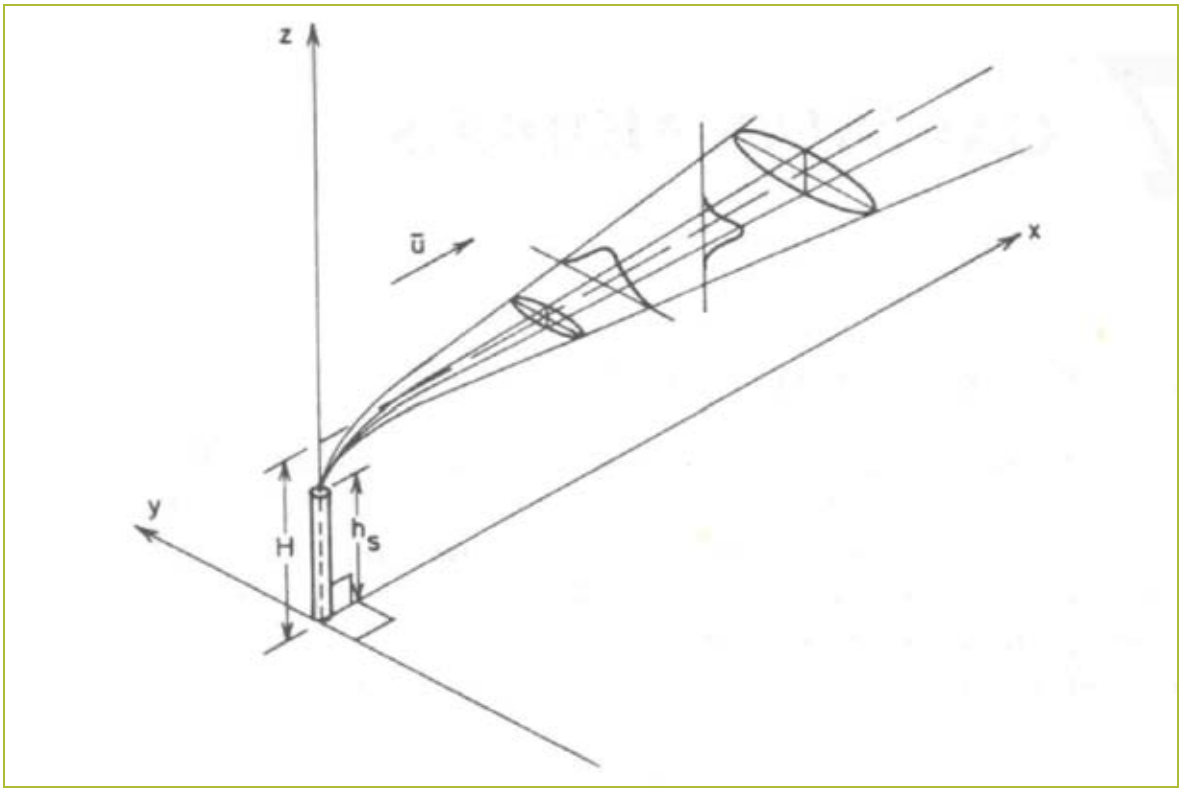

Figure 3.2: Schematic of the Gaussian plume model (modified after (Zanetti 1990)).

The Gaussian plume formulation has been used in a long series of dispersion models, and forms the basis of, for example, AUSPLUME and AERMOD (Cimorelli, Perry et al. 2005), although AERMOD incorporates more complex physics based on research into boundary layer behaviour over the past few decades.

In a Gaussian plume model, the concentration C of a pollutant at height z=0 (*i.e.* ground level) arising from a plume emitted from a source with a constant emission rate Q can be expressed in a very simplified form as:

$$C(x,y,0) = \frac{Q}{2\pi\sigma_z\sigma_y u}.\exp\left[-\frac{y^2}{\sigma_y{}^2}\right].\exp\left[-\frac{H^2}{\sigma_z{}^2}\right] \qquad (1)$$

where

x	is distance directly downwind (along the plume centreline)
y	is lateral distance from the plume centreline
z	is height above the ground
ū	is wind speed
H	is the height of the plume centreline
σ_z	is the vertical diffusion parameter
σ_y	is the lateral diffusion parameter.

This simplified equation ignores a number of features involved in plume dispersion, such as the presence of vertical limits to plume mixing (i.e., ground reflection and atmospheric mixing height[d]). The mixing height is relatively unimportant when plumes are emitted near ground level and the impacts of concern are a short distance downwind (*i.e.* in the order of hundreds of metres). The importance of mixing height is much greater with higher source releases and at greater downwind distances.

Note that during stable conditions (Pasquil Gifford classes E and F), a Gaussian plume model will ignore any mixing height value given, since under temperature inversion (stable) conditions a turbulent mixing height is not applicable in the same sense as under neutral and unstable conditions.

As distance from the source increases, a variety of effects related to terrain and other meteorological complexities can give rise to large departures from the behaviour assumed in (1). For example, spatial changes in wind direction, wind speed and turbulence alter the direction of plume travel and the rate of plume diffusion. Hence, the reliability of the basic Gaussian plume equation is to a large extent distance-dependent, and the strength of this dependency is related to the complexity of the meteorological fields. These in turn are affected by the nature of the underlying surface. Variations in the meteorological field are greatest in areas of variable terrain height and surface types.

Importantly for modelling odour dispersion, it should be noted that the Gaussian plume equation contains no explicit term for time, and is also unreliable at low wind speeds because wind speed is in the denominator: hence, as wind speed approaches zero, the calculated concentration (unrealistically) approaches infinity.

3.2.1.2 Non-steady State Models

Steady state dispersion models based on science current in the 1960s and 1970s are being replaced by a generation of advanced three-dimensional models that simulate behaviours ignored by the steady state models, but which are known to strongly influence plume dispersion in many situations.

[d] The vertical limit of ground based turbulent mixing during neutral and unstable conditions.

Non-steady-state models track air parcels as they move with the wind, calculating variable dispersion depending on position within the model domain and the corresponding local flow conditions.

Figure 3.3 is an illustration of how the formulation of the two types of model can lead to substantial differences in predicted plume behaviour. The non-steady-state solution evolves as the wind field changes in both time and space.

An important aspect of puff models is that zero wind speed can be dealt with, since the plume equation (equation 1) with wind speed (u) in the denominator, is not used. Plume history (time) is also explicitly treated.

For low-level emission sources such as poultry farms, the differences between predictions from steady state and puff models are expected to be greatest for stable, near-calm (light wind) conditions, which generally lead to the highest predicted short-term concentrations.

The steady-state Gaussian plume equation for concentration varies inversely with wind speed (see equation (1)). Consequently, in order to avoid extremely high predicted concentrations as the wind speed approaches zero, the Gaussian plume models impose a minimum value of 0.5 to 1.0 m/s. The value of 0.5 m/s is typically adopted in AUSPLUME.

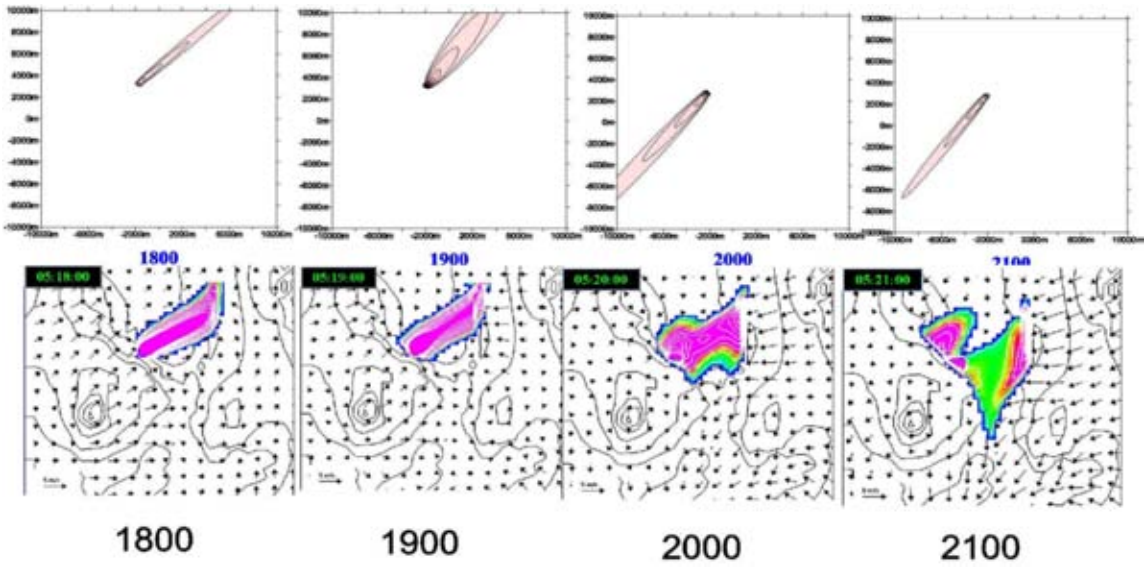

Figure 3.3 Hourly sequence showing differences between steady-state and non-steady-state models in conditions of changing winds and terrain influences. The top sequence was generated by AUSPLUME and the lower sequence by TAPM, for the same times and emission source location. In the TAPM sequence, arrows indicate surface winds and black lines are terrain contours.

3.3 The Common Models

This section briefly outlines the models most commonly used in Australia. Detailed model descriptions and user guides are referred to for those interested in obtaining more specific information.

3.3.1 AUSPLUME

AUSPLUME (Lorimer 1986) is a Gaussian plume dispersion model capable of simulating the effects of multiple sources, including stacks, volume sources and area sources. Their effects can be integrated over a long time period (>1 year), or evaluated for short-term maximum impacts (as short as 3 minutes). The effects of terrain on ground level concentrations due to elevated sources can be accounted for by invoking one of three relatively simple schemes, the most common of which is called the Egan half-height method. Gravitational effects (settling) can be accounted for in particle emissions by including information on particle characteristics. More details on the model can be obtained from the EPA Victoria website (www.epa.vic.gov.au/air/epa/ausplume-pub391.asp).

AUSPLUME v6.0 or later is recognised by the Queensland Department of Environment and Resource Management (DERM) as an approved dispersion model for use in applications where complex terrain or other features are not relevant. This is consistent with modelling guidance from NSW (NSW DEC 2005; NSW DEC 2006) and other jurisdictions.

With regard to the use of AUSPLUME for odour studies, the Queensland Odour Guideline (Queensland Environmental Protection Authority 2004) states:

EPA accepts the use of AUSPLUME as an appropriate model for most near-field assessments of odour sources located in relatively flat terrain and as an initial screening model to determine whether a more advanced model might be required for a particular situation. Proponents may consider alternatives to the steady-state Gaussian models when assessments require predictions of odour concentrations far from the source of release, in complex terrain or at locations where light winds, convective conditions and sea-breeze circulations occur frequently. In some cases, it may be necessary to weigh up the convenience and limitations of the steady-state Gaussian models against the complexity and additional demands of advanced models and seek advice from the EPA before embarking on the assessment.

Since 2004, there have been substantial improvements in the quality and accessibility of meteorological and geophysical data needed to run advanced models, and so the additional demands referred to above are becoming less significant, although there remain substantial user requirements to ensure good model configuration and performance.

An important aspect of odour modelling for meat chicken farms is the behaviour of the plumes at the point of release. Tunnel ventilation normally forces plumes horizontally from the endwalls of sheds. The implication of this is that if buoyancy and plume rise are relevant then the calculation of plume rise must not include any vertical momentum term. AUSPLUME does not allow vertical momentum to be switched off, so in order to reduce the vertical term to a level that does not trigger the vertical momentum rise calculation, it is necessary to create a pseudo-stack source with a diameter sufficiently large to preserve the volumetric flow rate while reducing the exit velocity.

3.3.2 CALPUFF-CALMET

CALPUFF model is a multi-layer, multi-species non-steady state puff dispersion model that can simulate the effects of time- and space-varying meteorological conditions on pollutant transport, transformation and removal (Scire, Strimaitis et al. 2000). This generally should give a more realistic simulation of plume behaviour than the steady state models such as

AUSPLUME, provided that meteorological and terrain inputs are of a suitable quality. CALPUFF has been accepted as a US EPA regulatory model, for long-range and complex non-steady-state meteorological conditions (US EPA 2008).

The user manual for the CALPUFF model, including a detailed technical description and examples, can be obtained from http://www.src.com/calpuff/calpuff1.htm.

Meteorological data used to drive CALPUFF are processed by the CALMET meteorological pre-processor (Scire, Robe et al. 2000). CALMET includes a wind field generator containing objective analysis and parameterised treatments of slope flows, terrain effects and terrain blocking effects. The pre-processor produces fields of wind components, air temperature, relative humidity, mixing height and other micro-meteorological variables to produce the three-dimensional meteorological fields that are used in CALPUFF. CALMET uses measured and/or modelled meteorological inputs in combination with land use and geophysical information for the modelling domain to predict gridded meteorological fields for the region of interest.

Specifically of benefit to modelling positively buoyant horizontal releases, CALPUFF includes a 'rain hat' switch that sets to zero the vertical momentum of a point source to account for horizontal release, as in the endwall emissions from tunnel-ventilated poultry sheds. This feature then removes the need to apply dimensional adjustments to source parameters (i.e., increasing diameter to achieve minimal exit velocity while conserving volumetric flow rate) to achieve the same end result.

3.3.3 AERMOD

AERMOD stands for the AERMIC Dispersion Model. AERMOD was designed by the AERMIC committee (the American Meteorological Society/ Environmental Protection Agency Regulatory Model Improvement Committee) to treat elevated and surface sources in terrain that is simple or complex (Cimorelli, Perry et al. 2005; Perry, Cimorelli et al. 2005).

The AERMOD modelling system consists of two pre-processors and the dispersion model. The meteorological pre-processor (AERMET) provides AERMOD with the meteorological information (morning soundings of winds, temperature, and dew point from the nearest upper air station; and on-site wind, temperature, turbulence, pressure, and radiation measurements) it needs to characterise the boundary layer (*e.g.* mixing height, friction velocity). The terrain pre-processor (AERMAP) both characterises the terrain and generates receptor grids and elevations for the dispersion model (AERMOD).

AERMOD is built on a Gaussian plume model framework and essentially retains the single straight line trajectory limitation. However, its treatment of dispersion in the presence of complex terrain improves on that used in standard Gaussian plume models like AUSPLUME without the full benefits of the current complex terrain models. Specifically, in stable conditions plume interaction with a hill is represented by the dividing streamline concept in which the part of the plume above the level of the dividing streamline passes freely over the hill and the lower section passes around the sides. This approach will not adequately deal with some complex situations, e.g., multiple hills and valleys, or hills with sufficient height to penetrate layers of directional wind shear.

AERMOD contains potentially improved algorithms for plume rise and buoyancy, as well as the computation of vertical profiles of wind, turbulence and temperature.

Despite the substantial improvements that AERMOD offers over AUSPLUME and other older Gaussian plume models such as ISC3[e], it is nevertheless a steady-state model with potentially significant limitations in very light wind, stable conditions.

The user manual for AERMOD and other documentation can be obtained from the US EPA website at http://www.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod.

3.3.4 TAPM

The Air Pollution Model, or TAPM, is a coupled three dimensional meteorological and air pollution model produced by the CSIRO Division of Atmospheric Research. It was released in late 1999 and has since been updated several times.

The meteorological component of TAPM is an incompressible, non-hydrostatic, primitive equation model. The model solves the momentum equations for horizontal wind components, the incompressible continuity equation for vertical velocity, and scalar equations for potential virtual temperature and specific humidity of water vapour, cloud water/ice, rain water and snow. Cloud microphysical processes, turbulence kinetic energy, eddy dissipation and radiative fluxes are also included (Hurley 2008).

TAPM may be used to generate meteorology for areas where there are no observations (Queensland Environmental Protection Authority 2004). TAPM may also be used as a plume dispersion model, although it is more often used to generate meteorological data in data-sparse areas for use in other dispersion models.

The Queensland Odour Guideline (Queensland Environmental Protection Authority 2004) states:

The CSIRO's air quality model TAPM can be used to generate hourly one-year meteorological data required for the dispersion models. This is a prognostic meteorological model, which eliminates the need to have site specific meteorological observations. The model can predict airflow important to local scale air pollution such as sea breezes and terrain induced flows. For sites where observed meteorological data is not available and the site is subject to the sea and land breeze effects, it is preferable to use TAPM model for the generation of meteorological data.

The air pollution component of TAPM uses the predicted meteorology and turbulence from the meteorological component and consists of:

- A Eulerian Grid Module (EGM) to solve prognostic equations for the mean and variance of concentration;
- A Lagrangian Particle Module (LPM) to represent near-source dispersion more accurately;
- A Plume Rise Module to account for plume momentum and buoyancy effects for point sources;

[e] Industrial Source Complex Model (Short Term) Version 3, now replaced in US regulatory guidance by AERMOD.

- A Building Wake Module allows plume rise and dispersion to include wake effects on meteorology and turbulence;
- Gas-phase photochemical reactions based on the Generic Reaction Set, gas- and aqueous-phase chemical reactions for sulfur dioxide and particles, and a dust mode for total suspended particles ($PM_{2.5}$, PM_{10}, PM_{20} and P_{M30}); and
- Wet and dry deposition (Hurley 2008).

Typically TAPM is not used for modelling odour dispersion from meat chicken farms, although there is no fundamental impediment: it is capable of being used as a dispersion model and has been shown to perform well compared to other models (Hurley, Hill et al. 2005). However, it does not have a built-in switch to eliminate vertical momentum from point sources, and hence requires source parameter adjustment in a similar way to AUSPLUME.

TAPM is often used to source, where appropriate, observed meteorological data and upper air data for input into CALMET or AUSPLUME.

The user manual for TAPM, including a detailed technical description and examples, can be obtained from http://www.cmar.csiro.au/research/tapm/index.html.

3.4 Model Uncertainty

Atmospheric dispersion models represent a simplification of the many complex processes involved in determining ground level concentrations of pollutants. Crucial issues in obtaining good quality results are the correct application of an appropriate model for the site conditions, and correct interpretation of the quality of the data used for modelling.

Model uncertainty is composed of model chemistry/physics uncertainties, data uncertainties, and stochastic uncertainties due to the inherent turbulent behaviour of the atmosphere, especially on shorter time scales. The main specific sources of uncertainty in dispersion models and their effects are summarised in Table 3.1.

If model results are to be used as support for regulatory decision-making, it is very useful to provide a measure, or at least some qualitative evaluation, of the model uncertainty. This information about sources of uncertainty associated with modelling results can be as important as modelling results, particularly if modelled concentrations are close to regulatory limits.

Table 3.1: Summary of main sources of modelling uncertainty.

Source	Effects
Oversimplification of physics in model code (varies with type of model)	A variety of effects that can lead to both under prediction and over prediction. Errors are potentially greater in Gaussian plume models, which do not include the effects of non-steady-state meteorology, where these conditions are relevant. However, all models – even with perfect input data – will predict concentrations with some variance around the 'real' result because all details relevant to dispersion cannot be represented precisely.
Errors in emissions data	Ground level concentrations (glcs) are proportional to emission rate. Plume rise and glcs are affected by source dimensions, temperature and exit velocity. Using constant emission rates when varying emission rates occur may also result in model errors for short term averaging periods.
Plume Rise Uncertainty	Most Gaussian dispersion models use the Briggs plume rise equations to predict buoyant plume rise. These equations could over-or under-predict actual plume rises by 20 percent (Beychok 2005). The performance of these plume rise equations with weakly buoyant plumes, interacting plumes from atypical sources has not been verified in any detail, although it has been demonstrated that plume rise does occur due to buoyancy (Dunlop, Duperouzel et al. 2010)
Errors in wind data	Wind direction affects direction of plume travel. Wind speed affects plume rise and dilution of plume, resulting in potential errors in distance of plume impact from source, and magnitude of impact. For steady-state models, use of a single-site meteorological data set to represent the whole model domain will normally introduce some errors, particularly if the station is not close to the emission source location or if the data are derived only from a met model. 3-D met data quality varies according to the type of met model, quality of inputs (e.g., terrain, surface characteristics, soil moisture, sea surface temperature) and spatial resolution.
Errors in stability estimates	Gaussian plume models use estimates of stability class, and 3-D models use explicit vertical profiles of temperature and wind (which are used directly or indirectly to estimate stability class for Gaussian models). In either case, errors in these parameters can cause either under prediction or over prediction of ground level concentrations, depending on circumstances.
Errors in dispersion Coefficients	Most Gaussian models use modifications of the dispersion coefficients derived experimentally by Pasquill in a rural area of fairly level, open terrain and for relatively moderate plume travel distances. Pasquill's coefficients could be in error by plus or minus 25 percent, especially when used for non-level, complex terrain and for large distances ranging up to 50 km or more (Beychok 2005). Improved dispersion treatments in AERMOD and 3-D models are reliant on good quality data on turbulence and temperature profiles.
Errors in mixing height estimates	The mixing height determines the volume of air that is essentially available to dilute emissions by atmospheric turbulence. Errors in the mixing height may therefore result in errors in short term concentration predictions, but mixing height is normally not a critical parameter for odour modelling.
Errors in temperature	Usually the effects are small, but temperature affects plume buoyancy. In the case of emissions modelling, ventilation and hence odour emissions rates from poultry sheds are temperature-dependent.
Inherent uncertainty	Models predict 'ensemble mean' concentrations for any specific set of input data (say on a 1-hour basis), *i.e.* they predict the mean concentrations that would result from a large set of observations under the conditions being modelled, as specified by the time-averaged (usually hourly) quantities such as wind speed, wind direction, turbulence, etc. However, for any specific period (hour) with those exact average conditions, the predicted ground level concentrations will never exactly match the actual pattern of ground level concentrations, due to the effects of random turbulent motions and random fluctuations in other factors such as temperature. The inherent uncertainty in concentrations downwind of a stack has been estimated as 50-75% for a 1-hour average simulation (Stein and Wyngaard 2001). However, for a long

Source	
	period of hourly calculations, the modelled concentration statistics should match measurements much better than this.

4 COMPARATIVE MODEL PERFORMANCE

This section of the document examines some comparative results of odour modelling using AUSPLUME, CALPUFF, TAPM and AERMOD.

As part of the background study to this document, AUSPLUME and CALPUFF were configured for hypothetical 200,000 and 300,000 bird farms using meteorological data for Caboolture, Ipswich, Felton (30 km SSW of Toowoomba), Warwick, Beaudesert and Silverdale (40 km SSW of Ipswich). These sites were selected because they are in areas with existing meat chicken farms and/or are potential growth areas for the industry.

4.1 Light wind stable (LWS) conditions

A feature of many parts of the region is the frequent occurrence of stable light wind conditions at night. Table 4.1 shows the percentage occurrence of very light winds in annual meteorological files used for modelling. A large range is evident, from 0.9% at Felton to 27% at Warwick. Some of this variation may be attributable to measurement and meteorological model factors, but it is clear that real differences between sites can exist, as a function of localised and more regional influences. The 'CALPUFF domain' region identified in Table 4.1 refers to an area south of Silverdale, about 20 km southwest of Ipswich.

Table 4.1 Occurrence of very light winds (<1 m/s) at regional locations

Site	% of Time < 1m/s
Felton	0.9
Ipswich	6.8
Beaudesert	9.5
Caboolture	11.8
Warwick	27.0
Silverdale	12.4
CALPUFF domain	~ 25

Light wind stable conditions remain the most difficult for dispersion models to handle. No single model can be said to handle these complex conditions completely reliably, although steady-state models are inherently less well equipped to do so. An evaluation of model performance using CALPUFF, AERMOD and AUSPLUME under light wind stable (LWS) conditions (Rayner 2007) found the following:

- AUSPLUME is unreliable for high percentile concentrations from surface non-buoyant sources under LWS conditions. Maximum and 99.9th percentile concentrations are strongly affected by the arbitrary assignment of a minimum wind speed threshold 0.5 m/s (or any other arbitrary value that might be set);
- AERMOD's scheme for coherent and random (pancake) plumes seems much more robust than the simple wind speed threshold in AUSPLUME, although questions remain about how well it has been verified;
- AERMOD is very sensitive to small changes in the lower limit height of the mechanical mixing layer in stable conditions, unlike CALPUFF;

- AERMOD's turbulence parameterisation is sophisticated, but it produces high predicted concentrations that are questionable;
- CALPUFF might appear to provide a solution to the speed threshold problem of AUSPLUME and AERMOD, but it sets a default lower threshold of 0.5 m/s for σ_v which presents a corresponding problem. This was examined by a sensitivity test with σ_v reduced to 0.45 m/s (10% reduction) for a 3-month (autumn) run of CALPUFF. The conclusion is that limiting 1-hour σ_v to 0.5 m/s is a blunt instrument for defining the wide range of σ_v possible in stable conditions;
- In strongly stable conditions, 1-hour σ_v is dominated by low frequency meander, which is not properly described by any existing models;
- σ_v relations within CALPUFF and AERMOD appear to be appropriate for ~10 minute averaging rather than 1-hour averaging;
- Running CALMET-CALPUFF on 10 minute time-steps to produce 1-hour average concentrations is a potential improvement (which requires testing against field data). This procedure potentially addresses two issues:
    - relations for σ_v and σ_w are appropriate to the averaging time (10 minutes); and
    - scalar 10-minute winds are used for calculating fluxes, whilst the vector summation of puff displacement occurs via the 10-minute timestep in CALPUFF;
- High concentrations from AERMOD require critical review. Contrasting results from CALPUFF also need review.

5 MODEL SELECTION

5.1 General considerations

Selection of a dispersion model involves considering several factors:

- technical suitability of the model for the intended application;
- data requirements and availability;
- regulatory acceptance;
- skill set and computing resources required; and
- cost and run-time.

For this document, the focus is on models that are already in relatively common use in Queensland and so factors other than technical suitability are considered to be more or less secondary to the selection process. However, for any specific application, all factors do need to be weighed up with due care.

Several key Australian and overseas guidance documents for dispersion model selection and application are available and should be consulted if further background is required (NZ MfE 2004; NSW DEC 2005; US EPA 2008). In Queensland, no specific model is recommended for odour modelling applications and instead "the appropriate model should be selected based on the requirements of each particular case" (Queensland Environmental Protection Authority 2004).

Existing guidance on model selection and use in Australia is often based on the current 'default' regulatory dispersion model, AUSPLUME. However, in line with the Queensland DERM (Qld EPA) approach, AUSPLUME is not recommended as the default model for meat chicken farm odour assessments in southern Queensland. Rather, specific site conditions and modelling issues should be considered along lines set out below. It is apparent that in most cases in southeast Queensland, there would be advantages in using CALPUFF or, subject to other considerations such as those listed above, perhaps TAPM or AERMOD.

An alternative to AUSPLUME that is capable of dealing with non-steady-state meteorology and very low windspeed (e.g, CALPUFF or TAPM) is recommended if:

- critical receptors[f] are located at a distance from the source that is greater than the minimum distance travelled by the plume in one hour[g], **and** there is evidence of significant effects of non-steady-state meteorology. Evidence of non-steady-state meteorology relevant to many odour modelling applications includes:
    - meteorological data or meteorological model results from the area showing significant and commonly occurring spatial variations in surface winds in the

[f] Likely, on the basis of initial screening or evaluation of similar cases, to be affected by odour levels at more than 50% of recommended criteria

[g] This is preferably determined from accurate on-site wind data (e.g., measured by sonic anemometer with near-zero threshold) and applies to conditions occurring for more than about 2% of the time.

region between the source and important receptors, particularly at night or under stable atmospheric conditions;

- on-site meteorological data showing a persistent pattern of winds that are aligned to or steered by local terrain features, and which would imply significant changes in wind direction between the source and receptors. Most importantly, this is likely where the source is located within a valley or drainage flow path, where the measured or modelled winds are persistently aligned with the local valley or drainage path orientation, and receptors are located either outside the valley or in the valley where it has a different orientation than at the source;

- in the absence of specific meteorological data, where the source or receptors are located in a valley or other terrain feature that is likely to confine stable drainage flows, especially where there are changes in orientation between source and receptor[h], or

- windspeed is less than 0.5 m/s at 10 m height for more than about 2% of the time[i].
- More than one facility is being considered in the same model application
- Where light winds and terrain drainage flow affects the dispersion of odour.

CALPUFF has been used for many odour assessments in Queensland, New South Wales and Western Australia, and to a lesser extent in other states.

The US EPA Guideline on Air Quality Models (US EPA 2008) contains the following at section 7.2.8 about complex wind situations and the applicability of a model such as CALPUFF:

a. *Inhomogeneous Local Winds*. *In many parts of the United States, the ground is neither flat nor is the ground cover (or land use) uniform. These geographical variations can generate local winds and circulations, and modify the prevailing ambient winds and circulations. Geographic effects are most apparent when the ambient winds are light or calm. In general these geographically induced wind circulation effects are named after the source location of the winds, e.g., lake and sea breezes, and mountain and valley winds. In very rugged hilly or mountainous terrain, along coastlines, or near large land use variations, the characterization of the winds is a balance of various forces, such that the assumptions of steady-state straight-line transport both in time and space are inappropriate. In the special cases described, the CALPUFF modelling system (described in Appendix A) may be applied on a case-by-case basis for air quality estimates in such complex non-steady-state meteorological conditions. The purpose of choosing a modelling system like CALPUFF is to fully treat the time*

[h] Drainage (or katabatic) flows can be complex, occurring at different scales in response to various scales of terrain influence. For example, gullies or small shallow valleys can generate shallow drainage flows which may be overtaken at times by deeper katabatic flows on a regional scale, driven for example by the effects of a large valley in which the smaller valley or gully is contained. In such cases, the effects may be significant for odour dispersion even when local relief is as little as 5-10 metres.

[i] This is consistent with US EPA recommendation that where calms are frequent a puff model should be used (US EPA, 2000)

and space variations of meteorology effects on transport and dispersion. The setup and application of the model should be determined in consultation with the appropriate reviewing authority (paragraph 3.0(b)) consistent with limitations of paragraph 3.2.2(e). The meteorological input data requirements for developing the time and space varying three-dimensional winds and dispersion meteorology for these situations are discussed in paragraphs 8.3.1.2(d) and 8.3.1.2(f). Examples of inhomogeneous winds include, but aren't limited to, situations described in the following paragraphs (i)–(iii)[j]:

i. Inversion Breakup Fumigation . Inversion breakup fumigation occurs when a plume (or multiple plumes) is emitted into a stable layer of air and that layer is subsequently mixed to the ground through convective transfer of heat from the surface or because of advection to less stable surroundings. Fumigation may cause excessively high concentrations but is usually rather short-lived at a given receptor. There are no recommended refined techniques to model this phenomenon. There are, however, screening procedures that may be used to approximate the concentrations. Considerable care should be exercised in using the results obtained from the screening techniques.

ii. Shoreline Fumigation . Fumigation can be an important phenomenon on and near the shoreline of bodies of water. This can affect both individual plumes and area-wide emissions. When fumigation conditions are expected to occur from a source or sources with tall stacks located on or just inland of a shoreline, this should be addressed in the air quality modelling analysis. The Shoreline Dispersion Model (SDM) listed on EPA's Internet SCRAM Web site (subsection 2.3) may be applied on a case-by-case basis when air quality estimates under shoreline fumigation conditions are needed.80 Information on the results of EPA's evaluation of this model together with other coastal fumigation models is available.81 Selection of the appropriate model for applications where shoreline fumigation is of concern should be determined in consultation with the appropriate reviewing authority (paragraph 3.0(b)).

iii. Stagnation. Stagnation conditions are characterized by calm or very low wind speeds, and variable wind directions. These stagnant meteorological conditions may persist for several hours to several days. During stagnation conditions, the dispersion of air pollutants, especially those from low-level emissions sources, tends to be minimized, potentially leading to relatively high ground-level concentrations. If point sources are of interest, users should note the guidance provided for CALPUFF in paragraph (a) of this subsection. Selection of the appropriate model for applications where stagnation is of concern should be determined in consultation with the appropriate reviewing authority (paragraph 3.0(b)).

With regard to CALUPFF and similar advanced models, the Queensland odour guideline (Queensland Environmental Protection Authority 2004) states:

These recent models (i.e. CALPUFF) can be expected to provide more accurate odour impact assessments than steady-state Gaussian plume models in the exceptional circumstances described above.

While some of the statements above would suggest that stagnation and complex flows are exceptional in nature, the data from sites in southeast Queensland relevant to the meat chicken industry clearly indicate that conditions are routinely of a type that satisfies the criteria for using CALPUFF (or a non-steady state model).

[j] Item iii (Stagnation) is the most relevant of these items to odour dispersion associated with meat chicken farms.

5.2 Special Purpose Models

Some specific modelling issues are not well handled by the routine dispersion models, or may be outside the intended range of their application. For example, the issue of plume behaviour in the near field of multiple buildings cannot be explicitly handled by routine models. If such behaviour is critical to a modelling study, then it may be worthwhile applying a specialised model such as a computational fluid dynamics (CFD) model or using a wind tunnel. The CFD option is increasingly popular owing to advances in computational power.

CFD codes solve the Navier-Stokes equations for predicting the airflow patterns at the local scale, as well as heat and mass transfer. The output of these codes depends on the numerical scheme used, the way boundary conditions are implemented, the model domain size and the grid resolution. Both Eulerian and Lagrangian methods have been developed.

In the Lagrangian approach, individual particles are tracked as they encounter various fluid eddies, while in the Eulerian approach, attention is focused on a fixed region in the flow field. The latter approach is computationally much faster than Lagrangian calculations (Trac and Pen 2003).

CFD modelling has been used to evaluate near-field plume behaviour from poultry sheds (Quinn, Wilson et al. 2001; Dunlop, Duperouzel et al. 2010) and can be a powerful adjunct to routine modelling to provide parameters for source inputs that better represent complex behaviours.

In contrast to typical dispersion modelling, CFD modelling does not assume any particular plume shape or dispersion pattern. Instead, it calculates the flow field around individual objects under specific conditions, for example, in assessing the free or forced ventilation within or around various building configurations.

There are commercial CFD software packages available, with varying degrees of sophistication and expense. These packages allow the user to effectively assess flows within practically any geometry or configuration. Despite the general availability of CFD software for flows as complex as those over arbitrarily shaped hills or buildings, and their greater accuracy (especially for groups of structures), these codes still require more computer time and more capacity than are available for a typical air pollution dispersion calculation for one particular meteorological situation. Such calculations have to be repeated hundreds or thousands of times to derive long term averages needed to meet regulatory requirements. Hence, CFD modelling is better used to assess short-term dispersion around or within farms or to assess the influence of factors such as vegetative barriers or screens.

For the reasons outlined above, CFD models are not suited to odour and dust modelling of poultry farms for long-term assessments but are a potential adjunct tool for exploring plume behaviours under specific conditions.

6

6 BEST MODELLING PRACTICE FOR THE POULTRY INDUSTRY

This section provides updated guidance on issues pertaining to the key model inputs for dispersion modelling.

6.1 Emissions Data

6.1.1 General principles

Emission sources for dispersion modelling must be identified by location and type (point source, volume source, area source or line source). For each source, data on physical characteristics (dimensions, flow rates, etc.) must be entered and emission rates assigned.

The estimation of odour emissions is a key part of any odour assessment. Factors to consider in estimating time-varying emissions from meat chicken farms include:

- Number of birds placed
- Batch length
- Cleanout days
- Thinning regime
- The weight of the birds over the batch
- Maximum ventilation rate and changes in ventilation over a batch
- Design and management practices.

6.1.2 Typical Batch Characteristics and Ventilation

A typical grow-out cycle will consist of a 6 – 8 week growing period (dependent on the bird size required for market) followed by a 1 – 2 week clean-out of the sheds, disinfecting and maintenance. Normally, four to six batches of birds are raised each year. During the grow-out period, birds are removed once or twice at or after day 30. This is to both meet market requirements for bird size and also to manage the bird density in line with industry standards.

Bird growth follows a curve similar to that shown in Figure 6.1. Variations occur according to chicken breeding and individual batch performance, and updated data are sometimes provided by producers to reflect documented improved growth performance. As bird mass increases, the “thermo-neutral” temperature setting required for optimum bird performance decreases.

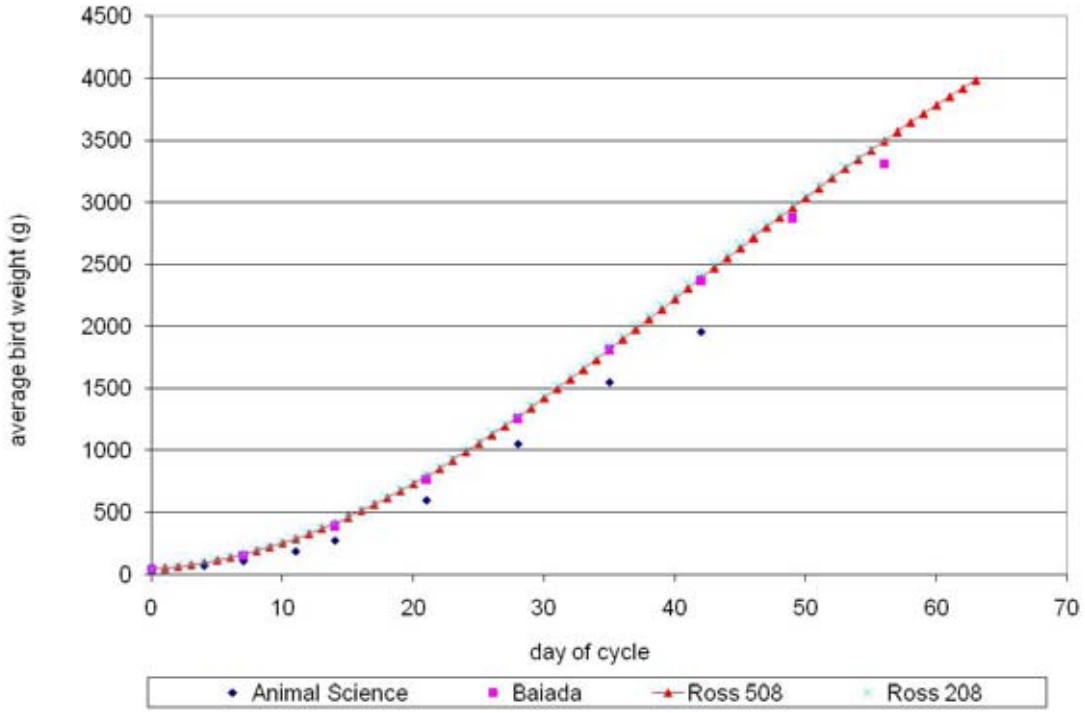

Figure 6.1: Typical Bird Mass Curve as a Function of Age

The emission rate is driven by ventilation rate and odour concentration in the shed. Ventilation is used to manage internal shed temperatures. Optimal shed temperature decreases with bird age, ranging from about 31-34°C when chickens are first brought into the shed down to about 18-21°C by week 5 (Jiang and Sands 2000). While very young, the chickens will normally be restricted to no more than 50% of the shed (brooding section) until old enough to maintain body temperature. Heaters are required to maintain optimal temperatures during the brooding phase.

An indicative maximum ventilation rate for meat chicken farms is approximately 10 m^3/hr/bird. During the course of a batch, ventilation rate varies widely. In a modern shed, the design airflow speed is about 3 m/s, which is significantly higher than for older sheds, say 10 or more years old. This is a useful benchmark flow speed for evaluating the maximum ventilation requirements. Some modern sheds are in fact over-deigned with respect to maximum airflow speed in the sheds, but using 3 m/s is a realistic basis for the calculation of ventilation rates relative to 'maximum ventilation', as applied in Table 6.1 below.

Changes in ventilation that are required to achieve the target internal temperature are linked to ambient temperature, although other factors are also involved. The ventilation rate at any time during a batch can be estimated approximately using guidance such as the University of Georgia data summarised in Table 6.1. Note, however, that real ventilation performance can vary according to both design and management factors.

Table 6.1: Nominal Shed Ventilation as a Percentage of Maximum Ventilation

Bird Age (weeks)	1	2	3	4	5	6	7	8
Temperature (°C) above Target[1]	Ventilation Rate (as a Percentage of the Maximum)							
<1	1.3	2.5	5.1	7.7	9.8	11.5	17	17
1	1.3	12.5	12.5	25	25	25	25	25
2	1.3	25	25	37.5	37.5	37.5	37.5	37.5
3	1.3	37.5	37.5	50	50	50	50	50
4	1.3	37.5	37.5	50	50	50	50	50
6	1.3	37.5	37.5	62.5	75	75	75	75
7	1.3	37.5	37.5	62.5	75	75	87.5	100
8	1.3	62.5	62.5	62.5	75	75	100	100
9	1.3	62.5	62.5	87.5	100	100	100	100

Based on data from the University of Georgia www.poultryventilation.com

1. Ambient temperature minus the target effective temperature inside the shed.

Detailed measurements of ventilation in operating meat chicken sheds will show departures from the pattern estimated using Table 6.1 (Dunlop, Gallagher et al. 2010). If more suitable data are available for a particular application, then they should be used along with evidence of suitability.

Figure 6.2 illustrates a typical target temperature profile for a meat chicken batch based on the Cobb broiler management guide (Cobb-Vantress Inc. 2008). Note that the target temperature is the effective temperature with the effect of wind chill included. Hence, the actual internal temperature when fans are running will be higher than the target, the extent depending on the rate of air movement and associated wind chill, which can be in excess of 5°C.

Shed internal temperature can be estimated by the following equation (Dunlop, Duperouzel et al. 2010):

$$T_{internal} = T_{target} + 0.31\ T_{ambient} - 4.2$$

This equation explains about 78% of the variance in the observed internal temperature data (i.e., $r^2 = 0.78$).

It is important to note that some breeds may require cooler conditions especially after week 4, with earlier and lower minimum temperature requirements than shown in Figure 6.2, e.g., reaching minimum temperature by the end of week 4 and using a minimum of 18°C. It is important to verify which temperature regime (based on bird breed) the proposed farm will operate and if there is doubt, the more conservative approach would be to adopt a curve that reduces the target temperature more sharply than shown in Figure 3.1 to 18°C by day 30.

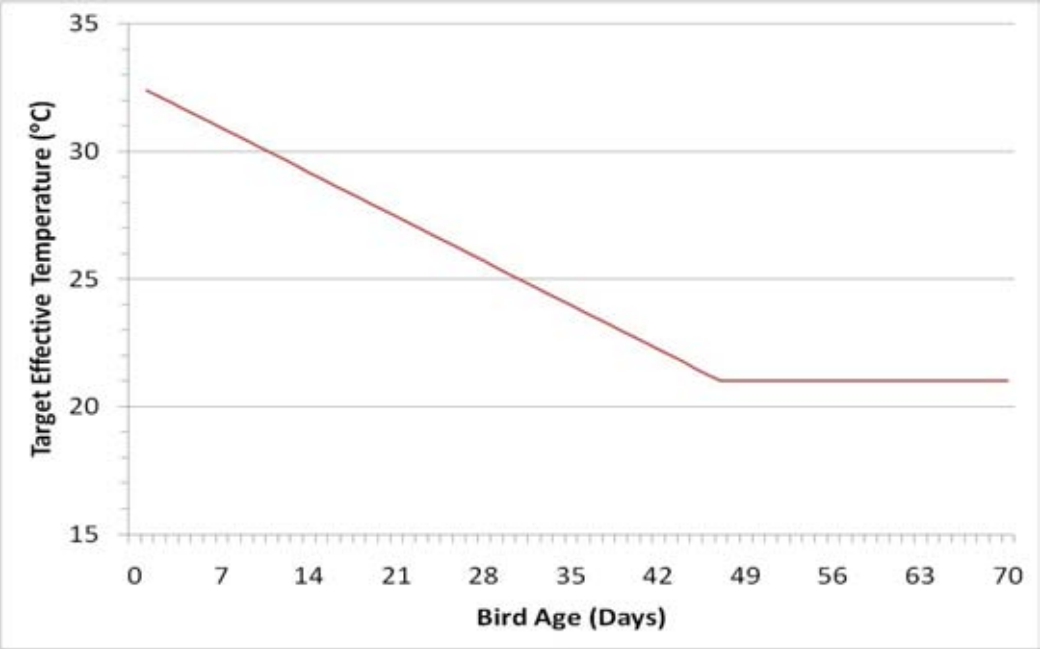

Figure 6.2 Indicative target effective temperature as a function of bird age (Cobb-Vantress Inc. 2008)

When providing a time-varying source exit temperature to the dispersion model, use of the target temperature will tend to underestimate the potential plume rise when the exit temperature exceeds ambient, because the target temperature takes into account the wind chill effect of shed ventilation. For example, at full ventilation a target temperature of 21°C may be achieved if the actual (sensible) temperature is as high as 26°C. The difference of 5°C represents the effect of wind chill.

If there are receptors within 1 km of the farm and they are higher in elevation than the sheds, then it is recommended that the source emission temperature be represented by the target temperature equation (Dunlop, Duperouzel et al. 2010) provided above.

6.1.3 Odour emission rate estimation

Odour emission rate is the product of ventilation rate and odour concentration. Odour emission rate data have been collected at a variety of farms by various groups and it is difficult to evaluate the data on like terms because of the influence of multiple factors, some of which are both poorly understood and highly variable. Despite this, there are some essential factors that can be used in predictive odour emissions modelling, where accounting for every detail that occurs in a temporal framework is not as important as replicating the statistical behaviour of emissions.

If relevant parameters are applied to emissions estimation the results will follow a particular type of pattern. As an example, the PAEHolmes emissions estimation method (Ormerod and Holmes 2005) has been compared below with real world data in Figure 6.3. The blue dots in Figure 6.3 represent the odour concentrations over a year predicted by the PAEHolmes

method at a K factor[k] of 2 and the green triangles represent odour samples collected from farms which had calculated K factors of 2 or less. The data show that the emissions estimation methods can be consistent with real world samples, although the fine detail of emissions variation will be more complex in the real situation. However, statistically – which is the critical point for modelling – the estimated emissions are likely to be adequate.

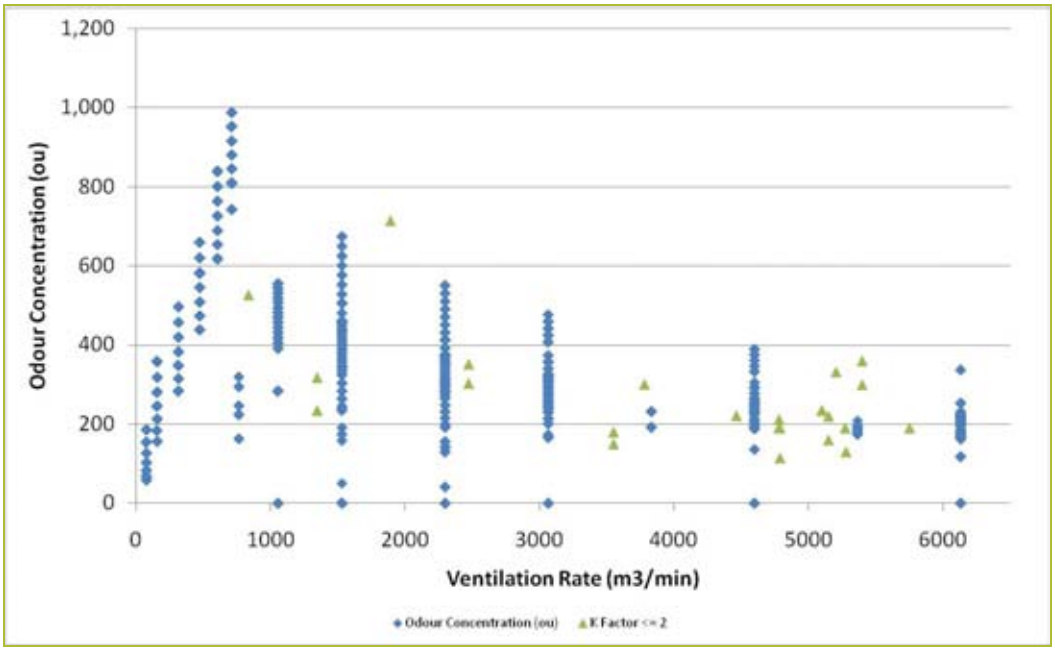

Figure 6.3: Example of estimated and measured odour emissions data

The modelling of odour emissions is not perfect, as variability in emissions due to other factors has been identified (Dunlop, Gallagher et al. 2010). It is recommended that the baseline for estimating new meat chicken farm emissions is to apply a nominal K factor of approximately 2. Results of odour sampling from modern well managed farms in recent years have usually returned values between 1 and 2.5, but with some higher values. In at least some of these cases there may have been departures from the 'best practice' farm management and design assumptions but this is difficult to verify after the event, noting that many measurements are not conducted for research but for compliance or simple benchmarking. Occasional higher (and lower) values around the nominal k value of 2 must also be considered in light of the inherent uncertainty in odour data, arising simply from the method of measurement.

An example of a typical annual series of batches is shown below in Figure 6.4. The batch length is approximately 56 days with thinning occurring at around days 35, 40 and 48. Maximum emissions depending on the season and ventilation conditions, normally peaking in summer when ventilation needs are greatest.

[k] In calculating odour emission rates, the K factor is a scalar that was originally introduced to account for variations between farms based on design and management. For new farms conforming to best practice it is now recommended that the value of K be set at approximately 2.

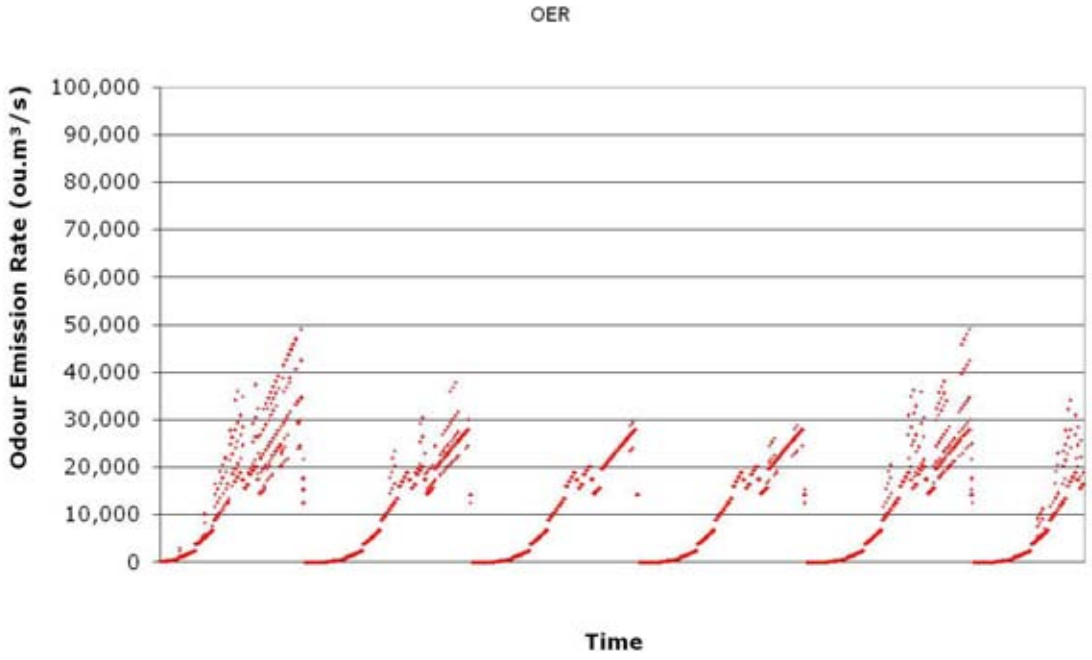

Figure 6.4: Example of Hourly Emissions Time Series based on a maximum ventilation rate of 10 m^3/hr/bird, a shed capacity of 40,000 birds and a K factor of 2

The data shown in Figure 6.4 are based on a modelling approach that calculates emissions deterministically based on the input variables (bird numbers, bird mass, ambient temperature, target temperature, ventilation regime, K value). In reality, variability around these estimated emission rates can be expected as a result of other factors (Dunlop, Gallagher et al. 2010), which may not be known or measured.

To account for this inherent variability, it is possible to apply a Monte Carlo simulation method to introduce random variability into the estimated emissions. Figure 6.5 illustrates the effect of applying the randomising function to emission rates: there is a spread of values around the 'base case' values shown in Figure 6.4.

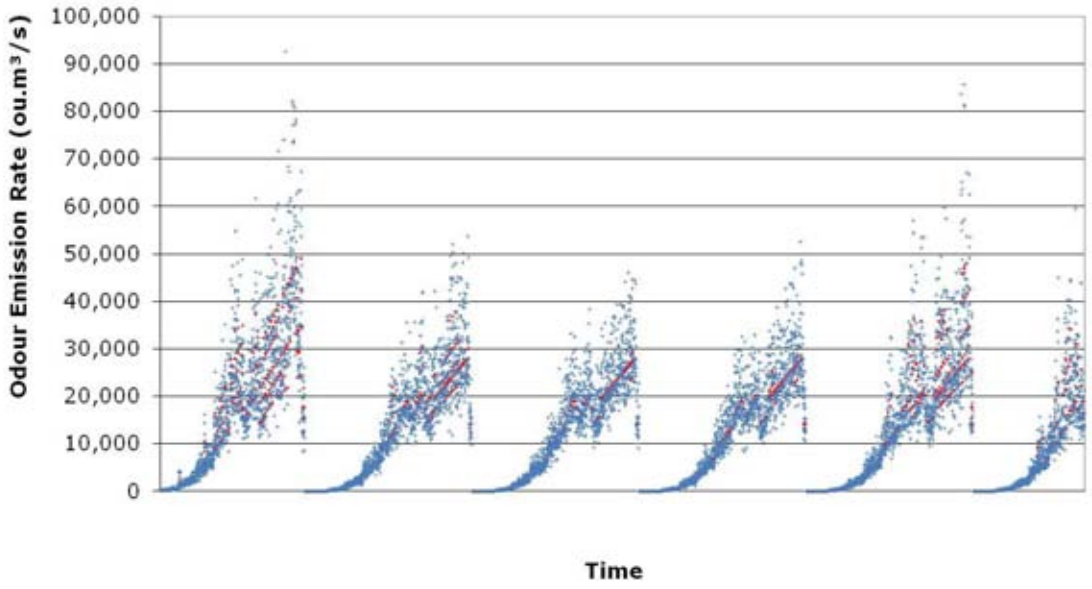

Figure 6.5: Times series of odour emission rates using the same basis as in Figure 6.4 but with the addition of Monte Carlo randomisation based on a skewed normal distribution to better simulate the spread of data implied from measurements across new farms and over time. Randomised data are in blue, overlain on the original data from Figure 6.4.

With Monte Carlo methods, the emission rates will be slightly different with each simulation. The hourly emission rates determined by the Monte Carlo simulation for this example were used to estimate an equivalent K value for each hour. The resulting distribution of K values over the year of data is shown in Figure 6.6. Approximately 45% of K values are less than 2.

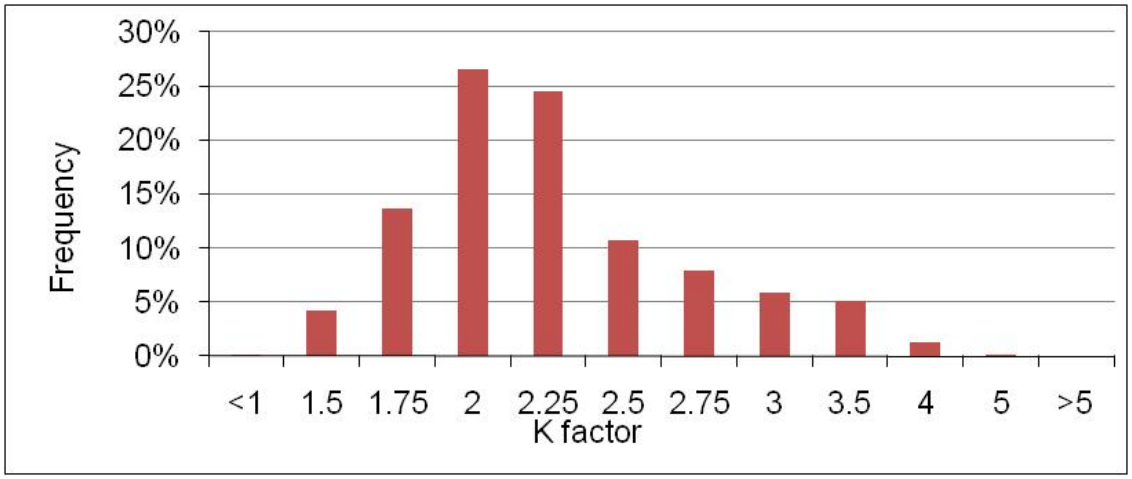

Figure 6.6: Example of statistical distribution of equivalent K values based on a median of K=2 and a skewed normal distribution applied via a Monte Carlo simulation

For comparison, a summary of 14 measurements from new or refurbished farms in the past 5 years is presented in Figure 6.7, which shows that the typical farm has a K value below 2 (72% of values) but some can be significantly higher. Larger sample numbers could be expected to yield a smoother distribution of values.

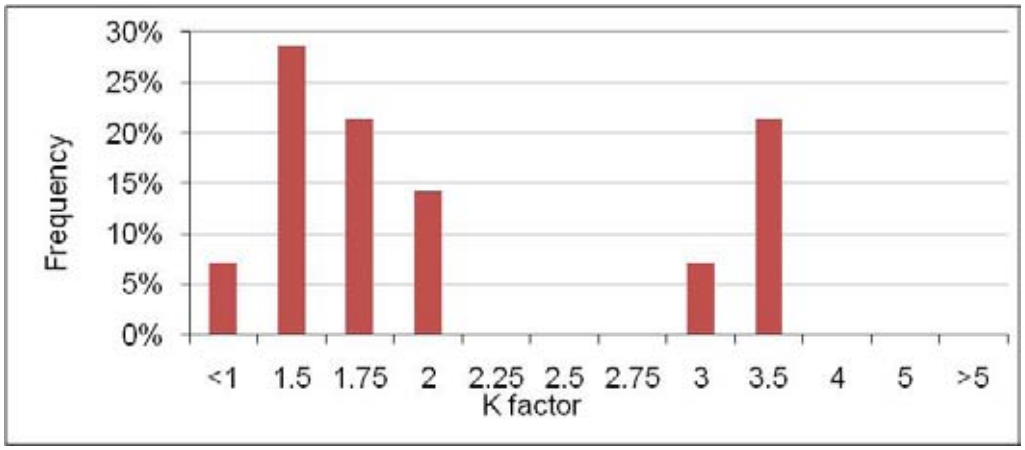

Figure 6.7: Summary of K-factor data from 14 measurements of new or refurbished meat chicken farms in southeast Queensland

For comparison, the distribution of K for all available (126) measurements in southeast Queensland yields 43% of values below 2. Note that the majority of cases are for older farms that would not qualify as current best practice, and the measurements are considered to reflect a bias towards 'problem' farms with complaint histories.

Statistically, the estimated emissions data from a farm in southern Queensland can be expected to follow a distribution similar to that in Figure 6.8

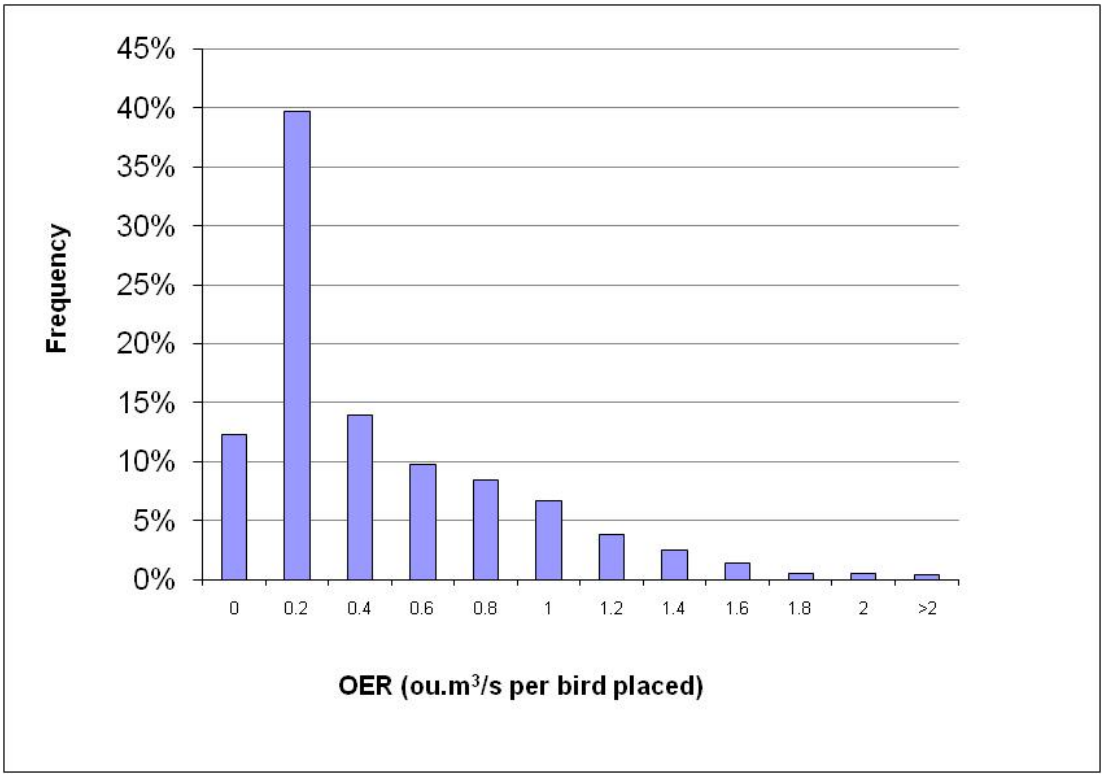

Figure 6.8: Typical frequency distribution of hourly emission rates over a full year at a new farm in southeast Queensland. Data are standardised to 'per bird' values. The lower values reflect periods of no birds and early stages of growth. Highest values can be expected to reach 2 ou.m^3/s per bird less than 1% of the time in a typical year.

6.1.4 Uncertainty in results

The best way to appreciate the effect of uncertainty in odour impact predictions is to run the dispersion model several times with different realisations of the randomised emissions model. An example of the differences between model runs is shown in Figure 6.9.

Given that there is not a large difference between the modelling approaches, an alternative to running the emissions model multiple times with randomisation would be to set a K value sufficient to encompass the outer envelope of the results from several randomised runs. It is suggested that an equivalent fixed K value of approximately 2.2 would achieve this, although to date this has not been tested extensively across a number of datasets.

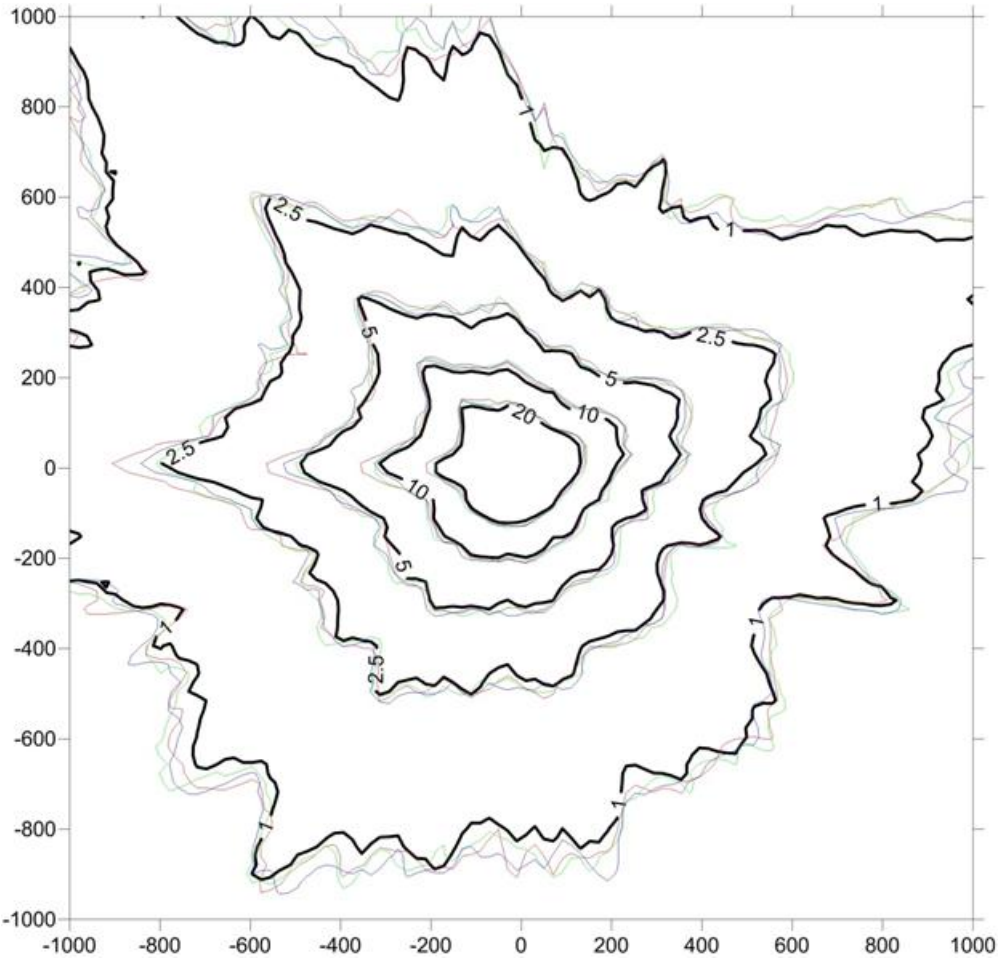

Figure 6.9: Example of $C_{99.5\ 1hr}$ odour concentrations from a model run with a fixed (deterministic) emissions model set at K=2 (dark contour) and three runs based on randomised emission rates (faint contours) with a basis of K=2 and a skewed normal distribution.

6.1.5 Emissions model availability

PAEHolmes can provide modellers with a copy of its odour emissions estimation method but to ensure transparency and the consistent use of agreed best methods it is recommended that DEEDI or a respected industry body act to provide a 'clearinghouse' for the model with regular revisions and updates based on new data and collaborative input.

6.2 Meteorological Data

Dispersion modelling is a form of applied meteorology, which depends critically on the use or simulation of meteorological data, and should be of an appropriate, verifiable standard in order to achieve the best results. This section examines meteorological data requirements for use in dispersion models.

With regard to meteorological data the Queensland Odour Guideline (2004) states:

The assessments in this guideline require the use of at least one year of hourly meteorological data which are representative of local conditions. EPA has available,

AUSPLUME meteorological input files derived from historic 3-hourly Bureau of Meteorology surface data for 22 locations in Queensland. These may suffice if predicted impacts are well below assessment guidelines but in other cases, proponents will have to gather or generate their site-specific data for modelling.

By and large, site-specific weather station data are not available for farm sites. For the majority of cases where odour modelling is required for meat chicken farm assessment, CALPUFF is likely to be the preferred model. Hence, in those cases the AUSPLUME files mentioned above will not be relevant.

6.2.1 Data Sources

Weather station data are used in both Gaussian plume models and, optionally, in meteorological models such as CALMET and TAPM. When considering use of data from a weather station, the sensors should be sited, maintained and operated in accordance with approved methods, e.g., (US EPA 2000; NSW DEC 2005).

Weather stations should be subject to regular maintenance and calibration to ensure high data quality. Many weather stations are not operated to sufficiently high standards, and data quality can be seriously compromised. Caution should also be exercised when obtaining data from reputable sources. For example, with the Bureau of Meteorology (BoM, 2009, *pers. comm*.) data:

- Wind direction and speed is stored as a 10-minute mean at the time of observation in the dataset
- Wind speeds are recorded in whole numbers, in knots.
- Very light wind speeds are problematic as it may take a couple of knots to restart the instrument cups after stalling, and once running these cups will normally continue to rotate at a 1 knot wind speed. Therefore anything less than a knot (0.5 m/s) is recorded as calm.

All weather station wind speed data are subject to a stall speed if a rotating cup anemometer or vane anemometer is installed. The stall speed is high with older BoM sites but may be significantly less than 0.5 m/s with sensors designed for air quality applications. In any case, the stalling speed creates data issues for modelling light wind conditions. A solution to this problem is a sonic anemometer, which will provide data down to 0.01 m/s, essentially eliminating 'calms' from the record.

Data for CALPUFF modelling is able to be sourced via direct import of prognostic model (MM5, WRF, TAPM) input. It is recommended that guidance on the use of meteorological data for CALPUFF be based on the guidance prepared for the NSW DECC by TRC Environmental Corporation. This guidance is expected to be officially available in early 2011 and refers to specific meteorological data issues for use of CALPUFF in Australia.

6.2.2 Selection of Representative Data

There are four factors that affect the representativeness of the meteorological data. These are:

- the proximity of the meteorological site to the area being modelled;
- the complexity of the terrain;
- the exposure of the meteorological measurement site; and
- the time period of the data collection.

While site-specific data is preferred, particularly for Gaussian plume modelling, data from the nearest off-site meteorological station can be used when on-site data are not available (Queensland Environmental Protection Authority 2004; NSW DEC 2005). This site-representative data should be selected on the basis of geographical and meteorological representativeness as well as the suitability of the individual parameters selected to characterise the transport and dispersion conditions in the area of concern (US EPA 2000). In other words, the off-site station must be located in an area with similar topographical characteristics (*e.g.* both sites should be located in the same valley or in close proximity to the coastline (NZ MfE 2004) and meteorological patterns (*e.g.* wind speed, wind direction, temperature, mixing height and stability class (NSW DEC 2005) as the site concerned.

Other factors representative of the surrounding site and associated topography may also be needed for modelling dispersion of pollutants. Where there is complex terrain that may cause wind channelling, and where there is the potential for slope flows, recirculation or sea breezes to affect dispersion, other dispersion models may be required to accommodate spatially variable meteorological inputs.

Generally, a minimum of one year of meteorological data is acceptable for dispersion modelling in Queensland (Queensland Environmental Protection Authority 2004). The US EPA recommends that a minimum of 5-years off-site meteorological data be collected and used in dispersion modelling if on-site data are unavailable (US EPA 2008). This is often not practical for large 3-D datasets such as those used in CALPUFF because of the computational issues that arise.

The data must, however, adequately represent the occurrence of worst-case meteorological conditions and the data should be assessed in terms of representativeness against climatic averages. In other words, the meteorology for selected years must be deemed representative of the "normal" range of conditions in the area. This should include adequate representation of conditions likely to influence maximum plume impacts. Where there is cause for concern about the representativeness of a weather station for the assessment area, multiple years (two or more) of meteorological data may be used. However, a single representative year may be used for decision-making purposes (Queensland Environmental Protection Authority 2004). To be deemed acceptable, the one-year site-representative data set should be compared against a site-representative climatological database and it must be established that the data adequately describes the expected meteorological patterns at the site.

6.2.3 Missing Data and Substitutions

Regulatory dispersion modelling for every hour in the analysis period (one to five years) requires a meteorological record for every hour in the analysis period. Most dispersion models will not run successfully if they encounter missing meteorological data. Substitution for missing or invalid data is allowed for up to 10 percent of the data; conversely, the meteorological data base must be 90 percent complete (before substitution) in order to be

acceptable for use in regulatory dispersion modelling (US EPA 2008). The following guidance should be followed for assessing compliance with the 90 percent completeness requirement:

- Lost data due to calibrations or other quality assurance procedures is considered missing.
- A variable is not considered missing if data for a backup, collocated sensor is available.
- The 90 percent requirement is applied on a quarterly basis (*viz.* 4 consecutive quarters with 90 percent recovery are required).
- The 90 percent requirement applies to each of the variables wind direction, wind speed, stability, and temperature.

Data substitution procedures that are considered to be "best estimators" include:

- Persistence – Persistence is the use of data from the previous time period (hour). This procedure is applicable for most meteorological variables for isolated one-hour gaps. Caution should be used when the gaps occur during day/night transition periods (US EPA 2000).
- Interpolation – This procedure is applicable for most meteorological variables for isolated one-hour gaps and, depending on circumstances, may be used for more extended periods (several hours) for selected variables; *e.g.* temperature. As in the case of persistence, caution should be used when the gaps occur during day/night transition periods (US EPA 2000).

Missing data for periods longer than 1 week cannot be interpolated and must be regarded as missing. If there are other on-site or nearby representative off-site data, they may be used when the primary data are missing.

Furthermore, Gaussian plume models assume that concentration is inversely proportional to wind speed (see Section 3.2.1), which results in overly conservative concentration estimates for wind speeds lower than 0.5 m/s (see Section 6.3.2). In some jurisdictions, these "calm" conditions are to be treated as missing (US EPA 2000; NZ MfE 2004). Alternatively, calm or wind speeds less than 0.5 m/s can be set to 0.5 m/s as recommended in AUSPLUME. In the US these are set to 1 m/s (US EPA 2000).

Gaussian puff models largely overcome the problem of calm wind speeds. The US EPA recommends that sites where calms are frequent should be modelled using a puff model (US EPA 2008). In a puff model the wind speed data should be unaltered with a low wind speed cut-off used, below which the model will invoke a different dispersion regime, neglect transport and only have horizontal and vertical dispersion.

6.2.4 Prognostic Meteorological Models

Prognostic models (*e.g.* TAPM v4, WRF, MM5) can be used to derive or supplement observational meteorology in data-sparse areas.

TAPM v4 specifically, has the capacity to generate ready-to-use CALMET (V5 and V6) and AERMOD (V1) upper air (temperature and wind profiles) and surface meteorological files. However, users should note that the terrain resolution generated by the default database is coarse compared to that typically used for poultry odour modelling (≤100 m).

Prognostic models may incorporate observational data in order to "nudge" the model to better reflect reality. A note of caution is that nudging may produce unrealistic or distorted wind fields if the prognostic data do not match the observational data very well in certain areas or at certain times.

Some diagnostic models (*e.g.* CALMET) may be run with TAPM, WRF or MM5 derived data. Prognostic model wind fields may be used as an initial guess field, which will then be adjusted for mesoscale and local scale effects. This is the preferred method because it provides consistent wind fields and may better simulate terrain effects than using observations which are widely spaced.

Alternatively, prognostic data can be incorporated as a network of pseudo observations or can be used in conjunction with observational data to create a dense network of data stations over the modelling domain, especially over data-sparse regions.

In any case, it is important to evaluate wind fields that are finally produced for dispersion modelling and use any available measurement data in the region as a validation check.

Both the prognostic and diagnostic approaches to meteorological modelling have advantageous features for the production of realistic meteorological fields for input to dispersion models. The advantages of each approach are:

- Prognostic models do not need local meteorological observations to run, so can simulate the meteorology of regions where few data are available;
- Diagnostic models can incorporate available measurements, and – provided the measurements are interpolated realistically – can potentially produce meteorology close to that observed (NZ MfE 2004).

6.3 Meteorological Parameters for Modelling

Meteorological data is one of the most important factors determining model accuracy. This section examines the various parameters used in meteorological files for modelling, and includes reference to data quality issues.

The basic meteorological parameters required for input to Gaussian plume and puff models are:

- Air temperature;
- Wind speed;
- Wind direction;
- Cloud amount and height;
- Pasquill-Gifford stability class; and
- Mixing height.

In addition to these mandatory inputs, optional data inputs in the meteorological file are:

- Standard deviation of wind direction, also known as sigma theta (σ_θ);

- Wind profile exponent;
- Vertical gradient of potential temperature;
- Decay constant;
- Directional wind shear;
- precipitation amount;
- Station pressure;
- Horizontal visibility;
- Wet bulb temperature; and
- Relative humidity.

The typical meteorological input file for a dispersion model consists of hourly averaged data in sequence, and must contain data for complete 24-hour periods. However, AUSPLUME does not require that days be consecutive. Format details for each record in the data file can be found in the relevant user manuals.

The basic input parameters are described below.

6.3.1 Air Temperature

Air temperature is important in influencing the buoyancy of plumes emitted into the atmosphere. Buoyancy affects the extent of plume rise, with more buoyant plumes tending to rise higher above the ground, thus reducing the ground level impact. For tunnel ventilated poultry operations, it is known that buoyancy effects occur (Dunlop, Duperouzel et al. 2010), albeit intermittently.

If sources are treated as area or volume sources with no buoyant effects, then the air temperature information in the data file is not used in the dispersion calculations. Hence, temperature data would not be critical because when non-buoyant area or volume sources are adopted no plume rise calculations are necessary. However, surface temperature data for a site may be used in determining mixing height, and it is therefore important to understand how mixing height has been determined and whether on-site temperature data have been used for that purpose (see Section 6.3.6 for more detail).

Air temperature should be measured as shade temperature, usually at a height of approximately 1.5 m above ground. It is important that the temperature sensor is properly shielded from radiation effects. If it is not, the measured temperatures will be too high during sunny conditions and too low at night. It is wise to check temperature data against data from a recognised (*e.g.* Bureau of Meteorology) site nearby with similar conditions (*e.g.* similar altitude, terrain and distance from coast) to help ensure quality.

6.3.2 Wind Speed

Wind speed has two main effects on plume dispersion:

- It influences the initial dilution of the plume as it leaves the source. See equation (1), where it is in the denominator of the first term. This means that

plume dispersion models based on equation (1) cannot accept zero wind speed values. Greater wind speeds result in greater plume dilution;

- It also affects plume rise, with higher wind speeds resulting in smaller plume rise.

It is normal to measure wind speed at a height of 10 metres, but this is not always the case. It is important that the measurement height be known, as most models require this information and adjust wind speed if measurements are at a different height. It is also important to know the measurement height when determining stability class via methods that use wind speed at 10 m, e.g., (US EPA 2000).

The wind speed value used should be a scalar hourly averaged wind speed, not a vector average. Automatic weather stations often provide both parameters and care is needed to select the correct one. Often, weather stations record data in sub-hourly increments. Hourly statistics may then be obtained by averaging these values. These statistics should be processed using recommended methods (US EPA 2000).

Siting of a weather station to provide representative wind speeds is critical for air quality modelling applications. The standard exposure height of wind instruments over level, open terrain is 10 m above the ground. The weather station should be located clear of obstacles such as trees, buildings or local terrain features that can disrupt the free flow around the sensor. The sensor should be separated from obstacles by a distance of at least 10 times the height of the obstacle. Australian Standard 2923-1987 (*Guide for the Measurement of Horizontal Wind for Air Quality Applications*) should be complied with. Where such an exposure cannot be obtained, the anemometer should be installed at such a height that it is reasonably unaffected by local obstructions and represents the approximate wind values that would occur at 10 m in the absence of the obstructions. This height can be determined on a case-by-case basis.

Another important aspect for wind data is the threshold speed for the wind speed sensor (see Section 6.2). Given the importance of low wind speeds in plume dispersion, it is important that the wind speed threshold is as low as possible to ensure proper representation of low wind speed conditions, which are critical for most odour dispersion cases. A wind sensor should ideally have a threshold of no more than 0.3 m/s. Note that some older Bureau of Meteorology sites using instruments such as the Dynes pressure tube anemograph and cup and vane anemometers have wind speed thresholds as high as 0.5 - 2 m/s, which is inadequate for dispersion modelling in situations where low wind speeds are important.

The best practical option is the use of data from a sonic anemometer, which determines instantaneous wind speed and direction by measuring how much sound waves travelling between a pair of transducers are sped up or slowed down by the effect of the wind. The sonic anemometer avoids the problems experienced by mechanical wind sensors in that it:

- has no moving parts to wear out or become contaminated;
- has absolute calibration;
- can measure wind velocity up to 20 times per second; and
- can measure extremely slow wind speeds accurately (thresholds in the order of 0.01 m/s).

Minimum wind speeds recommended for use in Gaussian plume models vary between 0.5 m/s and 1 m/s, depending on the regulatory authority. Given the information in Section 3.2.1, it

is apparent that the difference between 0.5 m/s and 1 m/s is a factor of two in the ground level concentration, if all other factors are equal. It is more conservative to apply a minimum of 0.5 m/s. Note that this does not imply the wind speed threshold of the sensor need only be 0.5 m/s, as distortion of wind speed data occurs near the threshold, and hence a lower threshold ensures better data quality at supra-threshold values.

Wind speed normally varies from minimum values at night to highest values in the afternoon. Check data to ensure that this expected pattern occurs. At most sites, absolute calms rarely exist, and so non-zero wind speed values should dominate at all times (subject to sensor type). Long spells of calms in the data may indicate problems with the sensor threshold.

6.3.3 Wind Direction

Wind direction is a measured parameter that affects the direction in which the plume travels. Thus, only points downwind and within the lateral bounds of the plume are affected at any given time. Over a long integration period, the temporal pattern of wind directions in conjunction with other meteorological parameters determines the spatial pattern of average ground level concentrations.

Wind direction data should be resolved to within 1°. If direction data are originally resolved more coarsely (*e.g.* 10° or 22.5°), then model results will be unrealistic unless the data are adjusted. Hence, in such situations randomisation of wind directions within sectors centred on the nominal values to achieve 1° resolution is recommended.

The same siting issues as for wind speed affect quality of wind direction data. Stalling of the wind direction sensor (wind vane) at low wind speeds can introduce errors in resultant hourly wind direction. Constant wind direction for consecutive hours generally indicates a stalled sensor. This type of problem will not occur with sonic anemometers, as they have no moving parts.

At many sites, wind direction displays diurnal variations due to the influences of different terrain and thermal effects, such as land breezes and sea breezes near the coast, and drainage flows in valleys. Data should be checked to ensure that expected patterns of variation occur.

Note that pre-processed data from some sources may contain wind data that records calms as zero for both wind speed and wind direction. Some models convert any wind speed value less than the model threshold (e.g., 0.5 m/s for AUSPLUME) to the threshold value (e.g., a zero becomes 0.5 m/s). If the wind direction is set at the arbitrary value of zero, then this will result in calm conditions being modelled as if in a very light northerly flow and will introduce errors into the model results. Hence, it is important to check meteorological data files to ensure this is not a feature.

6.3.4 Cloud Amount and Height

Cloud height and amount data are needed for some current dispersion models. Pre-processing uses this data to estimate stability class (see following section), which is employed in the dispersion model to facilitate estimates of lateral and vertical dispersion parameters. For example, the Pasquill-Gifford-Turner classification scheme assumes that stability in the layers near the ground is governed by convective fluxes from solar radiation (day), cloud

cover (night) and mechanical fluxes from wind speed. CALPUFF uses cloud data to estimate net radiation and sensible heat flux since the height of the boundary layer (BL) and the turbulence intensity profile throughout the BL is directly related to the sensible (convective) heat flux.

Cloud data is not readily available. The Bureau of Meteorology records cloud data, on average, every three hours at selected stations. The data should then be interpolated to produce hourly data. Quite often, however, the area in which dispersion modelling is to be conducted does not coincide with such a station. In these cases, an alternative source of this data needs to be considered. One such source is TAPM, where the cloud cover is calculated from the approach used in global and synoptic scale models (Hurley 2008).

AERMET uses net radiation (from the on-site data) and Bowen ratio to determine the sensible heat flux. This negates the need for cloud data. Similarly, using prognostic MM5 or WRF data in CALMET also negates the need for cloud data.

6.3.5 Stability Class

Stability class is a derived parameter, which is related to the degree of turbulence or mixing in the region of the atmosphere relevant to plume dispersion. The degree of mixing affects the rate of plume dilution by determining the rate of lateral and vertical spread of the plume, indicated by the terms σ_z and σ_y in the Gaussian plume equation. This parameter is required in a number of older-generation plume models, such as AUSPLUME. Newer generation plume models such as AERMOD, and puff models such as CALPUFF do not require derived stability class as they use dispersion schemes based on micrometeorological variables.

Modelling guidelines (NSW DEC 2005; US EPA 2008) recommend that stability categories be based on the Pasquill-Gifford (P-G) scheme. Stability class under the P-G scheme is designated a letter from A to F, ranging from highly unstable to strongly stable. Unstable conditions are associated with strong turbulence and mixing, and are most strongly developed on sunny days with relatively light winds. Strongly stable conditions are associated with very limited plume mixing and are most developed on calm clear nights and into the early period after sunrise. Neutral stability conditions, between stable and unstable and designated class D, occur most often during windy and/or cloudy weather.

There are a number of methods for determining stability classes. Turner's method is generally preferred (US EPA 2000; NSW DEC 2005; US EPA 2008). The method estimates the effects of net radiation on stability from solar altitude, total cloud cover and cloud ceiling height. The stability class is estimated as a function of wind speed and net radiation.

In the absence of the necessary data to implement the P-G-T (Pasquil-Gifford-Turner) method, the solar radiation/delta-T (SRDT) method can be used. This method retains the basic structure and rationale of Turner's method while replacing the need for cloud cover and ceiling observations with solar radiation observations. The method uses the surface layer wind speed (measured at or near 10 m) in combination with measurements of total solar radiation during the day and a low-level vertical temperature difference (T_{10m}-T_{2m}) at night. Evaluations indicate that this method identifies the same P-G stability category as Turner's method about 60 percent of the time and is within one category about 90 percent of the time (US EPA 2000).

The final stability class estimation technique is the sigma theta method (σ_θ) which is a turbulence-based method using the standard deviation of the wind direction in combination with the scalar mean wind speed (US EPA 2000). All modern meteorological data loggers include software to estimate σ_θ. This method does not yield reliable estimates in stable conditions where flows meander, and must be used with great caution to ensure realistic stability estimates.

Quality assurance includes visual inspection of the derived data where the user assesses whether the stability classes are realistic or not. For example, P-G stability classes A, B and C are unacceptable at night for overland sites. It is also generally accepted that for the hour before sunset and after sunrise the stability assignment should be forced to class D. Note: This is not relevant for dispersion schemes based on calculated micrometeorological variables (*e.g.* in CALMET for use in CALPUFF).

It is important that the method of determining stability class in a meteorological file is known, and that the method has been correctly applied.

6.3.6 Mixing Height

Mixing height is defined as the height of the layer adjacent to the ground over which an emitted or entrained inert non-buoyant tracer will be mixed by turbulence. Dispersion model predictions can be highly sensitive to changes in mixing height but generally in the case of odour the critical impacts are not significantly influenced by mixing height.

Four main methods are used to determine mixing height[l]. Details can be found in US EPA guidance (US EPA 2000). Generally, these methods are not used and typically mixing height can be obtained more easily via TAPM and other meteorological models, if needed.

6.3.7 Sigma Theta (σ_θ)

Horizontal diffusion of plumes can be parameterised according to either the P-G stability class or the standard deviation of wind direction fluctuations, denoted by σ_θ. The latter is useful because it is a direct measure of horizontal turbulence, and if σ_θ values are available they can be included in the data file (for Gaussian plume modelling). If there is no σ_θ value, the model will revert to lateral diffusion as a function of the stability class for that hour.

Values of σ_θ are generally high - in excess of 20˚- during unstable (class A, B and C) conditions, and tend to reduce to lower values around 10˚ under neutral (class D) conditions. Under stable conditions (class E and F), σ_θ may fall to even lower values. However, particularly under very stable conditions (class F), it is not uncommon for σ_θ to increase to very high values as a result of meandering of the flow. The high σ_θ values under stable conditions are associated with low-frequency variations, whereas high σ_θ values in unstable conditions are dominated by high frequency contributions.

Quality of σ_θ data can be an issue[m], and it is important to ensure that the spread of values is consistent with the guidance provided (US EPA 2000). The wind direction sensor (if

[l] Determining mixing height is a complex procedure that should not be attempted lightly.

[m] Use of σ_θ is not recommended by WA DoE unless used expertly

mechanical) must have certain characteristics, the most important of which is a damping ratio of 0.4 to 0.7.

6.3.8 Wind Profile Exponent

Most plume models assume that the wind speed (u) increases with height (z) according to a power law, such that u is a function of z^p. In AUSPLUME, if hourly data are available from a tower with multiple wind sensors, the exponent (p) may be computed for each hour and included in the file. If the data are not provided, the model will default to values based on the stability class.

6.3.9 Vertical Gradient of Potential Temperature

The vertical temperature gradient is used only in calculating plume rise under stable atmospheric conditions. If the data are available and included in the file, certain plume models like AUSPLUME will use it, and in its absence the gradient will be determined as a function of stability class. Importantly, the gradient typically varies with height, especially in very stable conditions, so it is important to know the heights of the temperature sensors.

In advanced models such as AERMOD and CALPUFF the vertical temperature gradient is either measured from upper air sounding data or determined from Monin-Obukhov similarity theory (Hill 1989).

6.4 Source Representation

6.4.1 Accounting for plume buoyancy

Given the existence of buoyant plume rise in exhaust emissions from meat chicken farms at certain times (Dunlop, Duperouzel et al. 2010), it is preferable that plume rise effects be incorporated into modelling. However, in many situations this may not have a significant effect on model results so judgement should be applied as to its necessity. Apart from altering near-field concentration predictions, accounting for plume rise could in some situations, where vertical wind shear is significant, lead to higher plume impacts on slightly elevated terrain nearby.

To represent a tunnel ventilated shed in a dispersion model so that buoyancy is accounted for, it is necessary to characterise the source as a stack, even though the exhaust air is almost invariably directed horizontally rather than vertically.

Plume rise is a function of momentum and thermal buoyancy components, both of which are calculated separately. CALPUFF includes a ‘rain hat’ switch that sets to zero the vertical momentum of a point source. This neatly accounts for horizontal releases. This feature removes the need to apply dimensional adjustments to source parameters to achieve the same end result (i.e., of removing the vertical term). In other models, it is necessary to adjust the source parameters so that mass flow is conserved but the maximum exit velocity is reduced to a very low value (normally less than 0.1 m/s) that triggers insignificant momentum plume rise. This means expanding the source diameter until the necessary reduction in velocity is achieved.

The exit temperature during tunnel ventilation can be based on the target effective temperature for the relevant stage of the bird batch (see Table 6.1), although as indicated in section 6.1.2, use of the target temperature will tend to underestimate the potential plume

rise when the exit temperature exceeds ambient, because the target temperature takes into account the wind chill effect of shed ventilation.

To apply a more realistic exit temperature, the target temperature should be adjusted for the estimated wind chill associated with the rate of ventilation for any given hour, or by actual performance data.

6.5 Building Downwash Effects

Wind flow is often disrupted in the immediate vicinity of buildings or by terrain features. The disrupted flow near structures can serve to enhance vertical dispersion of emissions, ultimately causing an increase in the maximum ground level concentration by bringing to ground plume material that would otherwise have remained aloft. Plumes are assumed to be unaffected by building wakes if they manage to reach building height plus 1.5 times the lesser of building height or width within two building heights downwind of the stack. The plume height results from the combined effects of stack height and buoyancy/momentum plume rise. These plumes are considered to be released into the free stream above the building. If this is not the case, pollutants can be brought to ground within a highly turbulent, generally recirculating, cavity region in the immediate lee of the building and/or be subject to plume downwash and enhanced dispersion in a turbulent region which extends further downwind behind the building (EPAV 1999).

The technical background of aerodynamic influences is described in greater detail in the Guideline for Determination of Good Engineering Practice Stack Height (US EPA 1985). Good Engineering Practice (GEP) stack heights are the stack heights that US EPA requires to avoid having to consider building downwash effects in dispersion modelling assessments (US EPA 2008). Dispersion from stacks lower than GEP should be assessed by case-specific modelling.

Most modern models calculate building downwash using the PRIME downwash model. The model includes improved algorithms for handling building downwash influences, including algorithms for the building cavity region. More specifically, it incorporates estimates of wind speed; streamline deflection, and turbulence intensities in the wake, as well as the location of the source. PRIME explicitly treats the trajectory of the plume near the building, and uses the position of the plume relative to the building to calculate interactions with the building wake. It calculates fields of turbulence intensity, wind speed, and the slopes of the mean streamlines as a function of the projected building dimensions and determines the change in plume centreline location with downwind distance as well as the rate of plume dispersion. This option is currently used in AERMOD, CALPUFF and TAPM.

If poultry sheds are represented as point sources in dispersion models, then it is necessary to incorporate building downwash effects. This requires locating shed co-ordinates and entering length, width and height data as required by the downwash algorithm.

When modelling with CALPUFF, the recommended approach is to treat each shed as a horizontally directed point source, centred approximately 30 metres out from the endwall fans. For farms with complex fan arrangements, alternative source parameters and locations may be necessary.

To remove the effect of vertical momentum (assuming that endwall fans are in place and not short stacks, which have been used in some cases), the CALPUFF program has a ‘rain hat’ switch to automatically exclude the component of plume rise caused by vertical momentum.

Plume rise then is attributable only to thermal buoyancy. Depending on the difference between ambient and shed exit temperatures for any given time, this may or may not be relevant.

If AUSPLUME is used instead of CALPUFF, the procedure required to remove the effect of momentum is to increase the 'stack' diameter to a value at which the maximum exit velocity at any time remains below the threshold velocity required to trigger momentum plume rise.

Treating the sheds as volume sources will generally result in little difference to predicted odour impacts beyond about 500-1000 metres from the sheds, compared to the use of the plume buoyancy approach. If no sensitive receptors exist, or are likely to exist in the future, within about 1 km of the farm, then use of volume sources is likely to be acceptable. As for point sources, these sources should be displaced about 30 metres out from the endwall fans to account for the horizontal momentum from fans.

6.6 Geophysical Data

Geophysical inputs for models include terrain information, land use or surface roughness data and other information, depending on the model employed. For best results, these data need to be as accurate as possible and suitably resolved in spatial terms. In some cases, default databases of terrain data and vegetation or land use are not of adequate resolution or accuracy to bring out local features that might influence meteorology and plume behaviour, and so it is important that terrain is resolved to 100 metres or better. On-line databases, e.g. satellite-derived terrain from NASA, are available and recommended. Databases for land use or vegetation type and soil type which may be required are recommended for optimum model performance.

Improved data sources and data settings for these types of model inputs continue to be developed and it is recommended that improvements be tracked (e.g., by consultation with regulatory agencies or the Clean Air Society of Australia & New Zealand) to ensure best practice approaches are used.

6.6.1 Co-ordinate Systems and Map Projections

Map projections are attempts to portray the surface of the earth or a portion of the earth on a flat surface. A map projection is the systematic drawing of lines representing the meridians and parallels (the graticule) on a flat surface. Different projections have unique characteristics and serve differing purposes. In dispersion modelling, the map projection defines the receptor grid, meteorological station location(s) as well as position of the source(s) in space.

In Australia the map projection most used in dispersion modelling is Universal Transverse Mercator (UTM). UTM is used to define horizontal, positions worldwide by dividing the surface of the Earth into 6° zones, each mapped by the Transverse Mercator projection with a central meridian in the centre of the zone.

In Australia a UTM projection of the GDA94[n] geographic coordinates produces Cartesian coordinates known as Map Grid of Australia 1994 (MGA94). This UTM projection was also used for the Australian Map Grid, 1966 and 1984 (AMG66/84) that have been superseded by

[n] Geodetic Datum of Australia

MGA94. Data on map grids are available at the Geoscience Australia website (http://www.ga.gov.au).

When a dispersion model run is set up, consistency of coordinate systems must be maintained. For example, the source locations must be consistent with the coordinate system used in the meteorological grid and/or receptor network.

The earth can be assumed to be a perfect sphere for many mapping applications. However, there is a difference between the distance around the earth between the poles versus the equator (ellipsoid or spheroid). The estimate of the earth's surface based on an ellipsoid provides a determination of the elevation of every point on the earth's surface, including sea level, and is called a datum.

Numerous datums have been developed and used. With more accurate means of measurement today (i.e. satellite and GPS), datums are referenced from the centre of the earth rather than a theoretical surface. The resulting North American Datum of 1983 (NAD83) and the slightly refined World Geodetic System (WGS84), from the U.S. Military in 1984, are internationally accepted as the geodetic reference system (GRS 80). In Australia, the AMG66/84 Cartesian coordinates are based on the geographic coordinates derived from the Australian National Spheroid [ANS] and the MGA94 Cartesian coordinates come from the geographic coordinates defined by the Geodetic Reference System 1980 [GRS80]. The difference between AMG66 and AMG84 is usually in the order of a few metres, whereas the difference between AMG66/84 and GDA94 is as much as 100 m to 200 m in both the easterly and westerly directions (GA, 2004).

CALPUFF requires input of a choice of datum. It is recommended that WGS84-G be used, as this datum is compatible with GDA94. A freely available conversion software package to convert between coordinate systems is available from www.geocomp.com.au.

6.6.2 Terrain Elevation

As discussed in Section 6.7, receptors are the locations at which the model calculates concentration or deposition. It is therefore necessary, in non-uniform topography, for the receptors to reflect the elevation on which they are located.

Because of the assumption that the wind speed and direction remain constant over the full length of the plume, the older Gaussian plume models[o] can only partially simulate terrain effects.

There are a number of simple adjustment methods to partially account for the effects of the terrain:

- ISC method - assumes that the terrain has no influence on the plume height above sea level and the plume is assumed not to be uplifted at all by the terrain below it. AUSPLUME and CALPUFF allow the use of this scheme; however, it is not recommended (EPAV 2001).

[o] Simple screening models do not incorporate terrain into their calculations.

- Egan Half Height Approach - In neutral or unstable conditions, a plume will tend to be uplifted by broad terrain features. Under stable conditions, this lifting will generally be less and the plume will pass closer to the face of the hill and may even impact on the surface (EPAV 2001). This scheme is incorporated into AUSPLUME.
- Plume path coefficient – the height of the plume depends at the receptor depends on the height of the plume over level terrain, the receptor height and a plume path coefficient which is dependent on stability class (Scire, Strimaitis et al. 2000). This scheme is incorporated into CALPUFF.
- CTDMPLUS method - the plume is modelled as a combination of two limiting cases: a horizontal plume (terrain impacting) and a terrain-following (terrain responding) plume. Generally, in stable flows, a two-layer structure develops in which the lower layer remains horizontal while the upper layer tends to rise over the terrain (US EPA 2008). AERMOD and CALPUFF incorporate variations of this scheme. This is the recommended scheme.

The more sophisticated models such as CALMET/CALPUFF also require terrain elevation data to resolve the smaller scale flow associated with topography: for example, drainage flows. The resolution of the topographic data must therefore be adequate to resolve these smaller-scale flows. An example of a coarser and finer-scale topographic dataset for the same geographical area is shown in Figure 6.10. It is clear that the dataset on the left is inadequate to resolve these flows with any degree of accuracy.

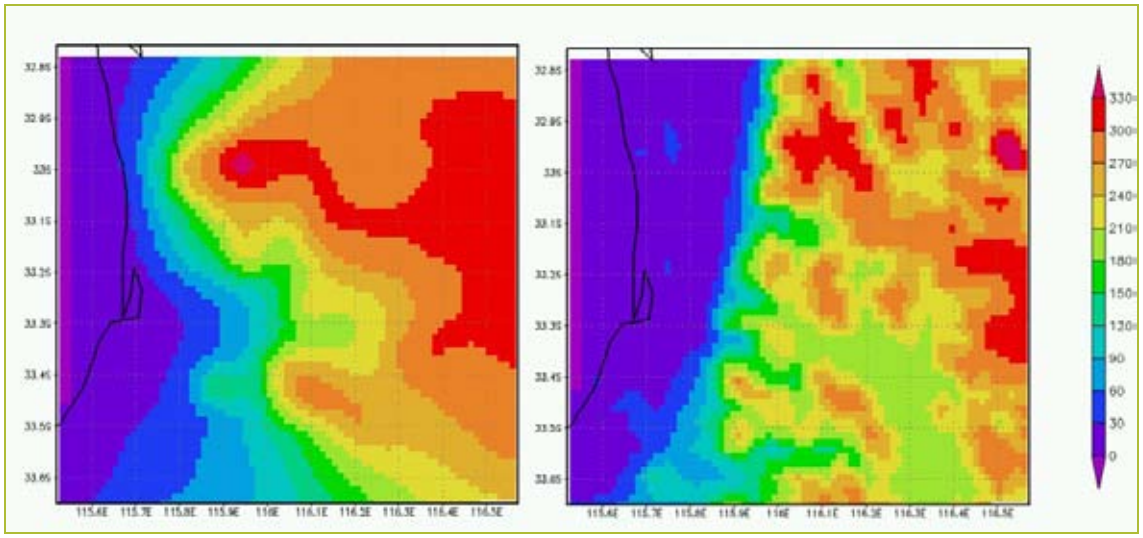

Figure 6.10: Coarse (left) and finer (right) resolution topographical data.

The recommended source of terrain data files is the Shuttle Radar Topography Mission (SRTM) dataset, obtainable from the NASA Jet Propulsion Laboratory website http://www2.jpl.nasa.gov/srtm/cbanddataproducts.html). Data for Australia is available at approximately 90 metre horizontal resolution. The data are derived from satellite-borne measurements.

6.6.3 Land Use

CALMET/CALPUFF and TAPM require land-use data to determine spatially-varying surface energy budgets and roughness lengths. As a default data source, TAPM utilises global land

cover characterisation data on a longitude/latitude grid at 30-second grid spacing (approximately 1 km) sourced from the US Geological Survey, Earth Resources Observation Systems (EROS) Data Center Distributed Active Archive Center (EDC DAAC) (Hurley 2008). The easy option in Australia is to utilise this data for both TAPM and CALMET/CALPUFF modelling. However, in certain applications, for example low-level odour modelling from ponds, the spatial resolution of this data is too coarse. In some regions there are also apparent anomalies in land use descriptions (e.g., littoral (coastal) vegetation near Toowoomba), and so care needs to be taken to ensure that the land use and vegetation data is sufficiently accurate.

Finer resolution GIS-based data are available and should be used to improve data quality if there is doubt about the representativeness of the default data. Sources include:

- Queensland Land, Vegetation and Water (DERM) at http://www.derm.qld.gov.au/property/mapping/order_data.html ;
- Land Use of Australia database from the National Land and Water Resources Audit (ANRDL) at the Australian Bureau of Agricultural and Resource Economics and Sciences website (www.abares.gov.au)

Note that the land-use classifications in these databases must be translated to the USGS 75-category format for recognition by TAPM and CALMET.

As an example, the land use pattern generated from the 1 km US Geological Survey database is compared to data from GIS databases in Figure 6.11. The GIS-based data show greater detail than the relatively uniform land use pattern based on USGS data and may have locally significant effects on derived meteorology.

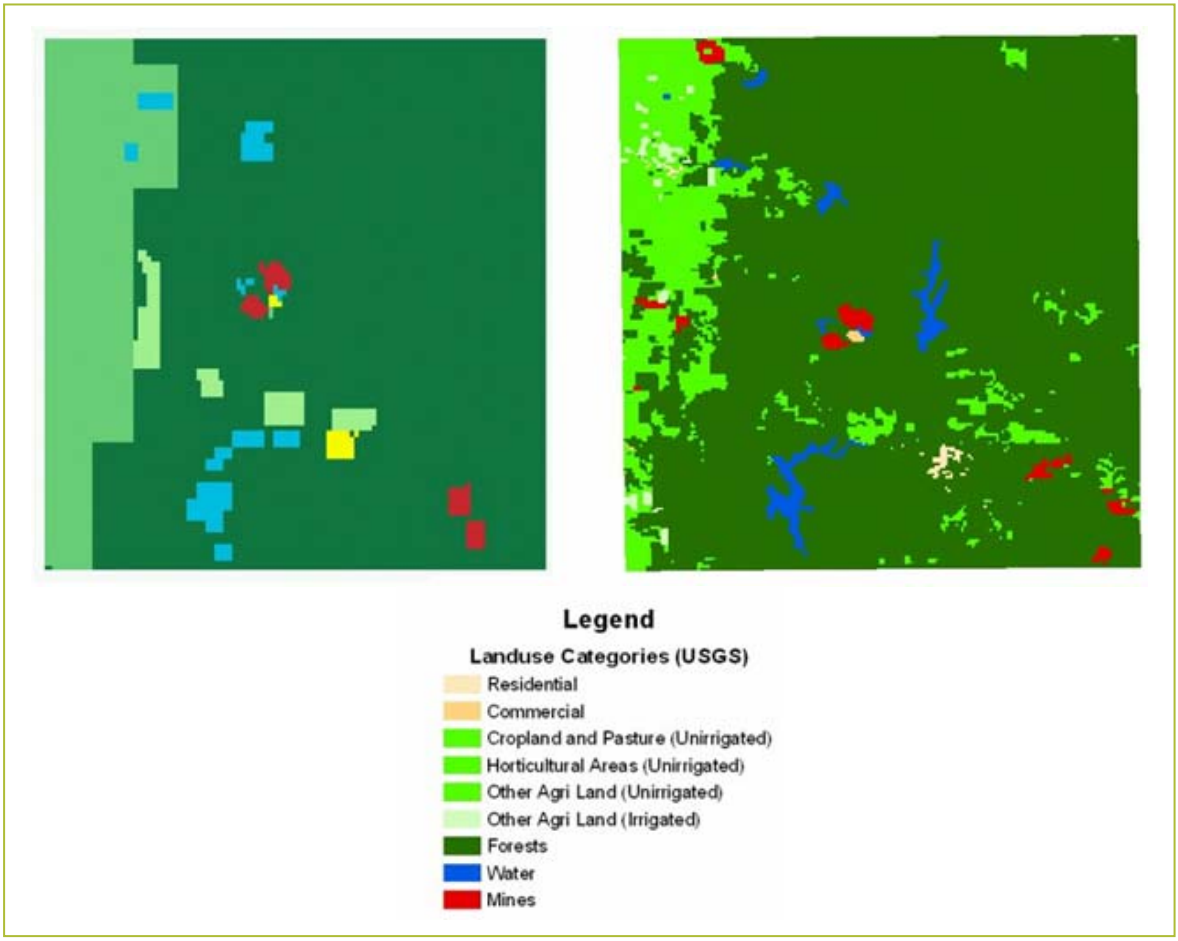

Figure 6.11: Comparison of land-use from the USGS (left) and GIS land use database (right).

6.6.4 Roughness Height

Roughness height, denoted by z_0, is a measure of the aerodynamic roughness of the surface, which generates mechanical turbulence in the overlying airflow. Higher roughness generates more turbulence, and acts to enhance the process of plume diffusion, spreading or dilution. As a result, this parameter is important in all models, whether used directly or indirectly.

Roughness length (Z_0) can be defined as the height at which wind speed (u) is zero when extrapolating the logarithmic wind- speed profile downward through the surface layer (Pasquill and Michael 1977):

$$\bar{u}(z) = \frac{u_*}{k} \ln\left(\frac{z}{z_0}\right) \qquad (5)$$

where u_* is the friction velocity, k is the von Karman constant and roughness length (z_o) is the height at which windspeed (u) is zero.

Roughness length is a theoretical height that is determined from the wind-speed profile. However there has been some success in relating this height to the arrangement, spacing, and physical height of individual roughness elements such as trees or houses.

The Lettau method utilises the following equation to estimate roughness lengths (Lettau 1969):

$$z_o = \frac{0.5h^* s}{A} \qquad (6)$$

where h* is the average obstacle height, s the total silhouette area of all obstacles in the area A, measured in a vertical crosswind plane (m^2) and A the area over which z_o is to be estimated.

The following equation describes the modified Counihan method (Counihan 1971):

$$z_o = h^* \left[1.08 \frac{A_r}{A} - 0.08 \right] \qquad (7)$$

where A_r is the total surface area of the roughness elements in area A.

Roughness length can also be estimated through the following methods:

$$z_o = \frac{z}{\exp\left(\frac{u}{\sigma_u} \right)} \qquad (8)$$

where z is the measurement height, σ_u is the standard deviation of along-wind velocity fluctuations and u is the mean wind velocity (US EPA 2000).

For general application, since typical landscapes almost always contain occasional obstructions, it is advisable to estimate an effective roughness length. A number of methods to estimate roughness length exist. The US EPA's recommended method for estimating the effective roughness length is based on single level gustiness measurements (Wieringa 1993):

$$\frac{\sigma_u}{u} = \frac{1}{\ln \frac{z}{z_0}} \qquad (9)$$

where $\frac{\sigma_u}{u}$ is the maximum gust in an observing period divided by the average wind speed in the same period; *z* is the anemometer height and z_o is the roughness length. A modified version of equation (9) (Verkaik 2000) solves for roughness length:

$$z_0 = z \times \exp\left[\frac{(0.88 \times f)}{\left(1 - \frac{\sigma_u}{u}\right)}\right] \qquad (10)$$

where *f* is 2.41 in the case of 10 minute average and 2.99 in the case of 1 hour average measurement data.

Wind measurements for use in the above equation should be made at a height between 20 z_0 and 100 z_0. To select the appropriate measurement level, an initial estimate of the effective roughness length must first be made based on a visual inspection of the landscape (see Table below). The sampling time for u should be between 3 and 60 minutes. Only data for wind speeds greater than 5 m/s should be used for each wind direction sector (using a minimum sector arc width of 30 degrees). Median z_0 values should be computed for each sector; results should then be inspected to determine whether the variation between sectors is significant. An average of the median values should be computed for adjacent sectors if the variation is not significant. Estimates of the effective surface roughness using these procedures are accurate to one significant figure (US EPA 2000), as per Table 6.2.

Table 6.2: Guidance on roughness heights (US EPA 2000)

Terrain Description	z_0 (m)
Open flat sea	0.0002
Open flat terrain; grass with few isolated obstacles	0.03
Low crops; occasional large obstacles	0.10
High crops; scattered obstacles	0.25
Parkland; bushes; numerous obstacles	0.5
Regular large obstacles (suburb, forest)	0.5-1.0

Other roughness length estimation techniques involve assessing the dimensions and spacing of vegetation and structures from land-use and satellite data and are based on the Lettau and Counihan methods.

Urban and rural land use should be defined by using US EPA procedures (US EPA 2008). It is noted that much of suburbia in Australia will be classified as rural with urban being referred to built up areas with tightly packed two storey houses, industrial and commercial areas and CBDs.

In AUSPLUME, a user-friendly option is to assign roughness via a land use category based on a number of defined choices in the model input menu. However, two main difficulties exist, causing an issue for modellers in assigning roughness height values:

- Only a single value can be used for an area, even though the surface characteristics influencing roughness height may vary significantly; and
- Values for the same or similar type of surface can vary significantly from one reference to another.

In situations where a range of land use types must be considered, the modeller may choose to:

- Use the category that has the lower surface roughness value. This will produce a more conservative ground level concentration;
- Estimate an average surface roughness value for the area and choose the land use category that is closest to this value (NZ MfE 2004).

TAPM incorporates the effect of spatially varying surface roughness via either land use data used or CALPUFF directly specifying roughness within each grid cell. It is therefore important to check the land-use data used in the model. It is also important to note that in the case of CALPUFF, default roughness length based on North American vegetation type may not always be appropriate for Australian applications. Figure 6.12 demonstrates the difference between the roughness length based on CALPUFF defaults and roughness lengths determined from the dimensions and spacing of vegetation and structures (Lettau and Counihan methods) from satellite imagery. The calculated version shows greatest detail and appears a more realistic depiction of reality than the relatively uniform roughness heights based on CALPUFF defaults.

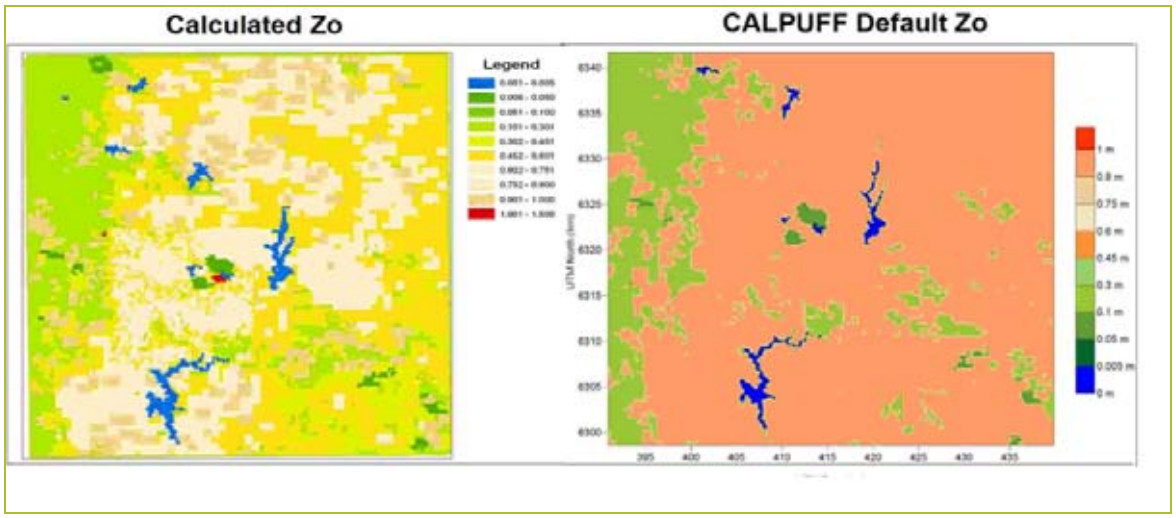

Figure 6.12: Calculated roughness length versus default CALPUFF roughness length based on vegetation.

6.7 Receptor network

Receptors are the locations at which the model calculates concentration or deposition. Most models allow the user to enter receptor locations based on either a Cartesian[p] or a polar grid[q]. The grid can be either spaced regularly to reflect the topography, population

[p] Cartesian receptor grids are receptor networks that are defined by an origin with evenly or unevenly spaced receptor points in x and y directions.

[q] Polar receptor grids are receptor networks that are characterised by an origin with receptor points defined by the intersection of concentric rings.

distribution patterns, and other site-specific factors or irregularly spaced as discrete receptors to represent sensitive locations not included by the receptor grid (*e.g.* schools, hospitals and houses). The model will calculate concentration or deposition for each point on the grid, and then use a suitable interpolation method to draw a continuous contour line.

The receptor grid spacing is a compromise between resolution and model run time, but should be selected so that peak concentrations are adequately captured by the receptors (MfE, 2004): a finer grid causes significantly longer runtimes for the modelling software, while a coarser grid increases the risk of errors induced by the interpolation to draw contour lines.

For poultry farms, the domain will generally be relatively small (e.g., 5 km by 5 km). A recommended maximum grid spacing to achieve adequate resolution of the concentration field beyond 1 km from the sheds is 100 m. In areas where there are sensitive receptors within 1 km, the recommended maximum grid spacing is 50 m.

6.8 Dispersion Coefficients

A key modelling consideration in the application of Gaussian models is the specification of the dispersion coefficients, σ_y and σ_z, respectively. These describe the horizontal and vertical dispersion parameters used to define the rate of diffusion of plume material in the horizontal and vertical directions (NZ MfE 2004).

There are three types of horizontal dispersion coefficients available in AUSPLUME and CALPUFF:

- Pasquill-Gifford (P-G):
  - The P-G dispersion curves were developed from 10-minute average experimental data from near ground level, released in flat terrain.
  - These curves should be used for all sources except those with very tall stacks.
  - CALPUFF and AUSPLUME have the option to scale the P-G dispersion coefficients for different averaging times or surface roughness lengths. AUSPLUME can scale both horizontal and vertical dispersion by the averaging time and roughness length, whilst CALPUFF does not scale the vertical dispersion by time. As such the models when run on P-G curves can give differing results, all other factors being equal.
  - The P-G curves used to define dispersion coefficients are applicable over distances up to about 1 km from the source and can also be extrapolated out to distances of about 10 km from the source, but with a loss of accuracy[r].
  - The P-G curves are less reliable for receptors less than 100 m from the source.
- Briggs Rural[s]:

[r] These range guidelines are applicable to steady-state Gaussian models.

[s] If more than 50% within a 3 km radius of the source has a rural land-use, then use the Briggs rural scheme, otherwise use McElroy-Pooler.

- This formulation was derived from experiments on dispersion from tall stacks, and should therefore be used only for stacks higher than 100 m located in rural areas (NZ MfE 2004).

- McElroy-Pooler[5]:
  - To be used for stacks higher than 100 m occurring in urban areas (CALPUFF).

- Standard deviation of wind direction (σ_θ):
  - Use of the σ_θ coefficient requires data on the standard deviation of wind direction to be included in the meteorological data file.
  - This method should be used with caution as unstable conditions coinciding with relatively low σ_θ values can result in unrealistically high concentrations being predicted close to the source. Conversely, high σ_θ values can be associated with very stable conditions due to flow meandering (Mahrt 2007; Seaman, Gaudet et al. 2008) and may lead to underprediction.

The presence of topographic features, buildings or vegetation increases the ground's surface roughness (see Section 6.6.4). For all but the unstable categories (where convective turbulence dominates), the effect of surface roughness is to increase the vertical mixing of the plume because of the enhanced mechanical turbulence. The vertical dispersion coefficient (σ_z) can be adjusted to take account of the surface roughness. A new value of σ_z based on the uncorrected value of sigma z can be calculated according to:

$$\sigma_z = \sigma_z \left[1.585 z_o^{0.1301} (0.001x)^B \right] \qquad (10)$$

where

$B = 0.0777 + 0.0215 \ln(z_o)$

x is the downwind distance (metres)

and z_o is the surface roughness (metres).

The above correction is not needed if u*, w*, etc are used for dispersion (see discussion below).

AUSPLUME, for example, can calculate the new value of σ_z internally from the roughness length selected or calculated.

The type of vertical dispersion coefficient chosen should be the same type as selected for the horizontal equations.

Dispersion coefficients can also be estimated by:

- Direct measurements of turbulence, σ_v and σ_w;
- Micrometeorological scaling parameters u*, w*, L, and h, from meteorological models yielding internally computed estimates of the crosswind and vertical components of turbulence based on similarity theory (AERMOD and CALPUFF). For example, Monin-Obukhov length (L) is used as the stability parameter by the AERMET meteorological preprocessor.

The P-G dispersion scheme is the most widely used method to estimate dispersion rates for models such as AUSPLUME. However, there are a number of problems associated with using this scheme (Venkatram 1996):

- P-G theory is based on observations applicable to surface releases and its applicability to elevated releases is not entirely justified;
- The P-G scheme assumes that the effective wind speed is constant through the depth of the plume;
- Pasquill's coefficients could be in error by plus or minus 25 percent, especially when used for non-level, complex terrain and for large distances.

More advanced models such as TAPM, AERMOD and CALPUFF negate the need for P-G estimates as they calculate dispersion based on turbulence measurements or turbulence estimates based on similarity theory.

6.8.1 Initial Dispersion Coefficients

The initial sigmas are based on the characterisation of the source. That is, first define the height, width, and depth of the release and then use these limiting dimensions to calculate the initial horizontal and vertical dispersion dimensions.

For volume sources, sometimes used to represent poultry sheds, initial σ_y is estimated as the side length of the volume source divided by 4.3 and initial σ_z as the source (*e.g.* building) height divided by 2.15 (US EPA 1992). AUSPLUME, by contrast, recommends an initial estimate of the plume width and height as a quarter of the building height and width respectively (EPAV 1999). Neither method is explicitly recommended by regulatory authorities in Australia. However, for consistency, it is suggested the latter method be used.

6.9 Model Documentation

Some regulatory authorities require that dispersion modellers report and justify all parameters and switches used in the dispersion modelling (NSW DEC 2005). Owing to the increasingly complex nature of dispersion models, it is recommended that this practice be implemented for all modelling studies undertaken for the poultry industry.

6.9.1 Validation Studies

A number of validation studies have been performed for the various models, for example:

- CALPUFF (Irwin 1997; Strimaitis, Scire et al. 1998; Hurley and Luhar 2000)
- TAPM over various regions in Australia and overseas (Hurley 2000; Hurley and Luhar 2000; Hurley, Manins et al. 2002; Zawar-Reza, Sturman et al. 2003; Hurley, Hill et al. 2005; Hurley, Edwards et al. 2008) and including southeast Queensland (Leishman, Bofinger et al. 2004);
- AUSPLUME (Hurley, Hill et al. 2005; Hurley and Luhar 2005; Hurley 2006);

- AERMOD (Hall, Spanton et al. 2000; Perry, Cimorelli et al. 2005; Harsham and Bennett 2008)

The interested reader is also referred to the 'Initiative on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes' website (http://www.harmo.org/) for an extensive selection of papers and conference proceedings on model validation.

7 OUTPUTS

All dispersion models allow results to be reported in a variety of ways. These include annual average, daily maximum or hourly maximum concentrations at each receptor. The results can be presented in the form of:

- Contour plots covering the region of interest with an adequate grid density to avoid significant loss of resolution;
- Numerical values of concentrations at the point of maximum impact and discrete receptors.

7.1 Contour Plot

As discussed in Section 6.7, the receptor network can either be regular or irregularly spaced as gridded or discrete receptors respectively. The model will calculate concentrations for each point on the grid, and then use a suitable interpolation method to draw a continuous contour line. This interpolation or contouring method can affect how the contours are drawn. Common methods used to draw contours are:

- Natural neighbour – best when data are evenly distributed over the grid area, as most often occurs with model output.
- Kriging – Creates a grid from irregularly spaced XYZ data.
- Nearest Neighbour – This method is useful when data are evenly spaced, but with a few missing values. This method is effective for filling in the holes in the data.
- Inverse Distance to a Power – One of the characteristics of Inverse Distance to a Power method is the generation of "bull's-eyes" surrounding the position of observations within the gridded area, making it unsuitable for model output and interpretation.
- Minimum Curvature – This is widely used in the earth sciences and generates the smoothest possible surface. It is not an exact interpolator, however. This means that the data are not always reflected exactly.

The method to use depends on the spacing of the predicted data points. A useful exercise is to predict concentrations at both specific locations and for a grid of receptors, produce contours for the grids using some of the methods listed above and check the agreement of results obtained at the specific receptors. A particular interpolation method may give better agreement for the model setup chosen. This will help to ensure that predictions at specific receptors match the contours drawn to define the area. In most cases, where model predictions are output as gridded ground-level concentrations, kriging is the preferred data gridding method.

Two examples of contour presentation are shown in Figure 7.1. The standard method is to depict concentration as contours overlain on a suitable base map of the area of interest[t]. The second presentation method is to depict concentration as graded colours (Figure 7.1, lower).

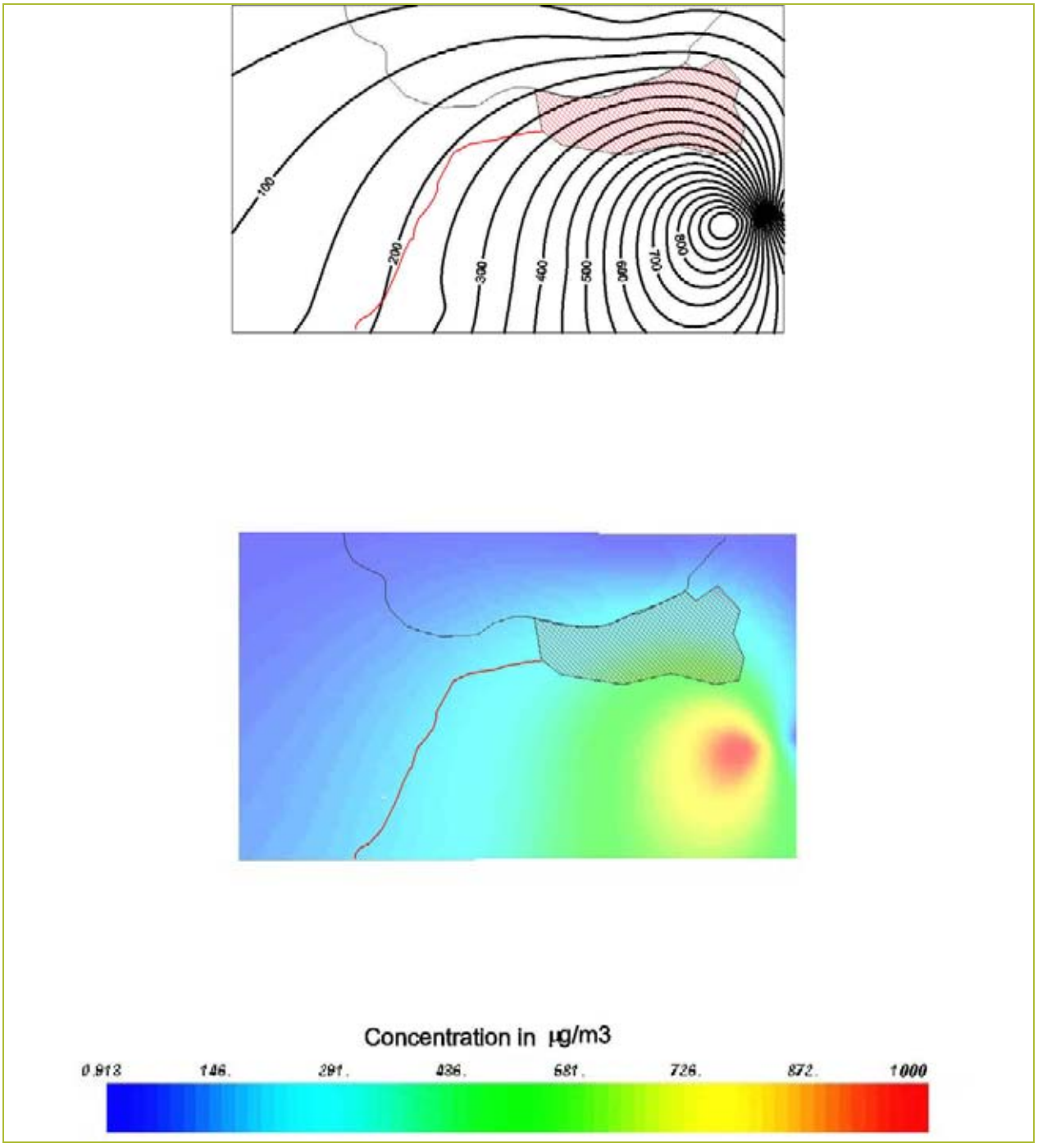

Figure 7.1: Presentation of concentration contour plots.

[t] The base map should include location of the source and any sensitive receptors.

The second method has an advantage over the former in that it allows for the inherent uncertainties associated with modelling to be taken into account in a sense by not indicating the precise locations of concentration level by discrete contour lines. This can be especially important when presenting model results, given that the inherent lack of precision in model results is not conveyed by the use of contour lines. When presenting modelled results as colour contours a check should be made to ensure that their significant features remain clear if they are reproduced in black and white.

The contours and numerical values should be presented with reference to relevant criteria.

Most models, including CALPUFF, TAPM, AERMOD and AUSPLUME, allow results to be processed and reported in a variety of formats to allow statistical analysis. For interpretation, it is important to note that the 1-hour 99.5th percentile plots often presented do not represent a snapshot of odour impact at a specific time. The plot 'joins the dots' between 99.5th percentile values that occur independently at different grid points: in other words, the 99.5th percentile concentration at a particular point does not necessarily occur at the same day/time as the 99.5th percentile concentration at any other point in the modelling domain.

7.2 Discrete Receptors

It is often necessary to determine modelled concentrations at specific locations of interest (*i.e.*, discrete receptors such as individual residences). These discrete receptors are usually located at ground level but may also be located at varying heights to investigate the potential downwind concentrations at the same elevation as a high-rise building, for example. The modelled concentrations at these receptors can be plotted as time series to illustrate the fluctuations of odour over time, or as percentiles to give an indication of the range of predicted concentrations over a year.

The percentile data may be presented in tabular or, as in Figure 7.2, in graphical form. The latter form has the advantage of allowing easy visual analysis of percentile statistics at a single receptor.

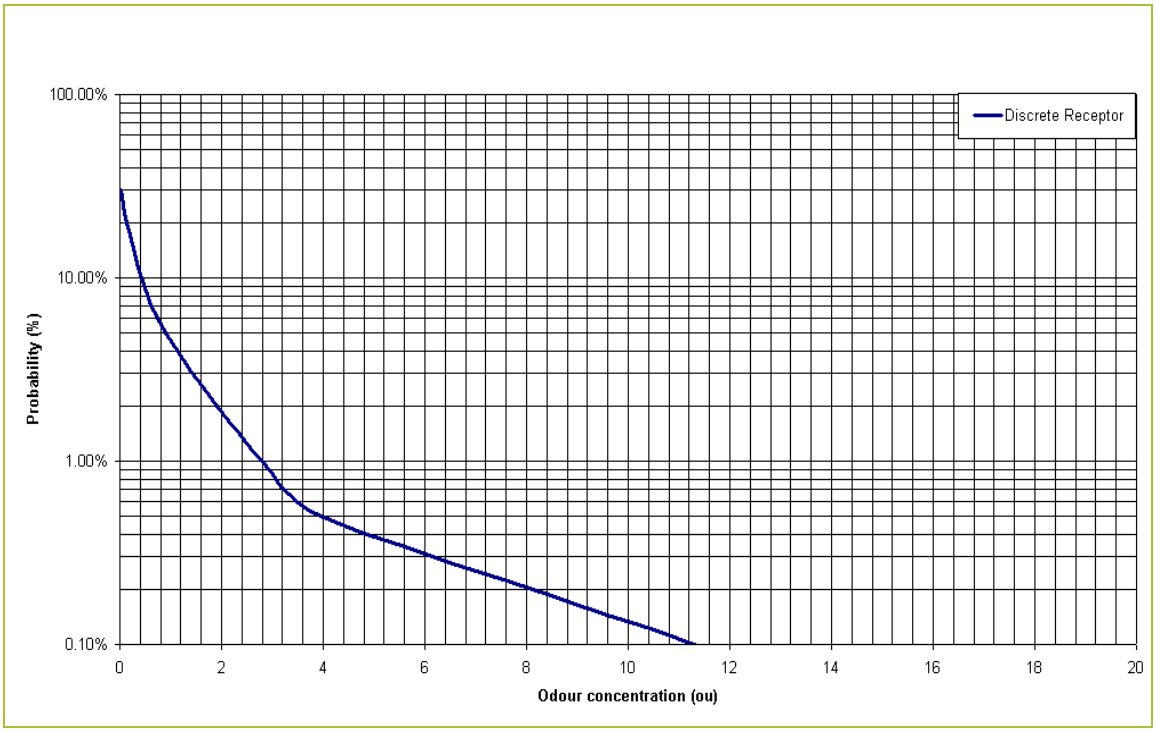

Figure 7.2: Example of percentage occurrence (percentile) at a discrete receptor. At any point on the curve , it describes the odour concentration equalled or exceeded for a given percentage of time (probability or frequency).

7.3 Source Apportionment

A method of dispersion modelling that is useful to inform air quality management plans is referred to as “source apportionment modelling”. This involves modelling each source separately so that the relative contribution to the total impact at all identified receptors surrounding a facility can be determined. This method is particularly useful for larger poultry farms, where two or more farm “groups” may be constructed, e.g., a farm with two separate units, each holding 500,000 birds.

An example of source apportionment is shown in Figure 7.3. The user can depict the contribution of each source at various discrete receptors in the form of a stacked bar chart, or at an individual receptor as a pie chart showing percentage or total contributions.

Most Gaussian puff models can perform source apportionment studies. CALPUFF in particular is ideally suited for this kind of study in that it allows for source apportionment studies to be performed for multiple scenarios with minimal model computational time.

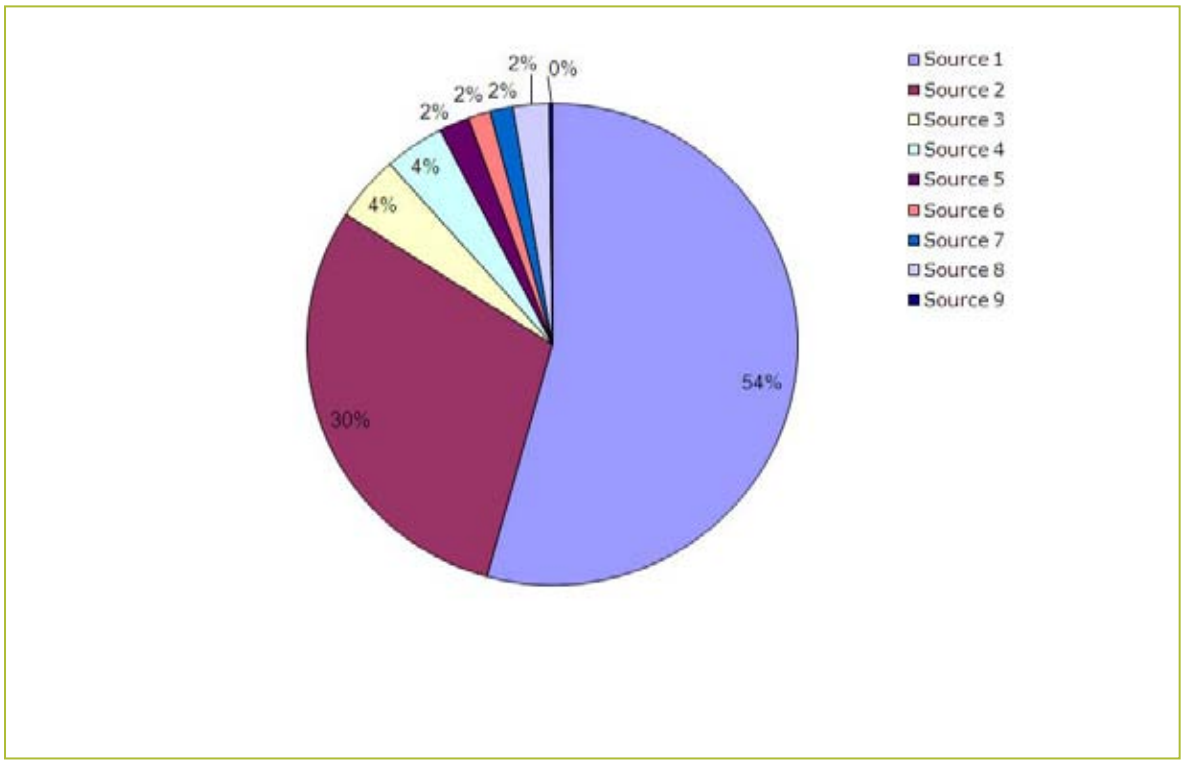

Figure 7.3: Representation of source apportionment results, showing source contribution to predicted maximum concentration at a receptor.

8 RECOMMENDED ASSESSMENT CRITERIA

Odour has been identified as the principal community amenity concern for meat chicken farms in Queensland. Hence the focus of separation distance determination is to limit the potential for nuisance odours. Experience in southeast Queensland, supported by more general scientific literature, has indicated that sensitivity to odour in some communities, particularly those not traditionally associated with livestock production, may not be adequately addressed by existing assessment criteria.

The Queensland Odour Guideline is generally regarded as a very useful reference point for odour assessment in the State and the criteria have been applied successfully in many instances. However, there is some evidence that for meat chicken farms compliance with the default criteria, whether in fact or because of modelling errors or differences between predicted and actual odour emissions, does not always seem to satisfy the aim of avoiding undue annoyance.

Growing population, changing demographics and lifestyle expectations have all contributed to increasing pressures on odour-generating activities such as meat chicken farming in the region. Accordingly, the recommended odour criteria (below) for meat chicken farms are aimed at taking a long-term, protective view of environmental values for residents near meat chicken farm developments and at providing some buffering to account for model uncertainty.

It is recommended that modelled odour levels should be assessed against the following criteria for strategic planning purposes:

- 2.5 ou, 99.5%, 1 hour average for a sensitive receptor in a compatible zone;
- 1.0 ou, 99.5%, 1 hour average for a sensitive receptor in a non-compatible zone.

The 1 ou recommendation for sensitive receptors in a non-compatible zone is more stringent than the default of 2.5 ou set out in the Queensland Odour Guideline (Queensland Environmental Protection Authority 2004). It takes into account a risk-based odour assessment procedure, such as that used in New South Wales, where odour criteria are dependent on the size of the population surrounding an odour source. The proposed value of 1 ou (99.5%, 1 hour average) is approximately equivalent to the odour performance criterion for urban areas in New South Wales (2 ou, 99%, 1 second).

9 REPORTING

Reports involving dispersion modelling should generally include the following information:

- Odour assessment criteria: identify the odour criteria used in the assessment. Present all relevant evidence if it is proposed to depart from these criteria, as per the considerations outlined in the Queensland Odour Guideline (Queensland Environmental Protection Authority 2004);
- Description of farm: size (no. of sheds, no. of birds), type of construction, etc., and operating characteristics, e.g., batch cycles, batch thinning, cleaning regime;
- Site layout – Indicate all shed sources on a site map and/or in tabular form;
- Terrain and receptor information – Document terrain and/or receptor resolution and discuss possible influence of terrain (including katabatic drift) on dispersion.
- Discrete (sensitive) receptors – List all discrete receptors, including locations on a map and/or as tabulated co-ordinates with corresponding identification;
- Source characteristics – Include all parameters related to how the odour sources were modelled (*e.g.* ground level point source, no vertical momentum – include locations, dimensions, flow characteristics);
- Emission rates – Present the data used to generate emission rates (i.e. bird numbers, batch length, thinning regime) in tabular form. Identify the source or describe the methodology used to determine the emission rates. Present the calculated emissions data in a form that enables the reader to gauge the emissions behaviour over the year, for example, by time series and/or frequency distributions, including emissions per bird or per 1000 birds;
- Meteorological data – Discuss the prevailing dispersion meteorology in the vicinity of the site. Include wind roses with diurnal information, stability class and mixing height frequency data as a minimum;
- Dispersion Model – Describe the dispersion model used, the major inputs/settings, and the assumptions/limitations of the particular model selected (see Section 6.9);
- Results – Present results as contour plots, tables and statistics as appropriate (see Section 7);
- Assessment of impact: include an evaluation of model results against the odour criteria. Include any relevant issues surrounding modelling assumptions that may be violated or weak, and consider model uncertainty in general. Consider, where relevant, issues such as time of day and seasonal or weather-related factors that may influence the evaluation of impact, and consider the farm design and management aspects that might need special attention in order to limit impacts adequately.

The inclusions listed above are not exhaustive. It is recommended that modellers consult with the relevant regulatory authority on reporting requirements in each case.

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