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Separation Distances for Broiler Farms

— Verifying methods and investigating the effects of thermal buoyancy —

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Verifying methods and investigating the effects of thermal buoyancy

by Mark Dunlop, David Duperouzel and Lyle Pott

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Foreword

The Australian chicken meat industry grows approximately 500 million chickens producing 800,000 tonnes of meat annually. Meat chicken farms are often built close to feed supply and meat processing infrastructure, with associated markets and labour force. Positioning poultry farms close to essential infrastructure usually means that the farms are also close to urban and rural-residential developments. Close proximity of neighbours to poultry farms can result in adverse impacts, primarily due to odour. Odour impacts are recognised as an issue by the Australian chicken meat industry and are most effectively minimised through the provision of adequate separation distance between farms and neighbours, which allows odour dispersion.

This investigation focused on two topics relating to the calculation of separation distances: thermal buoyancy; and assessment of a proposed separation distance formula (for use in Queensland). Addressing these topics has resulted in an improved understanding of thermal buoyancy of broiler odour plumes; plume rise; and how dispersion modelling simulates the effects of thermal buoyancy. Also, it will demonstrate how well the proposed separation distance formula compared with odour dispersion modelling.

The results of this investigation will benefit environmental regulators, the community and poultry producers by improving understanding of how odour plumes behave and highlighting potential shortcomings of the techniques used to calculate separation distances. These will lead to improved estimation of odour impacts and provide improved protection against odour nuisance from new or expanding broiler farms.

This work found that air exhausted from broiler sheds is frequently warmer than ambient air, and will therefore usually rise. Realistic emission temperatures should therefore be used during dispersion modelling rather than ignoring thermal buoyancy. However, odour dispersion modelling did not appear to accurately simulate this rise and thus may over-predict ground level odour impacts. Despite this finding, emission temperatures influenced the estimation of separation distances when modelling hypothetical broiler farms.

The proposed separation distance formula was found to estimate longer separation distances than Calpuff in most instances, but was inconsistent when conditions (especially wind, terrain and surface roughness) favoured extensive plume travel.

This project was funded from industry revenue which was matched by funds provided by the Australian Government.

This report is an addition to RIRDC's diverse range of over 2000 research publications and it forms part of our Chicken Meat R&D program, which aims to support increased sustainability and profitability in the chicken meat industry through focused research and development.

Most of RIRDC's publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

Tony Byrne
Acting Managing Director
Rural Industries Research and Development Corporation

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Contents

Executive Summary

What the report is about

This report has two themes: thermal buoyancy of broiler odour plumes; and comparison of separation distance formulas and Calpuff modelling for determining separation distances to minimise odour impacts.

The thermal environment in and around broiler sheds influences the dispersion of odour plumes; however, this environment is not well understood and it has been unclear how well odour dispersion models simulate the buoyancy (causing vertical rise) and subsequent dispersion of plumes. This work and report improves the understanding of thermal gradients between the usually warmer air exhausted from broiler sheds and ambient air; and demonstrates how exhausted air interacts with the surrounding environment.

Separation distances are calculated using odour dispersion modelling or separation distance formulas. The formulas offer a low-cost, simple and more transparent method to estimate separation distances. A separation distance formula (for broiler farms) has been proposed for use in Queensland, but required additional testing to validate it and support its adoption. Separation distance formulas were compared against Calpuff modelling using a variety of broiler farm scenarios and the Queensland odour impact criteria.

Information contained in this report challenges the current techniques for modelling broiler farm odours (with relation to emission temperatures) and calculating separation distances.

Who is the report targeted at?

This report is written for:
- current and future poultry producers, who may require dispersion modelling while undertaking an odour impact assessment;
- the chicken meat industry, which is under pressure to reduce odour and dust impacts and needs to ensure that separation distances are adequate to protect neighbours from most odour impacts, but not so excessive that the costs and availability of acquiring land unnecessarily restricts new developments and industry expansion;
- environmental regulators/government agencies, who require supporting evidence when making decisions relating to odour dispersion modelling and the calculation of separation distances; and
- consultants, who undertake odour impact assessments and need to ensure that the selection of inputs for modelling adequately represent the broiler farm scenario.

Background

Currently, the most effective way to minimise odour impacts is to provide adequate separation distance between the source and receptor thereby improving/increasing odour dispersion. Techniques used to predict odour impacts or calculate separation distances include odour dispersion modelling and separation distance formulas (or tables of set distances).

Odour dispersion models (for example Calpuff) cannot accurately simulate the horizontal dispersion and low temperature differential thermal buoyancy of broiler shed odour plumes. Modellers have developed ways to represent the horizontal emission; however, consensus cannot be reached on the most appropriate way to model plume thermal buoyancy.

Separation distance formulas offer an alternative to dispersion modelling and a significant cost advantage when they can appropriately be used. A separation distance formula has been proposed for use in Queensland. Further evidence to support the use of this separation distance formula will be required if it is to be adopted.

Aims/objectives

The aims of this investigation were to:

- demonstrate that Calpuff accurately simulates the rise and dispersion of odorous air exhausted from broiler sheds with the use of computational fluid dynamics (CFD) modelling. This will include an analysis of parameters, especially exhaust temperature, that affect plume buoyancy;

- monitor the temperature of air exhausted from a poultry shed in order to assess temperature gradients with ambient air, and to demonstrate how air temperature changes as the poultry exhaust air mixes with ambient air; and

- verify the separation distance formula, as specified in the *Draft best practice technical guide for the meat chicken industry in Queensland* (Queensland Chicken Growers Association, 21 October 2005), for calculating separation distances, using Calpuff.

Methods used

An array of temperature sensors was installed downwind from the tunnel ventilation fans of a broiler shed to measure the temperature of the exhausted air. Temperature data was processed along with on-site weather conditions and fan activity to assess temperature gradients and plume movement immediately after exiting the broiler shed. Smoke was used in a complimentary activity to enable visualisation of the exhaust plume.

A CFD model was configured to simulate the rise and dispersion of odour plumes from a broiler shed. The influence of environmental and shed management factors on thermal buoyancy was assessed (including exhaust temperature; wind speed; shed orientation with the wind; and fan activity). Calpuff was used to model the same range of scenarios and predicted odour concentrations were compared against the CFD model.

Separation distances were calculated with various separation distance formulas for comparison against odour impact contours generated using Calpuff. A variety of actual (based on existing enterprises) and hypothetical broiler farm scenarios were used. For the hypothetical broiler farms, additional Calpuff modelling was undertaken to assess the influence of emission temperature on predicted odour impacts.

Results/key findings

- Air exhausted from broiler sheds will frequently be warmer than ambient air.

- When warm air is exhausted from broiler sheds (even when only 1–2 °C warmer than ambient), it rises. The position and rate of rise is influenced by the temperature differential, wind conditions, atmospheric stability and fan activity.

- Compared with the CFD model, Calpuff did not simulate plume rise from broiler sheds. This may result in over estimation of odour impacts at ground level, and raises the possibility of under prediction of odour impacts for elevated receptors.

- Exhaust temperature influenced the prediction of odour impacts using Calpuff. In general, setting the emission temperature to be equal to target production temperatures resulted in shorter separation distances than if the emission temperature was equal to ambient temperature.

- Modelling broiler sheds as a volume source, rather than a point source (using stacks), changes the prediction of odour impacts in Calpuff.

- The proposed Queensland separation distance formula calculated longer, more conservative, separation distances than Calpuff for the majority of scenarios; however, it substantially under-predicted separation requirements in some cases.

Implications for relevant stakeholders for:

Outcomes from this report may change the way that separation distances are currently estimated for broiler farms. In particular, the adoption of a single methodology for modelling odour emissions from broiler sheds, using realistic shed emission temperatures (not ambient), will result in a more consistent approach to modelling odour impacts. This will reduce contention of modelling outcomes, and decrease the frequency of appeals during the development assessment process.

Recommendations

- Poultry sheds should be modelled to include thermal buoyancy by using emission temperatures that represent the actual emission temperature rather than ambient temperatures.

- A single methodology regarding source configuration and the selection of emission temperature inputs needs to be adopted to ensure consistency in modelling results when using Calpuff.

- The proposed Queensland separation distance formula should be considered for adoption because it calculates conservative separation distances most of the time. Some modifications to the formula’s methodology may improve its reliability.

- Elongated odour impact contours determined with Calpuff should be verified against odour complaint data to ensure that such extensive separation distances are required to prevent odour nuisance.

Introduction

Background

Odours emitted from broiler farms have the potential to be detected by nearby neighbours. Repeated detection of these odours may cause annoyance and result in odour complaints (Environmental Protection Agency (UK), 2001). Presently, the most effective ways to minimise odour nuisance are to use management practices that moderate odour generation, and to site the farm with appropriate separation distances and buffer zones to ensure that emitted odours can disperse before reaching nearby receptors.

When a new broiler farm (or expansion to an existing broiler farm) is proposed, it will be the subject of an odour impact assessment. The assessment process considers features of the farm, natural landscape and location of sensitive land uses or receptors surrounding the farm. To ensure that air quality objectives are met at receptor locations, separation distance requirements will be determined. There are several methods available to calculate separation/buffer distances for individual broiler farms, including:

1. tables of fixed separation distances;
2. separation distance formulas; and
3. odour dispersion modelling.

One or more of these methods may be applied during the assessment process depending on the size of the proposed farm and local regulatory or planning guidelines for calculating distances.

Fixed separation distances
Fixed separation distances offer the advantages of simplicity and consistency, but do not account for specific farm management or localised features or conditions (such as terrain). Fixed separation distances may vary according to farm capacity (State Government of Victoria, 2001b) or may define minimum distances to specific features such as roads, boundaries or residences (Environment Protection Authority South Australia (2007a) and Queensland Chicken Growers Association (2005)).

Separation distance formulas
Separation distances can easily, and rapidly, be calculated using separation distance formulas. Unlike fixed separation distances, these formulas incorporate parameters that allow for adjustment due to features or management practices that may influence the possibility for odour impacts. Depending on the specific method, these formulas may include factors for farm design, farm management, terrain, surrounding land use, receptor characteristics and wind patterns. To use these formulas, the assessor will refer to descriptive tables that provide values for each factor. These formulas generally take the form shown in Equation 1.

$$\textit{Separation Distance} = N^a \times S1 \times S2 \times S3 \times S4 \qquad \textbf{Equation 1}$$

Where: N is the number of birds (or sheds);
a is an exponent derived from modelling; and
$S1$ to $S4$ are factors relating to farm design, management and the environment.

Separation distance formulas are used to calculate separation distances for broiler farms in South Australia (Environment Protection Authority South Australia, 2007a) and in New South Wales (for farms with less than 250,000 birds) (Department of Environment and Conservation NSW, 2006b). A draft formula has been proposed for use in Victoria (for farms up to 400,000 birds) (State Government of Victoria, 2009b); and a separation distance formula has also been proposed for use in Queensland (for farms with up to 320,000 birds) (Queensland Chicken Growers Association, 2005), but is not currently used during regulatory assessment. Separation distance formulas are also used overseas (Nicolas et al., 2008).

Odour dispersion modelling

Site specific dispersion modelling may be used when the farm or environment has features that exceed the parameters of the fixed distance and separation distance formulas, or when trying to justify a short separation distance. Pollock and Anderson (2004) summarised the use of dispersion models for calculating separation distances for broiler farms. CALPUFF (Earth Tech Inc., 2008) and Ausplume (EPA Victoria, 2004) are two dispersion models used to assess odour impacts from broiler farms. Dispersion models require specific inputs such as meteorological data, terrain data, land use descriptions and odour emissions data. With each of these inputs specific to the farm, the model is used to predict the concentration and frequency of odour exposure in the surrounding areas.

Odour impact criteria are used to assess whether the strength and frequency of odours in the surrounding landscape, predicted by the model, is likely to create an odour nuisance. These criteria, whilst not designed to provide complete protection from ever experiencing odour, outline the odour concentration, averaging period and recurring frequency (expressed as a percentile) that would limit the frequency and intensity of odour nuisance below a reasonable level. A range of different odour criteria are used throughout Australia (see Table 1).

Table 1: Examples of impact criteria used when odour dispersion modelling

State	Odour Criteria[#] (ou**)	Averaging Period	Percentile
New South Wales[1]	2–7	Nose response time	99th
Queensland[2]	2.5	1 hour	99.5th
South Australia[3]	2–10	3 min	99.9th
Western Australia	Varies on the specific circumstances of each case: 2.5 ou, 1 hr, 99.5th percentile is one criteria that is used		
Victoria[4]	5	3 min	99.9th

Note: [#] The value of odour criteria may vary depending on the source and receptor characteristics
**ou - *odour unit* (as defined in AS/NZS 4323.3 (Standards Australia, 2001))

References:

[1] (Department of Environment and Conservation NSW, 2005, 2006a)
[2] (Environmental Protection Agency (Queensland Government), 2004)
[3] (Environment Protection Authority South Australia, 2007b)
[4] (State Government of Victoria, 2001a, 2009a, b)

Selection of data and source description when modelling broiler farms

To ensure that odour dispersion models can assess site specific odour impacts in a meaningful way, all data inputs need to reflect the actual conditions at the farm. For broiler farms, this is not a straightforward task because inputs such as weather and emission data (specific to the farm) are not always available. Odour emission rates are unknown at new farms because the sheds are not yet built and the emission rates for new sheds being built on an existing farm are likely to differ from the existing sheds. Also, the horizontal discharge of tunnel ventilated broiler sheds cannot be perfectly represented using the commonly used dispersion models. Disagreement between consultants regarding input data and model configuration can prevent acceptance of odour modelling and prolong the odour impact assessment process.

Pollock and Anderson (2004) reported that experienced modelling consultants have developed techniques to generate site representative weather data and estimate odour emission rates. Modellers were also developing ways to represent the horizontal discharge to ensure that building downwash effects, terrain influences and plume thermal buoyancy, which influences plume dispersion, are not ignored by over-simplifying the emission source. These authors recommended that further development and assessment of these modelling techniques was required. In particular, further investigation was required to ensure that source configuration was representative of real-life, and that height of plume rise due to buoyancy was being accurately modelled.

Dispersion modelling temperature inputs

Accurate emission temperature data is required for a dispersion model to simulate the thermal buoyancy of plumes. In the absence of actual data, emission temperature needs to be estimated. Because of the highly controlled temperature conditions within a broiler shed, a reasonable assumption can be made that the emission temperature will closely resemble the air temperature inside the shed. It is also reasonable to assume that the temperature differential between the discharged air and the ambient air will reduce as the plume mixes with and dissipates into the surrounding ambient air, until the plume temperature becomes very close to ambient temperature.

Dunlop and Duperouzel (unpublished) measured in-shed and ambient temperatures while monitoring fan activity at broiler farms. An assumption was made that placement of the in-shed temperature sensor near the exhaust fans would be a reasonable estimation of the emission temperature. Their data showed that while the in-shed temperature was related to the target production temperature, it varied with changes in ambient temperature. Consequently, shed emission temperature can potentially be estimated using production temperature following an adjustment for ambient temperature.

Comparing different models

Different types of models (for example: computational fluid dynamics (*CFD)*; Gaussian, Lagrangian puff; and separation distance formulas) are used for estimating plume dispersion, for predicting odour impacts and for determining appropriate separation distances. Due to the difficulty (or impossibility) of physically measuring the movement and dispersion of plumes, the use of these models is necessary. These difficulties as well as the absence of broiler sheds on new farms, also mean that model predictions cannot be readily verified using (or by taking) physical measurements. One way to check the performance of one model (or parts of that model) is to use another more specific or sophisticated model, as demonstrated in the following examples. In each case, a model with specific, proven capabilities was used to evaluate the relative performance of the other model. Regardless of the model, these investigations highlight the need for using accurate model inputs and use of appropriate model configuration in order to obtain accurate outputs.

Computational fluid dynamics (CFD) models numerically solve the governing equations of mass, momentum and energy (Li and Guo, 2006). This makes them an ideal choice for modelling plume movement in complex situations and provide a means to investigate the effects of thermal buoyancy (Li and Guo, 2006); building downwash (Olvera et al., 2008); wind conditions and atmospheric stability (Bjerg et al., 2004; Li and Guo, 2006); and plume release characteristics (Bjerg et al., 2004; Dunlop and Galvin, unpublished) on plume dispersion. While CFD models can be used in investigations of these complex situations, it is critical that the CFD model is properly configured and appropriate turbulence, buoyancy and dispersion routines are utilised.

Li and Guo (2006) used a CFD model to simulate odour plumes from a piggery and compared the downwind concentrations with Calpuff predictions. Both models demonstrated that odour concentrations were higher during low wind speed conditions, and that downwind odour concentrations were higher during stable atmospheric conditions; with the CFD model predicting higher odour concentrations in all simulations except during highly stable conditions at distances beyond 300 m.

Piringer and Schauberger (1999) and Nicolas et al. (2008) used dispersion modelling as a tool to verify the use of separation distance formulas (referred to as ‘guidelines’ in these papers) for use in intensive animal operations. These authors used the results from the dispersion modelling (which used site-specific inputs) to recommend changes to the separation distance formulas.

Phases of plume development

Broiler shed exhaust plumes transition through several phases from emission to ultimate dispersion. An understanding of these phases is required for interpreting CFD modelling outputs, plume temperature profiles and visible plume movement. Figure 1 is a diagrammatic representation of these phases (see the concluding remarks in PAE (2009) in Appendix 1 for additional information), including:

1. *Horizontal jet*: The horizontal jet stage occurs because the plume is exhausted from the ventilation fans at relatively high velocity (6–10 m/s). The length of the horizontal jet will depend on fan specifications, temperature difference (plume to ambient), wind speed, wind direction, ground roughness, building wake effects and number of active fans.

   Friction is created between the plume and the ground, and between the plume and the surrounding air, which slows the horizontal movement and shortens the length of the horizontal jet. When more fans are active, or when wind is blowing in the same direction as the jet, friction forces between the plume and surrounding air will be reduced. Friction also causes turbulence and mixing (including vertical mixing) with the surrounding air, which dilutes the plume and dissipates heat.

2. *Stall point*: When friction forces overcome the momentum of the horizontal jet, the plume effectively stalls. From this point, further movement is due to environmental forces, not those caused by the mechanical ventilation fans. When smoke was used to visualise plumes during this investigation, the stall point occurred between 10 m from the shed when one fan was active with a slight headwind, and 40-50 m from the shed when eight fans were active and there was a slight tail wind.

3. *Rise and horizontal movement*: From the stall point, the plume will move in the direction of the wind and will rise if the temperature of the plume is greater than the surrounding air. Upward acceleration will be dependent on the magnitude of the buoyant force and horizontal velocity will depend on the strength of the wind. If there is negligible temperature difference or the plume is cooler than ambient air, the plume is unlikely to rise from the ground unless it is warmed by heat radiating from the ground (due to the sun). Regardless of whether the plume rises or not, the plume will continue to expand and disperse due to natural turbulence.

4. *Plume levelling*: Temperature is dissipated from the plume as it rises and mixes with the surrounding air (the plume cools adiabatically according to the dry adiabatic lapse rate, which is approximately -1.0 °C per 100 m (Davis and Cornwell, 1998)). The plume will continue to rise until it reaches the same temperature as the surrounding air (which also varies with altitude according to the ambient lapse rate). This temperature loss with height influences atmospheric stability and the presence of thermal inversion layers, thus influencing the height to which a plume will rise.

5. *Dispersion*: When the plume reaches its ultimate elevation (which may be at ground level), it will continue to disperse due to turbulence. If the atmosphere is unstable, the plume will continue to rise until it has completely dispersed.

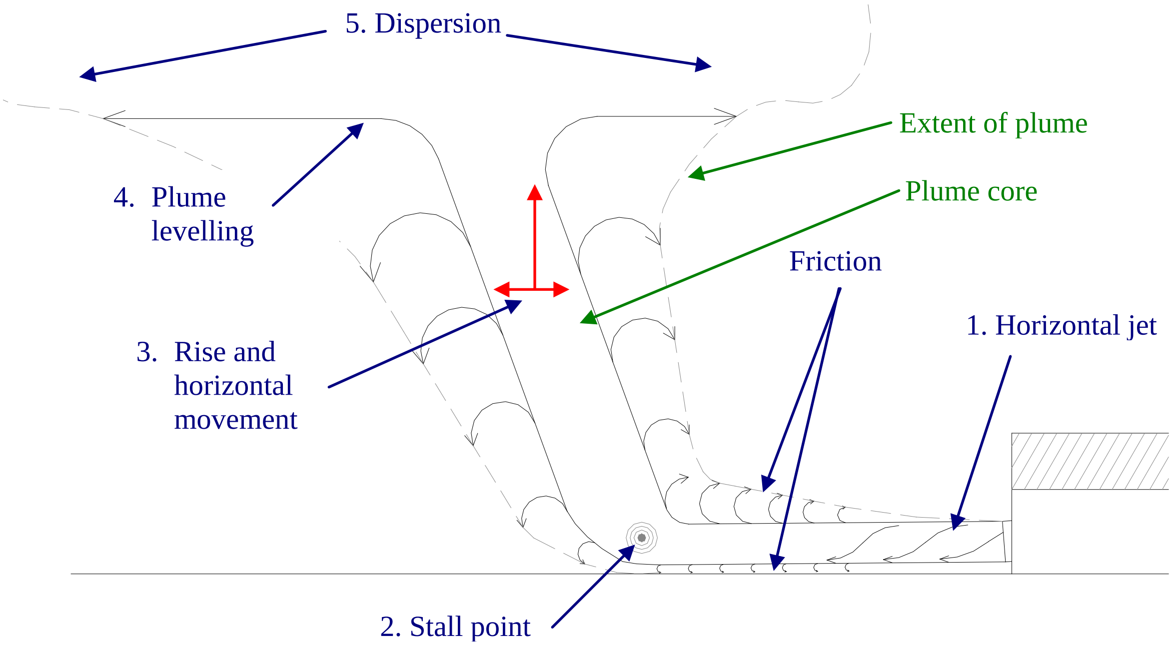

Figure 1: Diagram showing transitional phases of poultry shed plumes

Objectives and outline of activities in this investigation

Activities in this investigation have been organised according to three objectives:

1. *Use computational fluid dynamics (CFD) modelling to model plume rise and dispersion in a variety of scenarios, and comparing these results with those predicted by Calpuff.*

   CFD modelling was used to assess the ability of Calpuff to model the dispersion of thermally buoyant plumes emitted from broiler sheds using a variety of wind, temperature, ventilation rate and shed orientation conditions. Downwind odour concentrations, plume rise and plume spread were used to compare the outputs of both models. The effects of building downwash on plume dispersion were also considered. CFD was also used to estimate the velocity, position and temperature at the point where the plume began to rise (just downwind from the shed). The results of this model comparison study have been summarised in this report.

2. *Use temperature sensors, data logging equipment and smoke to measure the temperature of air exhausted from a broiler shed and visually assess rise and dispersion.*

   Sensors were arranged in a three dimensional array, immediately downwind from the tunnel ventilation fans to enable the temperature and vertical rise of plumes to be assessed. In conjunction with the temperature sensors, smoke was used to visualise and demonstrate the dispersion and vertical rise of exhaust plumes. Temperature data was filtered to identify periods when environmental conditions were conducive to plume measurement. Data was then presented using 3-D visualisation software.

3. *Comparison of separation distance formulas against Calpuff modelling (using the Qld odour impact criteria).*

   Firstly, Calpuff modelling outputs from existing broiler farms were acquired, along with descriptions of the farm, terrain and receptors. Each of these farms had been approved on the basis of the Calpuff modelling, which demonstrated compliance with the odour impact criteria

(Queensland Criteria, see Table 1). Separation distances were then calculated using the proposed separation distance formula for Queensland, as well as formulas approved in New South Wales, South Australia and drafted for use in Victoria. The separation distances calculated by the formulas and Calpuff were then compared on a receptor-by-receptor basis.

Secondly, a range of scenarios were modelled for hypothetical farms using Calpuff. The scenarios included different farm sizes, terrain, meteorology, emission temperatures and source definition (volume versus point). The distance to the 2.5 ou (1 $hr_{99.5th}$) contours from each scenario were compared to separation distances calculated using formulas.

Understanding the temperature environment in and around broiler sheds

The internal shed temperature will have a direct influence on the temperature of the air emitted from the ventilation fans. To precisely model thermal buoyancy, and understand how much influence thermal buoyancy will have on the dispersion of broiler shed odour plumes, it is first necessary to understand the thermal environment around broiler sheds.

The temperature within modern broiler sheds is strictly regulated using automatic control systems, heaters, evaporative coolers and high capacity ventilation fans. The target production temperature varies throughout the batch to maintain a comfortable environment and optimal growing conditions for the birds. Details of these target temperatures can be found in manuals provided by the major breed companies (Aviagen Incorporated, 2009a, b; Cobb-Vantress Inc., 2008), which describe the complex interaction between dry bulb temperature, humidity and wind chill. The target production temperatures referred to in this report are derived from the recommended dry bulb temperature, at average humidity, neglecting wind chill and loosely reflect the three major breeds. It was assumed that the target temperatures start at 31 °C on day 0, decrease linearly to 21 °C on day 35, decrease linearly again to 20 °C on day 42 and remain constant till the end of the batch. While not exactly the temperatures recommended in the growing manuals, these temperatures offer a close enough approximation considering that each producer and processing company follows their own temperature program that may vary with breed, bird age and season.

Dunlop and Duperouzel (unpublished) measured in-shed and ambient temperatures while monitoring broiler shed ventilation activity. In-shed temperature was measured 5–10 m from the fans and about 0.5 m above the floor, while ambient temperature was measured at 2 m height a short distance from the shed. The measured in-shed temperature was considered a reasonable estimate of emission temperatures. Temperatures were recorded every 15 minutes for one year. Five broiler farms were included in the study, located in southeast Queensland (2 farms), northern New South Wales (near Tamworth), central coast New South Wales and in southern Victoria (on the Mornington Peninsula). Temperature measurements from the central coast NSW broiler farm will not be included here because the chickens were brooded in the front of the shed, isolated from the in-shed temperature sensor, and the dataset was incomplete.

Temperature data collected by Dunlop and Duperouzel (unpublished) has been included in this report to assist with the selection of modelling scenarios, especially for the CFD modelling exercise, and to establish what temperature conditions are likely to be experienced at broiler farms.

Relationship between target production temperature and in-shed temperature

The temperature differential between the target and in-shed temperatures was calculated (target temperature minus in-shed temperature). This data was then grouped and analysed in terms of frequency of occurrence. Figure 2 shows that the in-shed temperature was relatively evenly distributed around the target temperature and the majority of data was within the range ±4 °C (greater than 90% of temperature recordings for all farms), but temperatures differentials of ±10 °C also occurred.

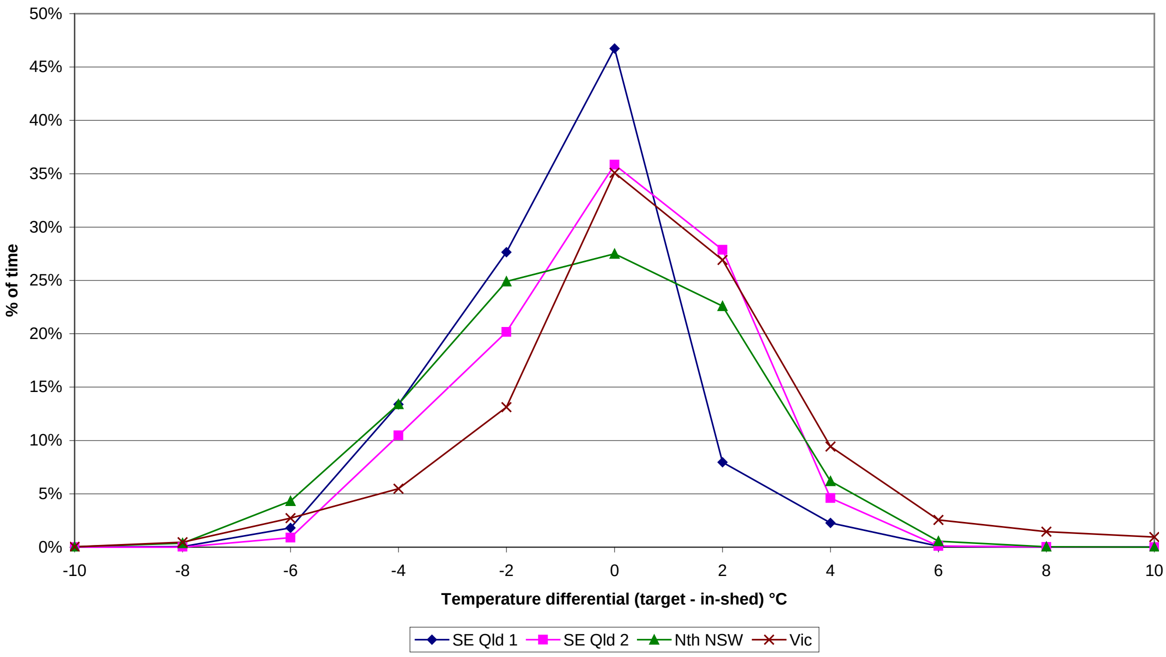

Figure 2: Frequency of occurrence for target temperature minus in-shed temperature differentials for four broiler sheds collected over 12 month period

The data was explored to identify reasons for the in-shed temperature to differ from the target temperature. Figure 3 displays a time series of the in-shed and target production temperatures from one of the broiler farms located in southeast Queensland. This figure shows that the internal shed temperature roughly corresponded with the target production temperature, but varied daily in response to changes in ambient temperature and seasonal effects. Similar trends were also observed at the other broiler farms.

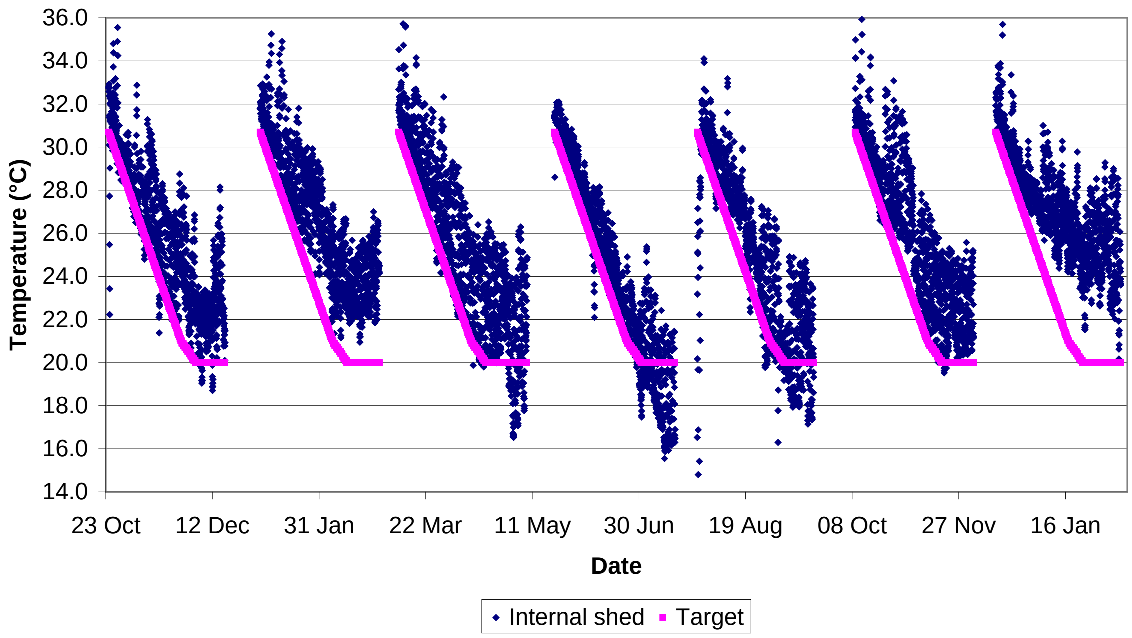

Figure 3: Time series showing target production temperature and internal shed temperature for a broiler shed in southeast Queensland

Closer examination of the daily variation between in-shed and target temperatures (see Figure 4) revealed that during the warmer part of the day, the in-shed temperature tended to be greater than the target temperature, while during the cooler times (night), in-shed temperatures during summer were warmer while during winter were sometimes cooler (this data is for the same shed used in Figure 3).

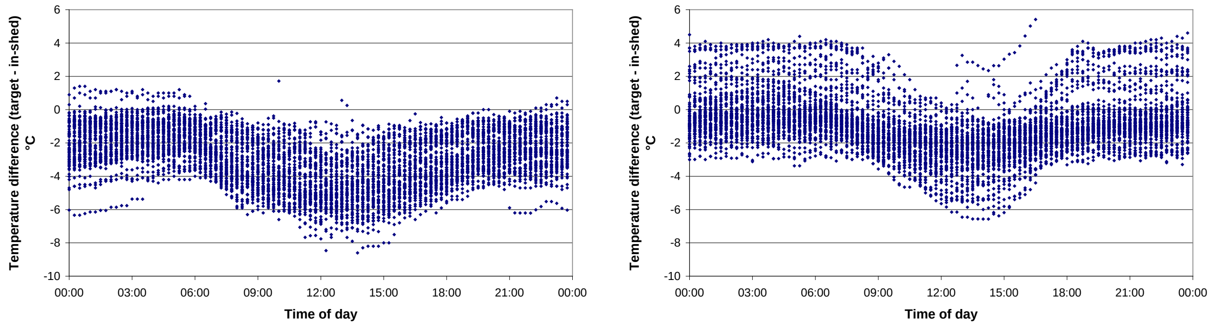

Figure 4: Temperature differential between the target temperature and in-shed temperature during summer *(Left)* and winter *(Right)*

This demonstrates that the shed emission temperature is often slightly different to the target production temperature.

Further processing of this data (combined from four farms) resulted in the development of a simple linear formula to estimate internal shed temperature (assumed to be similar to the shed emission temperature), see Equation 2.

Internal temperature ≈ Target temperature + 0.31 Ambient temperature - 4.2 **Equation 2**

A comparison between the measured internal temperature, predicted internal temperature and target production temperature (see Figure 5)shows that predicting the internal temperature using Equation 2 provides a better estimate of the internal shed temperature than using the target production temperature (combined data from all farms).

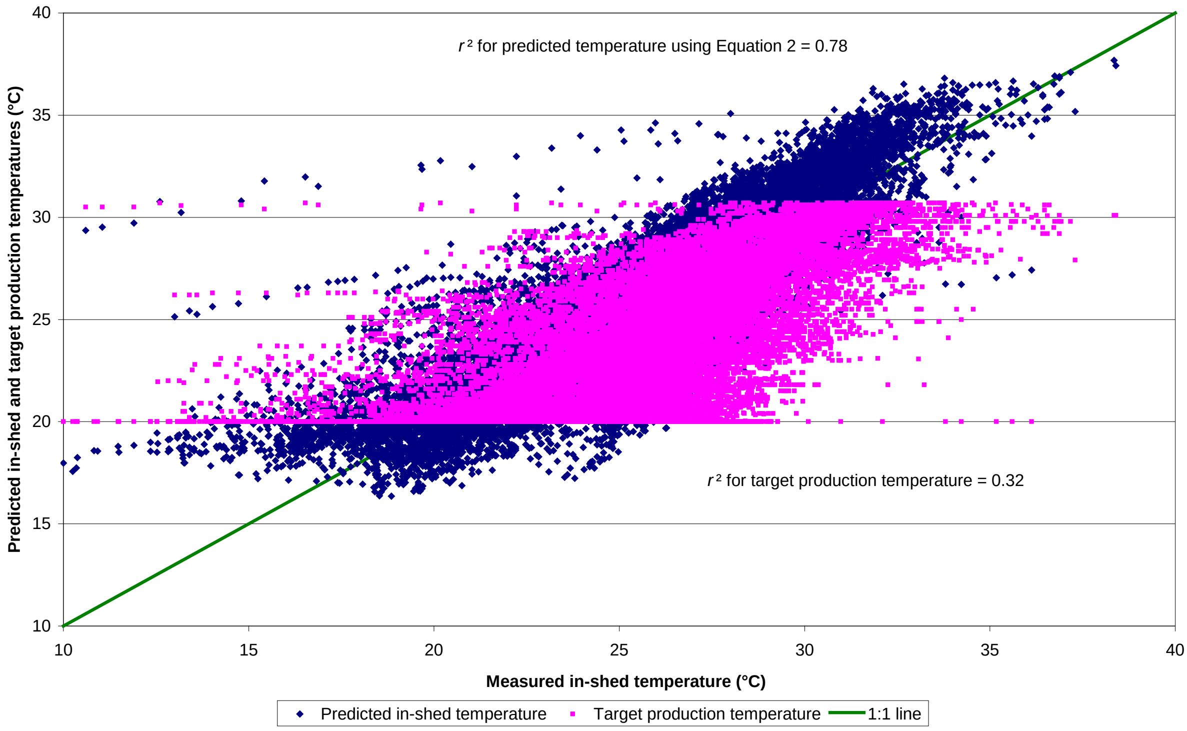

Figure 5: Comparison of measured in-shed temperature, predicted in-shed temperature using Equation 2 and target production temperature

Relationship between in-shed temperature and ambient temperature

The relationship between in-shed temperature and ambient temperature at the four broiler farms was examined. Figure 6 shows the frequency of occurrence for various temperature differentials. It can be seen that for the Queensland farms, the in-shed temperature was often 0–8 °C warmer than ambient temperature; and for the New South Wales and Victorian farms the in-shed temperature was often 2–12 °C warmer than ambient temperature.

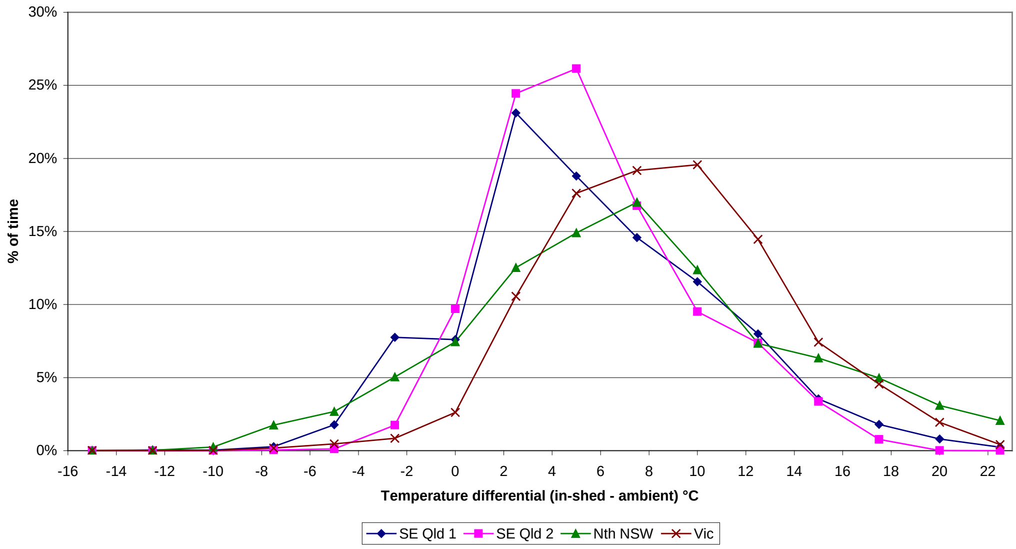

Figure 6: Frequency of occurrence for in-shed to ambient temperature differentials for 4 broiler sheds collected over 12 month period

A separate analysis of night time data (assumed to be from 6pm to 7am) was performed because plume rise may have a more pronounced influence at night when atmospheric stability and weather conditions tend to restrict odour dispersion. Figure 7 displays data for night time, where the difference between in-shed and ambient was found to be slightly greater than the recordings over a 24 hour period, previously shown in Figure 6.

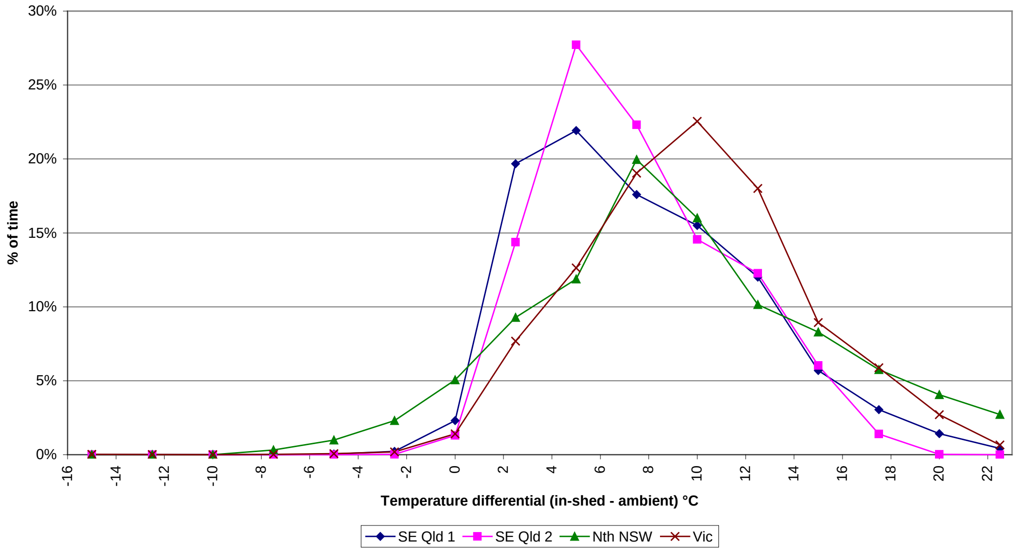

Figure 7: Frequency of occurrence for in-shed to ambient temperature differentials for 4 broiler sheds collected over 12 month period (data from 6pm to 7am)

These two frequency plots show that the in-shed air temperature was nearly always higher than ambient temperature, especially at night and where the climate was cooler.

Summary of the temperature environment of broiler sheds

- Broiler sheds have a strictly controlled temperature environment.
- The target production temperature ranges from approximately 31 °C at the start of each batch and reduces to approximately 20 °C at day 42 for the remainder of the cycle. The specific temperature program used at each farm will vary depending on season, climate, shed and breed of birds.
- It was assumed that in-shed temperature is likely to be representative of the exhaust temperature.
- The in-shed temperature was similar to the target production temperature, but is usually slightly higher.
- When in-shed temperature data is not available, it can be estimated using a simple linear model based on target temperature and ambient temperature (see Equation 2). When compared against the in-shed temperatures measured at these four broiler farms, the equation provided a closer estimate of the in-shed temperature than the target production temperature.
- In-shed temperatures are frequently warmer than ambient air, especially at night. This temperature differential is often within the ranges of 2–10 °C (in-shed warmer than ambient). This is not surprising considering that air of ambient temperature is drawn into the shed and is warmed by heat emitted from the birds. It therefore makes sense that the exhausted air will usually be warmer than ambient air.
- A differential temperature of +6 °C was frequently measured at these broiler farms and is approximately at the middle of the range of the recorded temperature differentials (2–10 °C). This temperature should therefore be adopted for use as the in the CFD modelling exercise.

The temperature data presented in this report was only measured at one location in each broiler shed. To confirm the conclusions drawn from this data, additional temperature measurements (with multiple sensors) need to be made at more farms. Also, the model for estimating in-shed (and therefore exhaust) air temperature may not be applicable to other broiler farms.

CFD modelling of shed exhaust

Project Objective 1: Use computational fluid dynamics (CFD) modelling to model plume rise and dispersion in a variety of scenarios, and comparing these results with those predicted by Calpuff.

Computational fluid dynamics (CFD) modelling is a powerful tool that can accurately model air movement within a defined domain, but requires careful selection of modelling inputs and configurations to simulate real life.

An experienced CFD modeller was engaged to model a typical broiler shed scenario and assess the effects of plume buoyancy on plume dispersion. The effects of plume downwash were also examined. These scenarios were also examined simultaneously by the modeller using Calpuff to assess differences in outputs from the two types of models. The detailed report, including full methodology, results and discussion for this modelling exercise, is included as Appendix 1.

Methodology

A variety of scenarios were compiled to test the effects of differential temperature (exhaust temperature versus ambient temperature), ventilation rate, wind direction and wind speed on plume rise and dispersion (see Table 2). Thirteen cases were modelled using both CFD and Calpuff. Calpuff was used to model two additional scenarios where the source was described as a volume source or as stacks with very low vertical velocity (0.01 m/s).

Case 1 was nominally designated as the 'control' case. A differential temperature of 6 °C was chosen following an analysis of temperature shed data (refer to the chapter 'Understanding the temperature environment in and around broiler sheds').

Table 2: Scenarios modelled using CFD and Calpuff

Case	Parameter Tested	Temperature Difference (°C, discharge minus ambient)	Vertical Velocity (ms^{-1})	Wind Direction	Wind Speed (ms^{-1})	Ventilation rate %	Model
1	**Control**	**6**	**0**	**0**	**2**	**50% (7 fans)**	CFD & CALPUFF
2	**Fan Activity**	6	0	0	2	**7% (1 fan)**	
3		6	0	0	2	**100% (14 fans)**	
4	**Temperature difference**	**10**	0	0	2	50%	
5		**2**	0	0	2	50%	
6		**0**	0	0	2	50%	
7		**-6**	0	0	2	50%	
8	**Volume Source**	N/A	0	0	2	50%	CALPUFF
9	**Stacks with low velocity**	6	**0.01**	0	2	50%	
10	**Wind Direction**	6	0	**45**	2	50%	CFD & CALPUFF
11		6	0	**90**	2	50%	
12		6	0	**135**	2	50%	
13		6	0	**180**	2	50%	
14	**Wind Speed**	6	0	0	**0.5**	50%	
15		6	0	0	**10**	50%	

A ‘typical’ broiler shed with dimensions 150 m long, 15.3 m wide, 2.7 m high walls and 4.5 m to the roof apex was configured into the modelling exercise. The ventilation system used on this shed model included 14 tunnel ventilation fans generating a maximum ventilation rate of 445,000 m^3/hr.

Odour was modelled using an emission ‘concentration value’ of 1.0. Consequently downwind concentrations are a percentage of the original concentration.

Plume rise and dispersion from the CFD and Calpuff models were assessed by measuring:

- the odour concentration at all heights from a point located 300 m downwind from the source;
- the ground level concentrations along the plume centreline; and
- the crosswind concentrations 300 m downwind from the source.

The CFD model was used to investigate the effect of building downwash on plumes; to assess how well Calpuff simulates complex plume-building interactions; and to evaluate the temperature of the plume at the stall point. The stall point is the location when horizontal momentum from the fans is dissipated and the plume movement is controlled by its interaction with the surrounding environment (including interactions relating to thermal buoyancy).

For improved presentation and understanding of plume movement, odour concentration, temperature and plume vertical velocity data from the CFD modelling outputs was extracted for selected cases (Cases 1, 3, 4, 6, 7, 11, 13, 14 and 15). This data was then processed using 3-D visualisation software (Voxler®, Version 1.1.1716, Golden Software Inc., Colorado USA), and is presented in Appendix 2, Appendix 3 and Appendix 4.

Results and discussion

A detailed explanation of the results from the CFD modelling exercise is provided in Appendix 1. The following is a summary of the important overall findings and the findings for key scenarios, based on this detailed explanation (Appendix 1), plume concentration (Appendix 2), plume temperatures (Appendix 3) and plume vertical velocity (Appendix 5).

KEY FINDINGS

- **On level ground, Calpuff resulted in an over-prediction of odour concentration and thus separation distance (more conservative estimation of odour impacts), compared to the CFD model; however, it may result in an under-prediction of odour impacts for an elevated down-wind receptor. Further investigation would be required to address this.**
- **Calpuff generally does not simulate plume rise, and is relatively insensitive to plume emission temperature; with building downwash and plume rise formulae contributing to this observed plume behaviour.**
- **The CFD model demonstrated that significant plume rise can occur with poultry shed emissions. This finding raises questions about the practice of ignoring thermal buoyancy; however, Calpuff may not adequately simulate thermally buoyant poultry shed plumes.**

- The CFD output for Case 2 (1 of 14 fans operating) demonstrated almost immediate vertical rise and appeared to defy wind activity. It was concluded that the CFD prediction for this case did not represent a reasonable simulation of plume behaviour for this particular scenario, and consequently should be excluded from analysis.

- Outputs from the two models were difficult to compare because CFD generated an ‘instantaneous’ plume whereas Calpuff generated a ‘time averaged distribution’.

- Plume width was much narrower in the CFD model than in Calpuff. It was concluded that stability-dependent puff spreading and plume meander inherent in Calpuff modelling would result in wider, lower concentration plumes.

- The CFD model predicted very little plume rise during strong winds (10 m/s, Case 15); when ambient and exhaust temperatures were similar (0–2 °C temperature differential, Cases 6 and 5); or when the emission temperature was cooler than ambient temperature (-6 °C, Case 7).

- The CFD model predicted substantial plume rise during low wind conditions (0.5 m/s, Case 14) or when the exhaust temperature was warmer than ambient temperature (6–10 °C temperature differential, Cases 1 and 4). When the exhausted air was 6–10 °C warmer than ambient, plumes rose by 30–50 m, at a position 300 m downwind (assuming wind speed of 2 m/s).

- The CFD model predicted considerably higher ground level concentrations than Calpuff whenever there was little or no plume rise (Cases 5, 6, 7 and 15).

- The CFD model predicted considerably lower ground level concentrations than Calpuff whenever substantial plume rise occurred (Cases 4, 13 and 14).

- For most modelling scenarios, the CFD model predicted slightly lower ground level concentrations when compared with Calpuff outputs.

- Plume prediction by the CFD model should be considered superior to Calpuff when wind direction was not in the same direction as the exhausted air direction (45°, 90°, 135° and 180° wind directions, Cases 10, 11, 12 and 13 respectively). Calpuff slightly under-predicted impacts when the wind was at a direction of 90° and 135° to the discharge, and over-predicted impacts when the winds was co-flowing or at angles of 45° and 180° to the discharge. This finding suggests that the crude building downwash formulations in Calpuff may not accurately simulate the plume dispersion when the wind is blowing at various angles to the building; however, the differences in predicted impacts were relatively small.

- Plume temperature and ventilation rate influenced the temperature of the plume and distance from the shed at which the plume began to rise. When the plume was warmer compared to ambient air, it began to rise closer to the shed and retained more heat at that point (compared to when the plume was cooler). The effect of ventilation rate was more complex: as the ventilation rate increased, the position at which the plume began to rise moved further away from the shed (distances ranged from 5 m with 2 fans to 50 m with all 14 fans operating); and the plume retained more heat even though the emission temperature was the same.

- The CFD model was configured to simulate odour plumes in neutral conditions. In general, Calpuff predicted higher odour concentrations (requiring larger separation distances compared with the CFD model).

  It was suggested that during unstable conditions, the CFD model would predict greater plume rise and therefore Calpuff predictions would be even more conservative, and from a regulatory perspective there would be no need to reconfigure Calpuff for odour impact assessment.

  On the other hand, modelling plume dispersion in stable atmospheric conditions may result in the slight under-prediction of odour impacts by Calpuff (when compared to the CFD model). Calpuff re-configuration may be required to ensure accurate (and conservative) prediction of odour impacts under stable atmospheric conditions.

Visualising exhaust plumes and measuring temperature profiles

Project objective 2: Use temperature sensors, data logging equipment and smoke to measure the temperature of air exhausted from a broiler shed and visually assess rise and dispersion.

Methodology

Description of the shed used during the temperature monitoring study

The broiler shed chosen for this study was a tunnel ventilated grow-out shed (see Figure 8). It was 97 m long, 14.8 m wide, 3.1 m to the roof apex and had 2.6 m high walls, with a capacity of approximately 30,000 birds. The building had an insulated roof and curtain side walls. The farm was located near Gatton, approximately 75 km west of Brisbane in southeast Queensland.

Figure 8: The broiler shed used in this study

Mechanical ventilation was provided by eight tunnel ventilation fans fitted to the western end of the building. These fans were 1270 mm diameter belt driven axial fans (Munters Euroemme EM50, 1.0 hp, Italy), which have a maximum design flow rate of approximately 35,900 m^3/h. Given the fan dimensions and flow rate, exit airspeed for the fans would be approximately 7.0–7.5 m/s. Fan activity was automatically controlled to maintain ideal temperature conditions for the birds.

The shed was built on flat, level ground, oriented with the tunnel ventilation fans pointing towards 280° (10° north of west) (see Figure 9). There was an identical shed and thick bushland to the north, a few trees on the southern side and a grassy area with few trees to the west. This grassy area was crucial for the installation of the temperature sensor array.

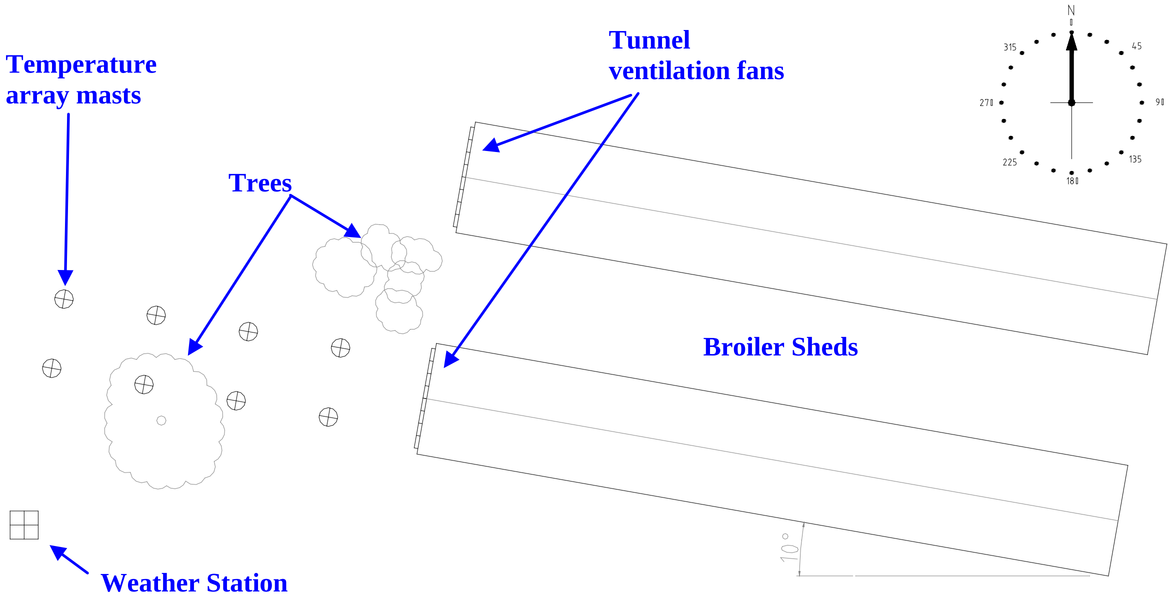

Figure 9: Orientation of sheds and position of the sensor array, weather station and trees

Temperature sensor array

An array of temperature sensors was installed at the broiler farm to allow measurement and tracking of exhaust air plumes. It was anticipated that data collected from this activity would improve understanding of:

- how far plumes exhausted horizontally before rising;
- how the plume temperature changed as it mixed with the ambient air; and
- the temperature of the plume at the point where it started to rise.

The array was installed at the exhaust end of a tunnel ventilated broiler shed (see Figure 10) and consisted of 32 temperature sensors, extending 40 m from the end of the shed, 7.5 m wide and 10 m tall. The sensors were positioned at heights of 2.5 m, 5.0 m, 7.5 m and 10.0 m. An additional sensor was installed on the outside of one of the exhaust fans to measure the temperature of the exhaust air. This fan was the first tunnel ventilation fan to turn on, and remained on as the other fans turned on or off depending on ventilation requirements.

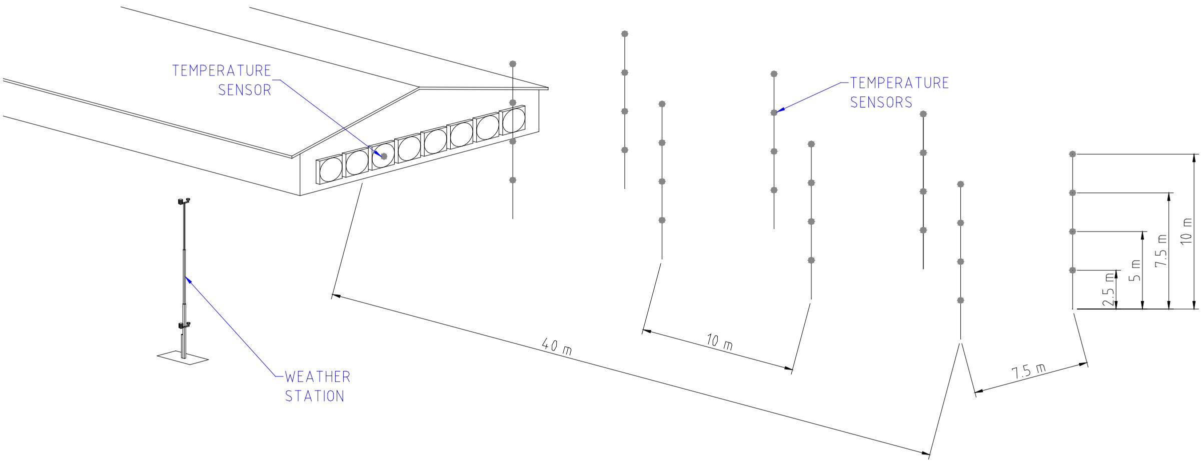

Figure 10: Schematic of the temperature sensor array commencing 10 m from the fan end of the shed, with 10 m spacing (Weather station for illustrative purpose only; its position is correctly shown in Figure 9)

The temperature sensors were mounted on eight, ten metre tall masts constructed from 100 mm diameter PVC water pipe. Guy ropes were used to support the masts. Figure 11 shows the completed sensor array installed at the broiler farm.

Figure 11: Temperature sensor array as installed at the broiler farm

The temperature sensors used in the array needed to be accurate with a fast response time. Platinum resistance temperature detectors (RTD, PT100, 1/10th DIN, mineral insulated 3 mm diameter stainless steel sheath, OneTemp Pty Ltd, Brisbane) were selected as their characteristics met the requirements by providing measurement resolution of 0.1 °C and fast response times. Figure 12 displays one of the temperature sensors used in the array.

Figure 12: Platinum RTD (PT100 sensor inside a thin stainless steel sheath)

Shields were used to protect the sensors from direct solar heating. On the masts, shields were manufactured using galvanised sheet and styrofoam (75 mm thick). Where these shields were used, the temperature sensor protruded from the bottom of the foam by approximately 20 mm. On the weather station and at the exhaust fan, a six plate radiation shield was used (RM Young Company Meteorological Instruments, Michigan USA) (see Figure 14).

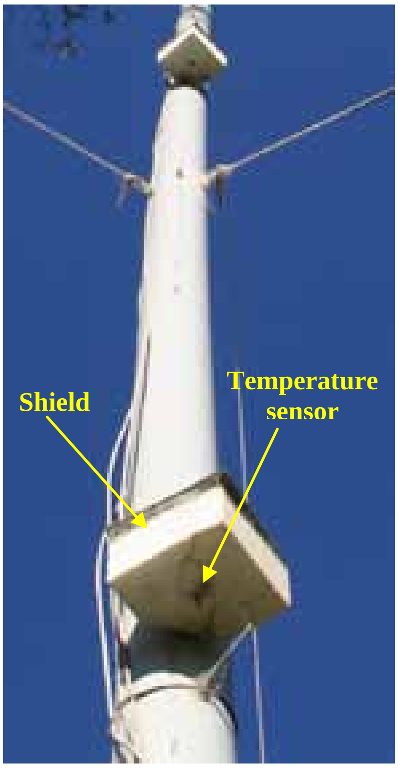

Figure 13: Solar radiation shield used on the masts

Figure 14: Radiation shield used at the exhaust fan (to measure shed emission temperature) and on the weather station

Data loggers were used to continuously monitor and record temperature information from the sensor array. Four data loggers (dataTaker® DT500, dataTaker® Pty Ltd) were required because of the number and spatial distribution of the sensors. Each logger was housed in a weatherproof metal box and powered using a solar panel and battery. To ensure comparable temperature measurement by the four data loggers, a high precision, temperature stable 100 Ω resistor was installed on each data logger as a representative temperature sensor.

Temperatures were measured every second by the data logger, which then reported an average temperature every twenty seconds. Recordings needed to be frequent so that temperature changes due to wind fluctuations or changes in fan activity wouldn't be 'averaged out'. Frequent recording required significant data logger processing and memory capability with 4320 readings per sensor per day (142,560 readings for the entire grid per day). Due to the large amount of data, downloading was undertaken frequently. The weather station data logger was also programmed to record data every twenty seconds so that all data could be synchronised.

Data filtering was used to identify periods when the wind was blowing in the correct direction (no cross-winds). A range of wind speeds and ambient temperatures were examined. Temperature recordings were analysed using 3-D data visualisation and graphing software (Voxler®, Version 1.1.1716, Golden Software Inc., Colorado USA). This software enabled individual temperature measurements to be presented. It also had in-built interpolation capabilities that allowed prediction of temperatures between the temperature sensors. Figure 15 is an example of an output from the 3-D visualisation software. This output includes the individual temperature sensor readings and interpolated temperature estimates (shaded colours). Temperatures are indicated by the scale bar. In this example, the opacity of the area shading was uniform for the entire temperature range. For ease of interpretation of the other temperature profiles presented in this report, the opacity of certain parts of the temperature range were reduced to emphasise the most likely position where the exhaust plume was influencing the temperatures (see Figure 16 and Figure 17 for examples). The most important thing to remember is that the point temperatures were actually measured whereas the shading is only an estimate. Consequently, the colour of the point temperatures should be used as an indication of the temperature in the areas where shading has been made invisible.

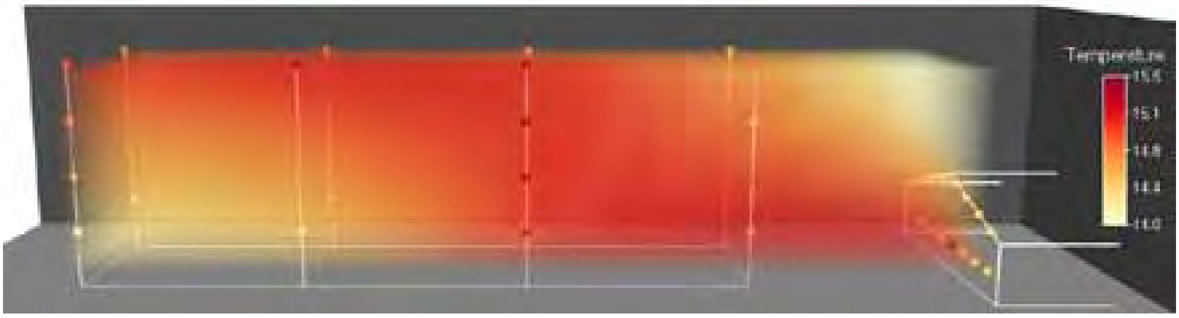

Figure 15: Example of output of temperature data using 3-D visualisation software showing point temperature measurements and estimated area temperatures

The position of active fans can be seen by the different indicated temperatures. In the case shown in Figure 16, two fans were active. The temperature corresponding to inactive fans and the temperature along the roof line were estimated from the 2 m temperature measured at the weather station. The temperatures indicated in this figure suggest that relatively warm air emitted from the shed (19.9 °C compared to ambient temperature of 14.1 °C) rose as it passed through the first and second rows of temperature sensors.

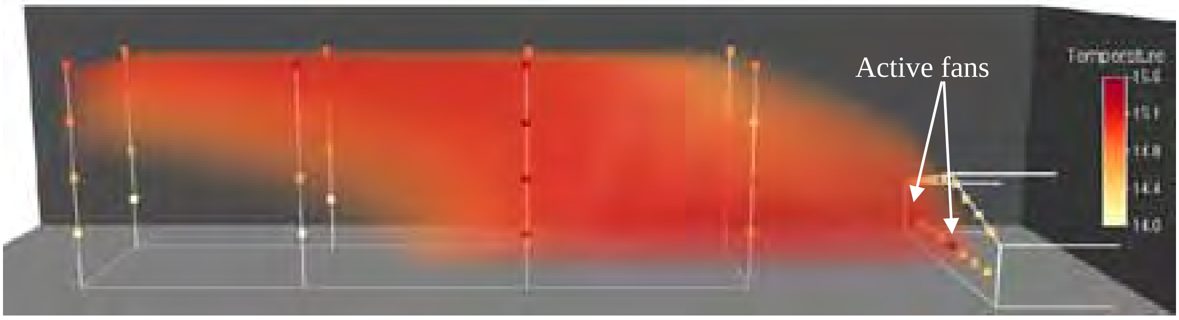

Figure 16: Output of temperature data using 3-D visualisation software with 2 fans operating

Figure 17 is another example output from the 3-D visualisation software. In this figure, all fans were active and the emission temperature (27.7 °C) was very similar to ambient temperature (27.6 °C). This figure shows no apparent rise of the exhaust plume. Warmer temperatures along the ground may be due to warmth rising from the ground surface.

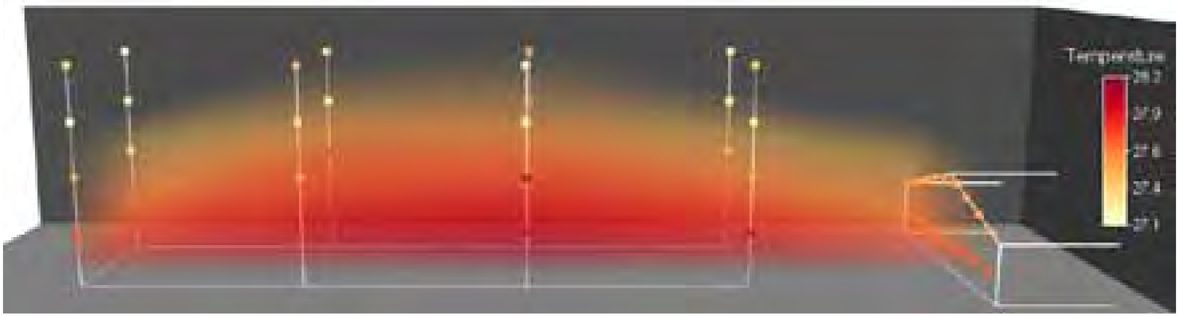

Figure 17: Output of temperature data using 3-D visualisation software with eight fans operating

Fan activity monitoring

The number and position of active fans was expected to influence the temperatures measured by the temperature sensor array because:

- greater number of active fans would increase the distance that the exhaust air was projected horizontally from the shed;
- greater number of active fans would increase the volume of the exhaust plume, potentially demonstrating greater temperature conservation by the plume; and
- fan activity on one side of the shed would tend to be monitored by only one side of the temperature array.

It was therefore essential that fan activity was monitored. Equipment and methodology for monitoring fan activity was essentially identical to those used by Dunlop and Duperouzel (unpublished), and is summarised below.

Mercury tilt switches (see Figure 18 and Figure 19) were attached to the fan back-draft shutters to monitor fan activity, similar to the approach used by Wilhelm et al. (2001). The use of tilt switches was selected over other techniques due to low cost (sensors cost approximately $3.00/fan), availability of components, expected reliability (when compared to more complex systems) and unobtrusiveness.

Figure 18: Mercury tilt switch with fan turned off (shutters closed, switch closed)

Figure 19: Mercury tilt switch with fan turned on (shutters open, switch open)

Tilt switches were connected to a data logger, via a voltage dividing circuit (refer to Dunlop and Duperouzel (unpublished) for full details). The data logger recorded any change in fan activity as it happened (recording the on/off status of each fan) and was also programmed to record the average fan activity every twenty seconds to enable the fan activity data to be synchronised with the temperature array and weather station data sets.

Weather station

Weather conditions were monitored with a 10 m portable automatic weather station (AWS) (see Figure 20 and Figure 21).

Weather information collected during the trial is displayed in Table 3. Wind speed, wind direction and temperature data were reported every 20 seconds. Details of the weather station sensors are displayed in Table 4.

Table 3: Weather information collected by the AWS

2 m wind speed	10 m wind speed standard deviation
2 m wind direction	2 m temperature (2 sensors)
10 m wind speed	2 m relative humidity
10 m wind direction	10 m temperature
2 m wind direction standard deviation	Total radiation
10 m wind direction standard deviation	Barometric pressure
2 m wind speed standard deviation	Rainfall

Table 4: Sensors used on the AWS

Sensor/Parameter	Brand	Model Number	Sensitivity	Range
Data Collection	DataTaker	DT500 (version7)	0.11% for Voltage 0.21% for Current	0-2500 mV 0.25-25 mA
Temperature (2 m)	Vaisala	50Y Humitter	±0.6 °C at 20 °C	-10 to +60 °C
Temperature (2 m & 10 m)		PT100		-50 to + 250 °C
Humidity (2 m)	Vaisala	50Y Humitter	±3% at 90% RH	10–90%
Wind Speed	Gill Windsonic	1405-PK-040 Option 3	±4% at 20 m/s	0 to 60 m/s
Wind Direction	Gill Windsonic	1405-PK-040 Option 3	+- 3° at 20 m/s	0 to 359°
Total Radiation	Li-Cor	LI200SZ	0.2 kW/m^2/mV	
Barometric Pressure	Vaisala	PTB101B	±0.5 hPa at 20 °C ±2 hPa at 0–40 °C	600 to 1060 hPa
Rainfall	Hydrological Services	TB3	one tip/0.2 mm rain	0 to 700 mm/hr

The AWS was located and managed by according to AS 2923–1987 (Standards Australia, 1987); however, it was not possible to locate the weather station in strict accordance with the standard due to a few trees that were between the temperature array and weather station. Nevertheless, the weather station was positioned as close as possible to the trial site to record temperatures and wind patterns through the temperature array, which required small compromises in relation to established trees.

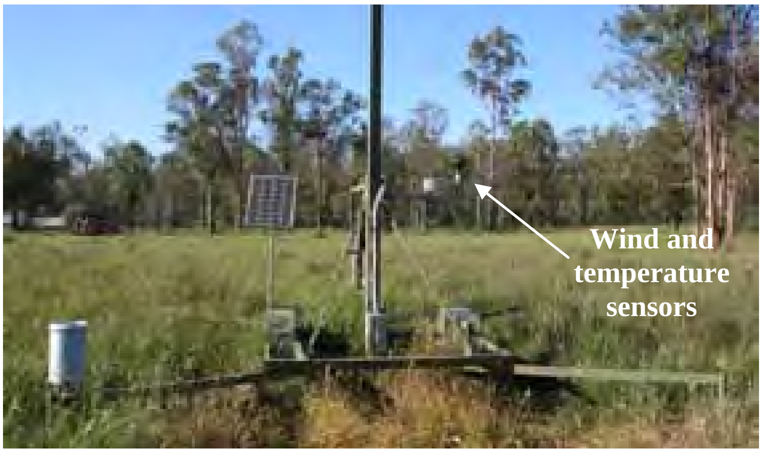

Figure 20: Weather station used for this project: close up of the lower sensors

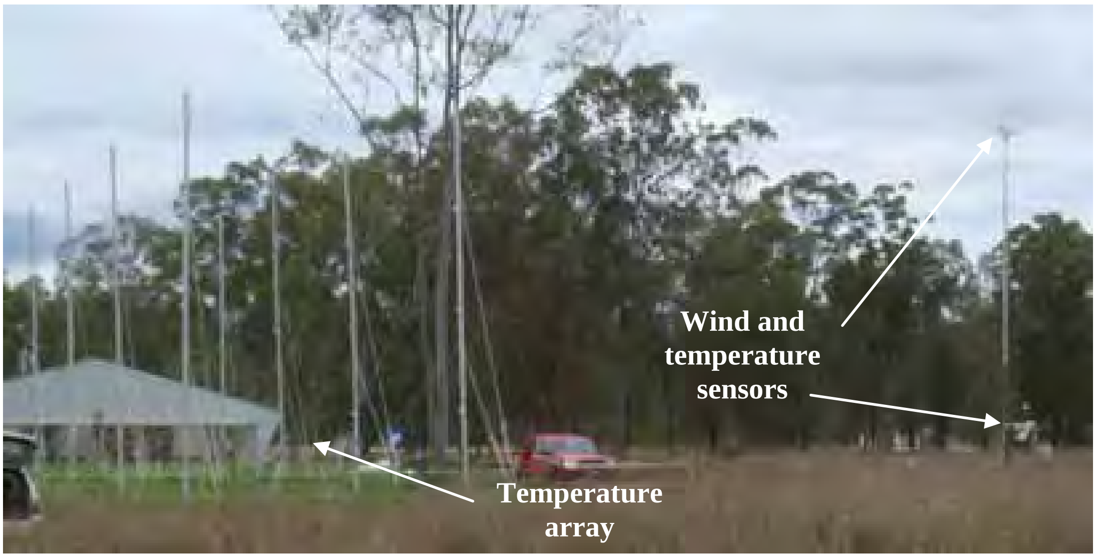

Figure 21: Weather station used for this project: temperature array in the background

Using smoke to visualise exhaust plumes

On the morning of 2 December 2008, smoke was used to visualise the exhaust plume from the broiler shed. Air temperatures, exhaust temperature, fan activity and weather conditions were simultaneously measured and recorded for direct comparison.

Hand smoke flares (Pains Wessex Handsmoke, Chemring Australia, Victoria) were used to provide large volumes of persistent smoke. Orange and white smokes were used because these provided the greatest visibility. The smoke produced by hand smoke flares is a pyrotechnic smoke consisting of fine coloured particles. The duration of smoke production was typically 60 seconds.

Smoke was used to visualise exhaust plumes through the full range of fan activity (one to eight active fans). Smoke was released on the outside of the tunnel ventilation fans, with one or two smoke flares used per release depending on the density of smoke required. Fan turbulence was effective in mixing the smoke.

A digital camera (Canon EOS350D, digital SLR) and digital video camera (Sony HDR-FX1E Digital HD Video Camera Recorder) were used to record the smoke plumes. Sequential images were taken with the still camera. Cameras were positioned approximately 80 m south of the broiler shed and 20 m to the west, providing a side view of the exhaust plumes.

Results and Discussion

Summary of data collection

The temperature array was installed and data loggers were actively collecting data on 8 October 2008, prior to placement of the birds. Shortly after installation, a severe storm struck the area, with a suspected lightning strike causing significant damage to the system and terminal damage to several data loggers. This issue was resolved, and the monitoring equipment was fully operational again by 26 November 2008, at which stage the birds were 35 days old.

On 2 December 2008, smoke was used to visualise the exhaust plumes and plume movement was compared with temperatures recorded at the time. On this day, the birds were 41 days old and there were 22,800 birds housed in the shed.

Smoke visualisation of exhaust plumes

The first release commenced at 4:25 am, close to sunrise; at which time, the ambient air temperature was approximately 14.2 °C. Smoke was intermittently used as more fans became active. The final smoke release occurred at 7:30 am, when all tunnel ventilation fans were active and ambient temperature was approximately 24.0 °C. Throughout the course of the morning, the temperature of air exiting the shed ranged between 19.6 °C and 24.8 °C. Whilst wind direction was initially opposite the discharge direction (albeit light 0.4–0.9 m/s), a wind shift to the east (co-flow direction) occurred between 5:05 and 6.30, to result in a subsequent cross-wind of 1–1.4 m/s from the SE and then settled to a lighter breeze of 0.8-1 m/s co-flowing with the discharge direction. Table 5 summarises the wind conditions, temperatures and number of fans during each smoke release.

Table 5: Summary of conditions during each smoke release on 2 December 2008

Smoke release	Time (am)	Wind Speed# m/s	Wind direction# °	Ambient temperature# °C	Shed air temperature** °C	Number of active fans$
1	4:25–4:28	0.52	292	14.6	19.7	1
2	4:31–4:33	0.52	313	14.6	19.9	1–2
3	4:38–4:41	0.44	289	14.5	19.7	2–1
4	4:42–4:44	0.44	318	14.5	19.9	1–2
5	5:01–5:03	0.90	287	14.5	19.8	1–2
6	5:49–5:54	0.35	60–90	16.6	20.7	2–3
7	5:55–5:57	0.34	300° at 2 m 43° at 10 m	17.1	20.7	3
8	6:21–6:23	1.16	161	19.6	22.3	6
9	6:24–6:26	1.10	153	20.1	22.4	6
10	6:58–7:00	1.06	154	22.6	23.6	6–7
11	7:00–7:02	1.39	141	22.7	23.6	7–6
12	7:13–7:15	1.03	139	23.0	24.3	7
13	7:28–7:30	1.02	107	23.7	24.7	8
14	7:31–7:33	0.78	101	24.0	24.8	8

Average of 2 m and 10 m readings, with the wind direction indicating the direction from which the wind was blowing

** Measured at the exhaust fan

$ e.g. 2–1 indicates that the number of fans changed from 2 to 1 during the smoke release (maximum 8)

Some of the smoke releases were undertaken sequentially while conditions remained similar (in terms of wind conditions, temperatures and fan activity). These smoke releases were grouped for comparison to temperatures recorded within the temperature array.

Smoke releases 1, 2, 3 and 4

Smoke releases one to four (see Figure 22 to Figure 25) were undertaken at dawn when the temperature of the exhausted air was about 5.3 °C greater than ambient. A very slight breeze tended to push the exhaust plume back over the shed (counter-current flow). Almost immediate plume rise occurred, with plumes rarely extending beyond 15–20 m from the shed at ground level before rising sharply. However, despite the sudden plume rise, the smoke never rose far above tree height (approximately 20 m) and lingered in the clearing immediately surrounding the sheds (see Figure 26).

Figure 22: Smoke release 1

Figure 23: Smoke release 2

Figure 24: Smoke release 3

Figure 25: Smoke release 4

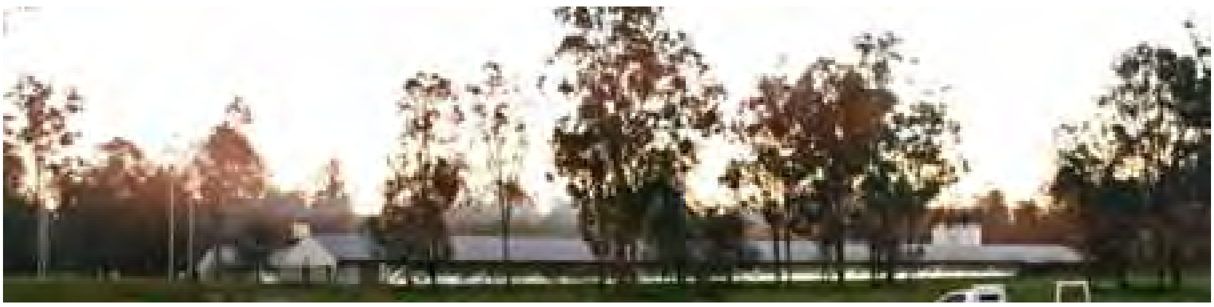

Figure 26: Smoke lingering in the clearing surrounding the sheds (combination of white and orange smoke from smoke releases 1 to 4)

The temperature profile during these smoke releases (see Figure 27, which was recorded during smoke release 3) closely resembled the visible smoke plumes. The temperature sensors in the first row (10 m from the tunnel fans) did not appear to register the exhaust temperature. Cross-referencing this observation with the smoke photos suggests that the exhaust air passed below the lowest sensor (positioned 2.5 m above the ground). We know from the temperature sensor mounted on the tunnel fans that the exhausted air was 19.8 °C, however, the highest recorded temperature was approximately 15 °C, suggesting that the temperature of the air exhausted from the shed rapidly reduced to near ambient temperatures. Alternatively, wind and plume fluctuations may not have exposed the temperature sensors to a constant elevated temperature, resulting in the measurement of an averaged temperature influenced by exposure to both ambient air (14.0–14.5 °C) and exhaust air (19.7 °C).

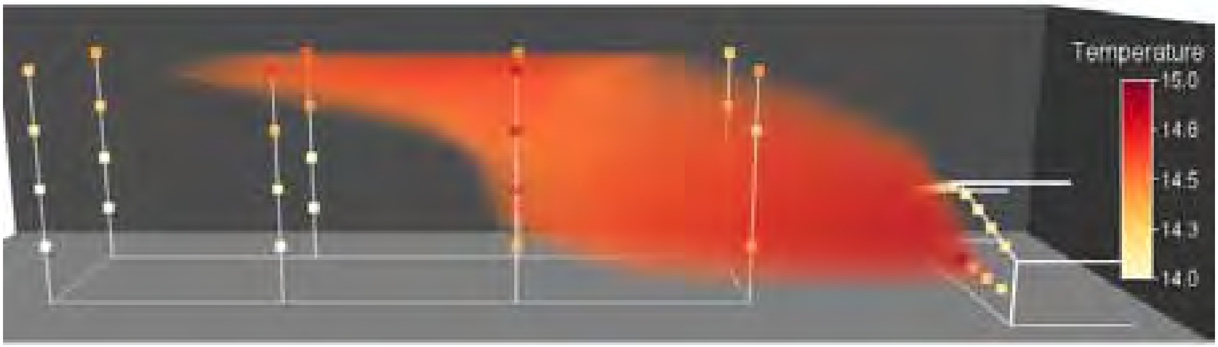

Figure 27: Temperature profile of the exhaust plume during smoke releases 1, 2, 3 and 4

Smoke release 5

Smoke release 5 (see Figure 28) was undertaken shortly after smoke release 4. The exhaust and ambient temperatures had not changed, however the wind was stronger, which again tended to blow back over the shed (counter-current flow). The plume did not travel far enough to reach the second row of temperature sensors, but instead rose up and engulfed the first row of temperature sensors. Consequently, higher temperatures (due to the warm exhaust air) were only recorded in this first row (see Figure 29). As with the earlier smoke releases, the maximum temperature recorded in the grid was approximately 15.1 °C, which is lower than the exhaust temperature (19.8 °C), suggesting that heat quickly dissipated from the exhausted air. This scenario was similar to Case 2 in the CFD modelling.

Figure 28: Smoke release 5

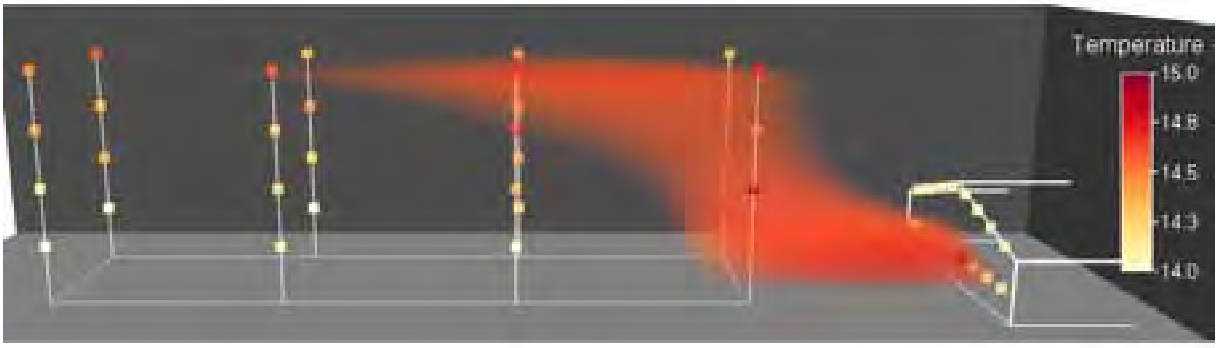

Figure 29: Temperature profile of the exhaust plume during smoke release 5

Smoke releases 6 and 7

Smoke releases six and seven were undertaken when the exhaust temperature was about 20.7 °C while ambient temperature was 16.7–17.7 °C, creating a temperature differential of about 3–4 °C. Wind direction switched to be in approximately the same direction as the exhaust air direction (co-current flow). Three tunnel fans were active during these smoke releases. Photos of the smoke plumes (see Figure 30 and Figure 31) demonstrate that the plume remained attached to the ground for about 22 m before rising. The plume then rose steadily and dispersed until the smoke was no longer visible. The temperature profile during these releases (see Figure 32) do not clearly show the temperature distribution, however, fluctuating wind conditions during smoke release seven may have prevented steady state temperature measurements from being recorded.

Figure 30: Smoke release 6

Figure 31: Smoke release 7

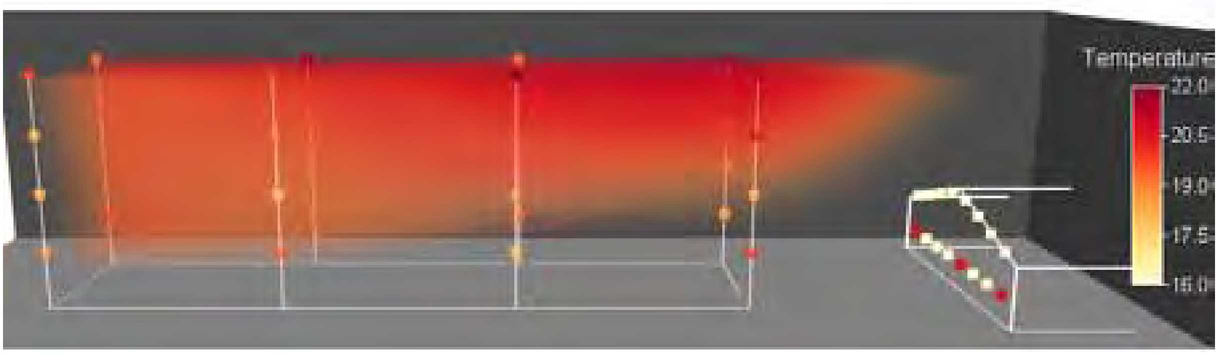

Figure 32: Temperature profile of the exhaust plume during smoke releases 6 and 7

Smoke releases 8 and 9

Smoke releases eight and nine (see Figure 33 and Figure 34) were undertaken when six tunnel fans were operating. Exhaust temperature was about 22.3 °C while ambient temperature was 19.6–20.1 °C, resulting in a temperature differential of 2.2–2.7 °C. Wind speed was higher and blew across the shed (away from the camera). Consequently, the plumes remained attached to the ground for 25-40 m before rising. Plume rise still occurred and the plumes continued to rise until dispersion of the smoke made them invisible.

Figure 33: Smoke release 8

Figure 34: Smoke release 9

The temperature profile during these smoke releases (see Figure 35) indicated that the smoke rose at a distance of approximately 30 m, where it exited the temperature sensor array.

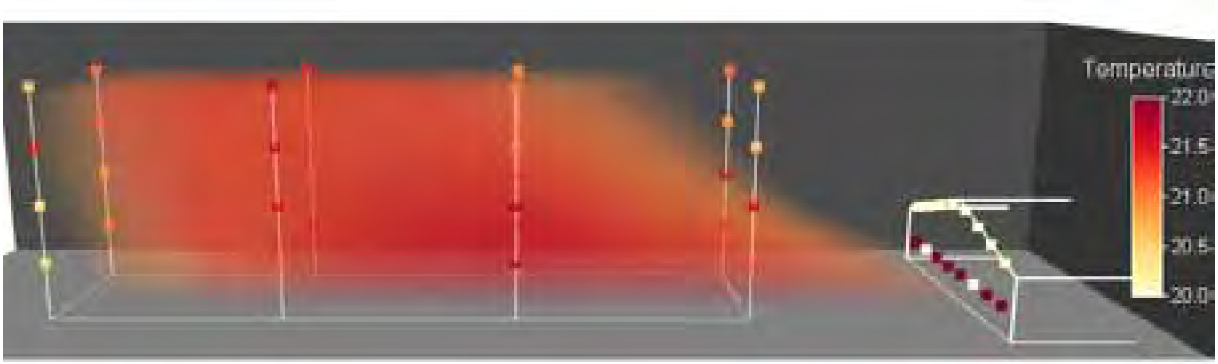

Figure 35: Temperature profile of the exhaust plume during smoke releases 8 and 9

Smoke releases 10, 11 and 12

Smoke release 10 (see Figure 36) was undertaken when seven tunnel fans were operating. A light breeze from the south-south-east did not appear to have a significant effect on plume dispersion. The plume remained in contact with the ground for approximately 30 m before rising slightly. Vertical dispersion was evident to 50 m. At a distance of 50–70 m from the shed, the plume rose vertically and rapidly dispersed (see Figure 37).

Figure 36: Smoke release 10

Figure 37: Smoke release 10: plume dispersing vertically

Smoke release eleven (see Figure 38) displayed similar vertical dispersion to smoke release 10, but a stronger crosswind prevented the plume from extending itself as far from the shed. In this example, the plume rose vertically at a distance of 12–28 m from the shed.

Figure 38: Smoke release 11

During smoke release 12, the camera position was changed to be in line with the shed, as shown in Figure 39, highlighting the sideward plume movement due to cross-winds at the time.

Figure 39: Smoke release 12

The temperature profile recorded during smoke releases 10 to 12 did not clearly demonstrate the shape of the plume (see Figure 40). The small temperature differential between exhausted and ambient air as well as fluctuating wind conditions contributed to the temperature array not clearly recording the plume temperatures. Despite the temperature sensors not clearly recording a rising plume, the photographs demonstrate that the plume did rise.

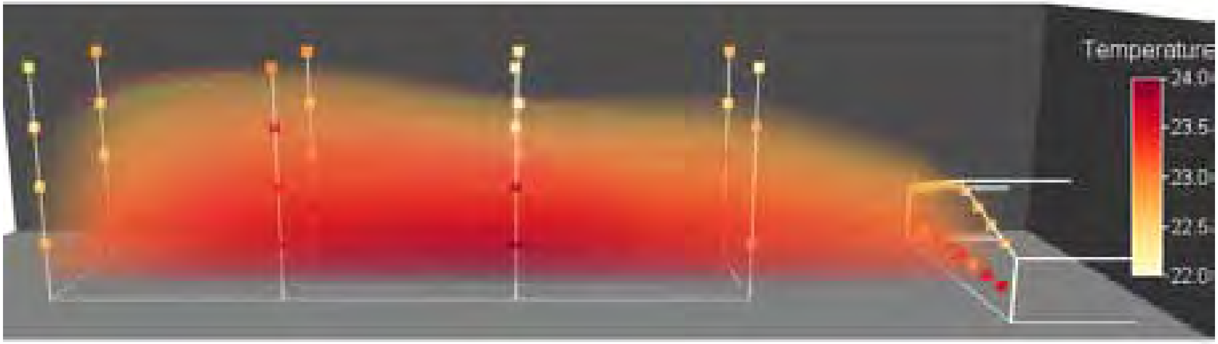

Figure 40: Temperature profile of the exhaust plume during smoke release 10 (and representative of conditions during smoke release 11 and 12)

Smoke releases 13 and 14

Smoke releases thirteen and fourteen (see Figure 41 and Figure 42) were undertaken when all tunnel fans were active. The temperature of the exhausted air was barely 1.0 °C above ambient temperature. Minimal vertical plume movement was seen and the plume tended to hug the ground, especially when compared to the other smoke releases when the temperature differential was greater. Plume dispersion occurred as it moved downwind, including some vertical dispersion.

Figure 41: Smoke release 13

Figure 42: Smoke release 14

The temperature profile during smoke releases thirteen and fourteen (Figure 43) showed elevated temperatures at the lowest height (2.5 m). These temperatures were warmer than the ambient temperature recorded at the weather station and warmer than the exhausted temperature, suggesting that radiant ground heating may have started to influence temperature measurements. Warmth at ground level would contribute to unstable conditions, and would have supported vertical dispersion, as observed during the smoke releases.

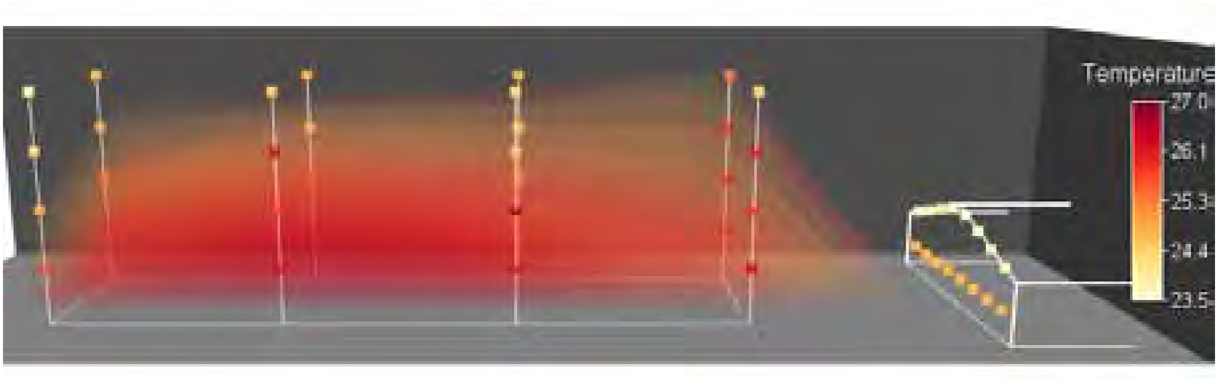

Figure 43: Temperature profile of the exhaust plume during smoke releases 13 and 14

Exhaust plume temperature profiles

Conditional data filtering was used to identify periods between 26 November and 2 December 2008 when the plume was likely to be within the temperature sensor array. These conditions included:

- when the wind was blowing in the same direction as the exhausted shed air (i.e. co-current flow, wind angle between 90–110° and no cross-winds);
- when wind speeds were less than 0.25 m/s, so that wind direction would not greatly influence the plume movement within a very short distance from the shed; and finally
- when conditions were sustained and steady for at least one minute to ensure that the temperature sensors would have sufficient stabilisation time.

Outside of these conditions, the exhaust plume would be unlikely to traverse through the temperature sensor array, and temperature recordings would therefore be unrepresentative of the exhaust plume.

A range of wind speeds and ambient temperatures were examined. Spatial temperature distributions for specific discrete periods are presented in Appendix 5 (and are labelled Appendix 5 Case 1 to Appendix 5 Case 20).

These examples were grouped according to the difference between exhaust and ambient temperatures:

- exhaust air cooler than ambient temperature;
- exhaust air warmer than ambient temperature by 1.0–3.5 °C;
- exhaust air warmer than ambient temperature by 3.5–5.0 °C; and
- exhaust air warmer than ambient temperature by 5.0–6.5 °C.

Exhaust air cooler than ambient temperature
Figure 44 displays an example of the temperature profile when the exhaust air was cooler than ambient (additional detail of this example is given in Appendix 5 Case 10). Under these conditions, it was challenging to clearly resolve the shape and dispersion of the exhaust plume. The plume would not be expected to rise; however the measured temperature profile suggested that it may have. At the time when this temperature profile was recorded (3:46 pm), radiant heat from the ground appeared to influence the temperature readings at the lowest height (2.5 m), which prevented the plume profile from being clearly distinguished.

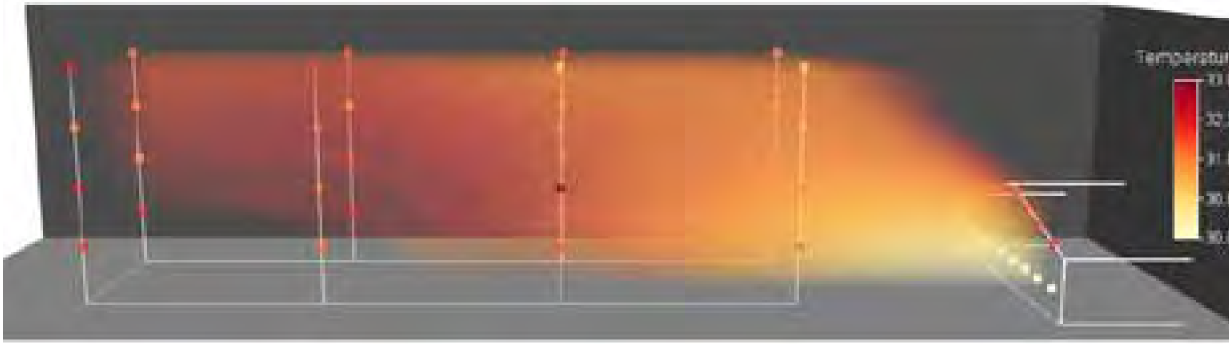

Figure 44: Temperature profile when the exhaust air was cooler than ambient

A similar example of this condition is also provided in Appendix 5 Case 9.

Exhaust air warmer than ambient temperature by up to 1 °C

Figure 45 displays an example of the temperature profile when the exhaust air was warmer than ambient by about 1 °C (additional detail of this example is given in Appendix 5 Case 2). Because of the similarity between ambient and exhaust temperatures, it was difficult to resolve the temperature profile of the exhaust plume from temperature variability in the ambient air; however, the plume appeared to stay close to the ground. As with the previous temperature condition, radiant heat from the ground appeared to increase the temperature readings at the lowest height (2.5 m), complicating the interpretation of this temperature profile. Under these conditions, heat exhausted from the shed and additional heat radiated from the ground should have caused the plume to rise into the cooler air above, and this may have happened outside the sensor array.

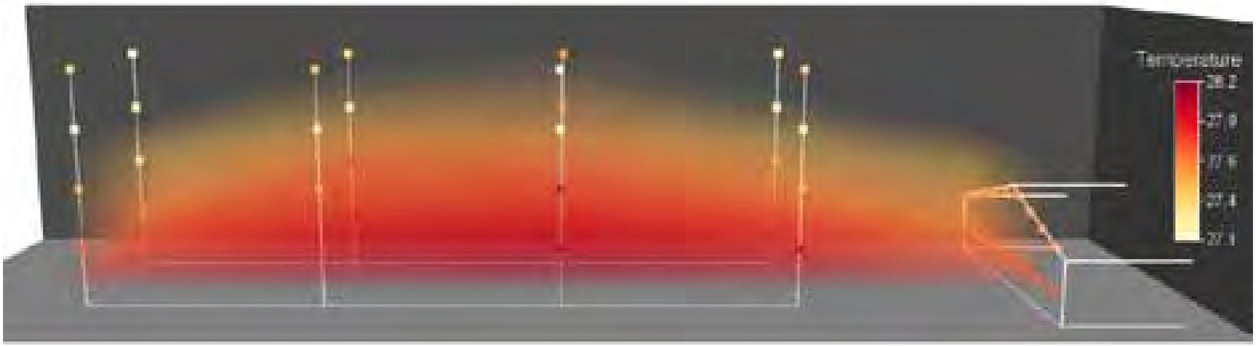

Figure 45: Temperature profile when the exhaust air was warmer than ambient by less than 1 °C

Similar examples of this condition are also provided in Appendix 5 Case 1 and Appendix 5 Case 20.

Exhaust air warmer than ambient temperature by 1.0–3.5 °C

Figure 46 displays an example of the temperature profile when the exhaust air was warmer than ambient by 1.0–3.5°C (additional detail of this example is given in Appendix 5 Case 5). Compared to the two previous examples, the increasing difference in temperature between the exhaust and ambient air allowed the exhaust plume to be more easily defined. In this example, the plume appeared to stay close to the ground, but warming of the upper temperature sensors in the third and fourth row suggests that the plume rose and warmed these sensors. Unlike the previous examples, radiant heat from the ground would be unlikely to influence the temperature profile because it occurred at 8:00 pm.

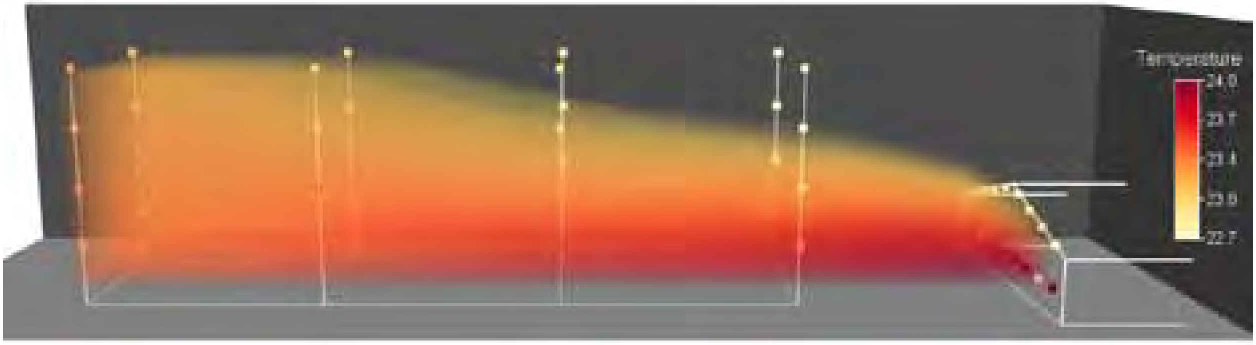

Figure 46: Temperature profile when the exhaust air was warmer than ambient by 1.0–3.5 °C

Table 6 displays the temperatures recorded for different positions within the temperature profile shown in Figure 46. Exhaust air did not appear to contact sensors in the first row, which also occurred during the smoke releases.

Table 6: Temperatures for various positions within the array shown in Figure 46

Position	Temperature (°C)	Temperature differentials (°C)
Exhaust	25.0	2.1 (exhaust - ambient)
Ambient	22.8–22.9	
20 m from shed, 2.5 m height	23.6	0.7 (reading - ambient) -1.4 (reading - exhaust)
30 m from shed, 2.5 m and 5 m height	23.4	0.5 (reading - ambient) -1.6 (reading - exhaust)
40 m from shed, all heights	23.3	0.4 (reading - ambient) -1.7 (reading - exhaust)

For this example, two thirds of the temperature difference between the exhaust and ambient air had dissipated within 20 m of the shed, with only a minor change to the furthest distance of 40 m as the plume continued to disperse.

Similar examples of this condition are also provided in Appendix 5 Case 3, Appendix 5 Case 4, Appendix 5 Case 6, Appendix 5 Case 7 and Appendix 5 Case 11.

Exhaust air warmer than ambient temperature by 3.5–5.0 °C

Figure 47 displays an example of the temperature profile when the exhaust air was warmer than ambient by 3.5–5.0 °C (additional detail of this example is given in Appendix 5 Case 13). The difference in temperature between the exhaust and ambient air allowed the exhaust plume to be easily defined. In this case, the plume appeared to stay close to the ground, but lifted off the ground before reaching the third row of sensors, 30 m from the shed. This example is also different from the previous examples because only two fans were operating.

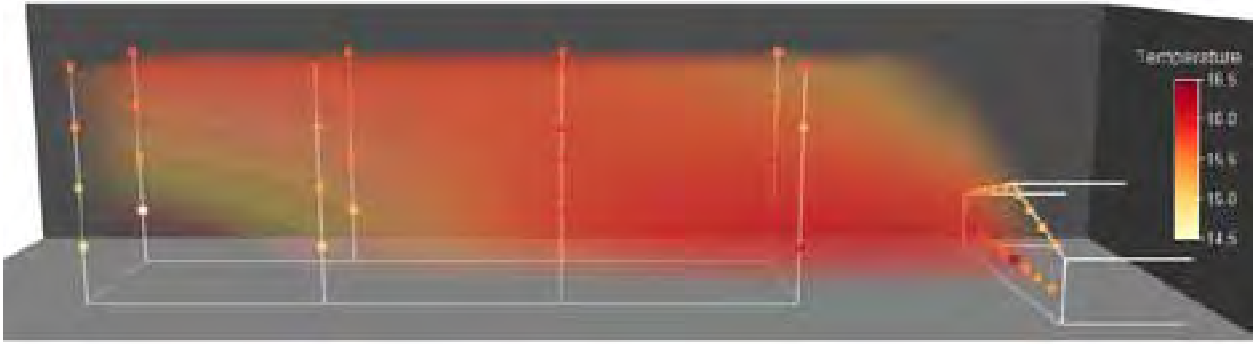

Figure 47: Temperature profile when the exhaust air was warmer than ambient by 3.5–5.0 °C

Table 7 displays temperatures recorded at various positions within the array in Figure 47.

Table 7: Temperatures for various positions within the array shown in Figure 47

Position	Temperature (°C)	Temperature differentials (°C)
Exhaust	19.9	4.9 (exhaust - ambient)
Ambient	14.8-15.3	
10 m from shed, 2.5 m height	16.3	1.3 (reading - ambient) -3.6 (reading - exhaust)
20 m from shed, 2.5 m and 5 m height	16.5	1.5 (reading - ambient) -3.4 (reading - exhaust)
30 m from shed, 10 m height	15.6	0.6 (reading - ambient) -4.3 (reading - exhaust)
40 m from shed, 10m height	15.6	0.6 (reading - ambient) -4.3 (reading - exhaust)

For this example, two thirds of the temperature difference between the exhaust and ambient air had dissipated within 10-20 m of the shed, with even more heat dispersed by 30 m. However, it is likely that the plume exited the top of the temperature array at about 20 m from the shed.

Similar examples of this condition are also provided in Appendix 5 Case 12, Appendix 5 Case 14 and Appendix 5 Case 19.

Exhaust air warmer than ambient temperature by 5.0–6.5 °C

Figure 48 displays an example of the temperature profile when the exhaust air was warmer than ambient by 5.0–6.5 °C (additional detail of this example is given in Appendix 5 Case 15). The difference in temperature between the exhaust and ambient air allowed the exhaust plume to be easily defined. In this case, the plume appeared to stay close to the ground, but lifted off the ground before reaching the third row of sensors, 30 m from the shed. The conditions that existed during this example are very similar to those during smoke releases one to four. It was observed during the smoke releases that even though the smoke rapidly rose, the rise stopped and the plumes dispersed horizontally once it reached a height of 15–20 m, presumably because of a thermal inversion layer. In the following example, the relatively even distribution of slightly elevated temperatures across the top of the sensor array suggests that a similar situation may have occurred.

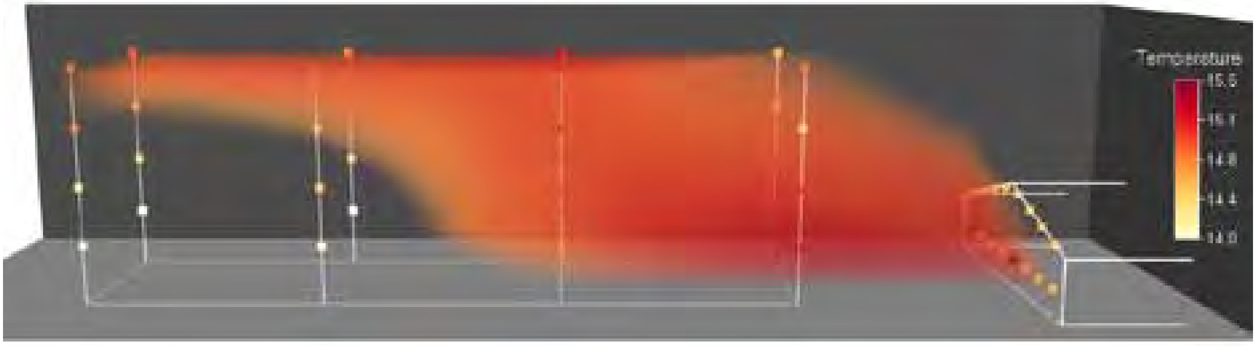

Figure 48: Temperature profile when the exhaust air was warmer than ambient by 5–6.5 °C

Table 8 displays the specific temperatures recorded for various positions within the array shown in Figure 48.

Table 8: Temperatures for various positions within the array shown in Figure 48

Position	Temperature (°C)	Temperature differentials (°C)
Exhaust	20.4	6.5 (exhaust - ambient)
Ambient	13.9–14.9	
10 m from shed, 2.5 m height	15.4	1.5 (reading - ambient) -5 (reading - exhaust)
20 m from shed, 2.5 m to 7.5 m height	15.2–15.8	1.9 (reading - ambient) -4.6 (reading - exhaust)
30 m from shed, 10 m height	14.7–14.9	1.0 (reading - ambient) -5.5 (reading - exhaust)
40 m from shed, 10m height	14.8	0.9 (reading - ambient) -5.6 (reading - exhaust)

For this example, three quarters of the temperature difference between the exhaust and ambient air had dissipated within 10-20 m of the shed, with even more heat dispersed by 30 m. It is likely that the plume exited the top of the temperature array at about 20 m from the shed.

Similar examples of this condition are also provided in Appendix 5 Case 16, Appendix 5 Case 17 and Appendix 5 Case 18

Exhaust air warmer than ambient temperature by more than 6.5 °C

Figure 49 displays an example of the temperature profile when the exhaust air was warmer than ambient by more than 6.5 °C (additional detail of this example is given in Appendix 5 Case 8). In this example, the plume appeared to rise sharply about 20 m from the shed.

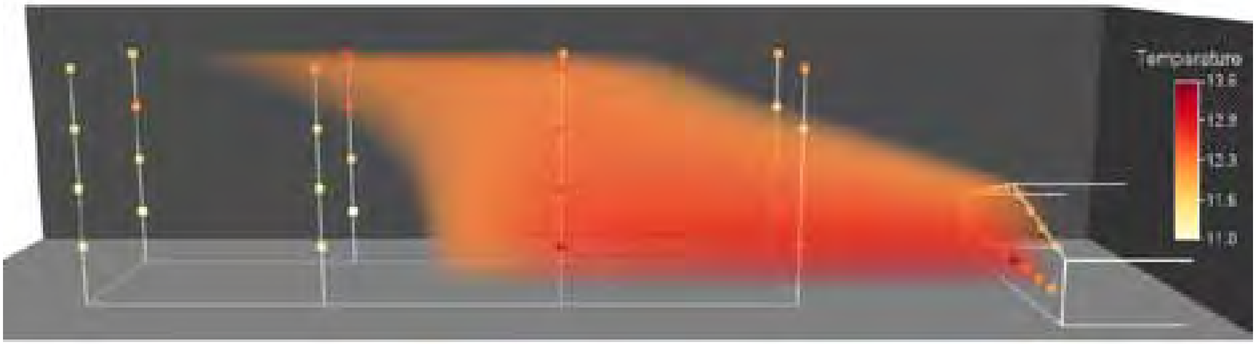

Figure 49: Temperature profile when the exhaust air was warmer than ambient by more than 6.5 °C

Table 9 displays the temperatures recorded for various positions within the array shown in Figure 49.

Table 9: Temperatures for various positions within the array shown in Figure 49

Position	Temperature (°C)	Temperature differentials (°C)
Exhaust	20.1	8.9 (exhaust - ambient)
Ambient	11.2-12.0	
20 m from shed, 2.5 m to 5 m height	13.1-13.6	2.4 (reading - ambient) -6.5 (reading - exhaust)
30 m from shed, 10 m height	12.1-12.5	1.3 (reading - ambient) -7.6 (reading - exhaust)

For this example, three quarters of the temperature difference between the exhaust and ambient air had dissipated within 20 m of the shed, with even more heat dispersed by 30 m. However, it is likely that the plume exited the top of the temperature array about 20 m from the shed.

Summary of plume visualisation and temperature profiles

Utilising smoke flares to visually represent exhausted air from broiler sheds to identify plumes is a well-grounded method which can be employed under a wide range of conditions. Vertical plume rise and dispersion were evident especially when the air exhausted from the shed was warmer than ambient air. The greatest temperature differential recorded during this activity was approximately 8.9°C.

Importantly, the smoke and temperature profiles recorded here reflect the CFD predictions produced under Objective 1, as well as reflecting the general plume temperature principles outlined in the chapter ‘Understanding the temperature environment in and around broiler sheds’ and as described in the PAE (2009) report in Appendix 1.

Temperatures recorded in the temperature sensor array indicated that this temperature differential rapidly reduced as the plume travelled downwind from the shed, but this may have been due to averaging of exhaust and ambient temperatures by the temperature sensors during fluctuating exposure to the exhaust plume.

Wind conditions influenced the movement of the exhaust plume. Counter-current flow prevented the plume being projected far from the shed and encouraged vertical rise and dispersion. Co-current flow enabled the plume to move further from the shed before rising.

Temperature profiles generally correlated well with plume visualisation techniques, especially during still or co-current wind conditions, and when there was a difference of at least a few degrees between exhaust and ambient temperatures. This correlation supports the use of temperature profiles to demonstrate poultry shed exhaust plume movement and temperatures.

The following points summarise the analysis of exhaust plume temperature profiles:

- When the exhaust air was cooler or very close to ambient temperature, the analysis of temperature profiles was challenging, and natural temperature variation (for example due to radiant heating from the ground) prevented plumes from being clearly defined.

- When exhaust temperatures were between 3.5–5.0 °C warmer than ambient, plume rise was noticeable and plumes appeared to rise and leave the top of the temperature sensor array within 40 m from the shed. Also, plume shape could be estimated from the temperature recordings. Within 10-20 m from the shed, the temperature difference between exhaust and ambient temperature had been reduced by two thirds (the plume temperature was much closer to ambient temperature than the exhaust temperature).

- When exhaust temperatures were more than 5.0 °C warmer than ambient, plume shape was able to be estimated from the temperature recordings. Within 10-20 m from the shed, the temperature difference between exhaust and ambient temperature had been reduced by three quarters (the plume temperature was much closer to ambient temperature than the exhaust temperature).

(Note: When closely examining the temperatures measured within the temperature sensor array, it must be remembered that the sensors would need to be continuously exposed to the centre of the exhaust plume for a reasonable time (for example 30-60 seconds) to record the actual plume temperature. It is unlikely that this occurred and the sensors were more likely exposed to the sides of the plume, or exposed intermittently. Consequently, the temperature readings most likely under-predict the temperature at the centre of the plume and consequently more warmth may have been retained in the centre of the plume than has been recorded.)

Comparison of separation distance formulas with Calpuff modelling

Project objective 3: Comparison of separation distance formulas against Calpuff modelling (using the Queensland odour impact criteria).

Separation distances for new or expanding poultry farms may be estimated using site specific odour dispersion modelling or separation distance formulas (where legislation allows). Dispersion modelling is generally accepted to provide superior predictions of odour impacts because farm specific emission rates, terrain and weather patterns are included in the simulation; and the predicted concentration and frequency of odour plumes are compared against odour impact criteria.

While dispersion modelling may be accepted as superior, it requires significant data inputs, computing power and experience, which can make the process of assessing odour impacts time consuming and expensive. Input selection and generation is quite subjective and discreet, and can possibly lead to ambiguous outputs and disputes. In contrast, separation distance formulas can rapidly estimate separation requirements using minimal inputs, which may then be openly presented for review.

To address this objective, separation distances determined using Calpuff were compared to those obtained using separation distance formulas for a selection of existing and hypothetical broiler farms in southeast Queensland. Our focus was on the proposed formula for Queensland (Qld) (see Equation 3) that has been described in detail by Queensland Chicken Growers Association (2005). Other separation distance formulas used in New South Wales (NSW) (Department of Environment and Conservation NSW, 2006b), South Australia (SA) (Environment Protection Authority South Australia, 2007a) and Victoria (Vic) (State Government of Victoria, 2009b) have also been included. When comparing the results it must be remembered that each state has different air quality objectives (as confirmed by their respective odour impact criteria (see Table 1). It is therefore expected that differences will exist between the outputs of the various separation distance formulas. Additionally, only the Queensland formula should be compared with the Calpuff modelling under the southeast Queensland conditions.

$$\textit{Separation Distance}\ \mathbf{(m)} = N^{0.6} \times S1 \times S2 \times S3 \times S4 \qquad \textbf{Equation 3}$$

Where: *N* is the maximum number of chickens divided by 1000;
0.6 is an exponent derived from modelling;
S1 farm design and management factor
S2 land use sensitivity factor;
S3 surface roughness factor; and
S4 terrain weighting factor.

The purpose of using existing broiler farm scenarios was to see whether the separation distance formula would have predicted equivalent or longer (more conservative) separation distances than the Calpuff modelling, which would reduce the potential for odour nuisance. If this were the case, the farm may have been approved on the basis of the odour assessment using the formula. If a receptor was within the distance calculated by the formula, it may have prompted the need for site-specific dispersion modelling (i.e. with Calpuff).

The purpose of modelling hypothetical farms was to see how well the separation distance formula worked for various farm sizes in different terrain and with different weather. A range of modelling inputs was used to assess the effect of emission temperature on odour impacts. The hypothetical farms were modelled with emission temperature equal to ambient temperature (no buoyancy effect) and target production temperature (buoyancy effects).

Methodology

Comparing separation distance formulas to existing broiler farm scenarios modelled with Calpuff

Calpuff odour modelling outputs and other data were obtained for five existing broiler farms; together with descriptions of the farms, terrain, and receptors (see Table 10 and Appendix 6 for full details). Farms were selected on the basis that they had been approved by the relevant local authority based on the Calpuff modelling, which demonstrated compliance with the odour impact criteria (see Table 1).

Table 10: Summary of existing broiler farms modelled with Calpuff

Farm	Number of birds	Shed design	Number of Receptors	Distance to receptors (m)
A	200,000	Tunnel	7	740–1900
B	200,000	Tunnel	8	1410–2130
C	200,000	Tunnel	5	837–1860
D	240,000	Tunnel	4	700–900
E	200,000	Tunnel	5	370–1623

A spreadsheet was developed to calculate separation distance requirements from the farm to the neighbouring receptors using the proposed formula for Queensland, as well as the formulas currently used in New South Wales, South Australia and Victoria. Details regarding farm management, terrain, vegetation (between farm and receptor), receptor type, and dominant wind direction (for the NSW formula) were supplied by the modelling consultant. Alternate separation distances were calculated whenever the project team did not agree with the terrain descriptions suggested by the modelling consultant (who provided the data). Copies of the spreadsheet for each of the five farms are included in Appendix 8.

The following distances were tabulated for each farm (see Figure 50 for an example). It was assumed that separation distances originated from the centre of the shed cluster, rather than the odour centroid, because orientation of the tunnel fans was unknown. The distances calculated were:

- distance from the farm to each receptor;
- separation distance calculated using each of the separation distance formulas in the direction of each receptor;
- distance from the farm to the Calpuff derived odour contour (Qld odour impact criteria, 2.5 OU, 1 hr, 99.5th percentile) in the direction of each receptor;
- distance from the farm to the furthest point on the Calpuff derived odour contour (Qld odour impact criteria, 2.5 OU, 1 hr, 99.5th percentile); and
- separation distance calculated using the Qld separation distance formula in the direction of the furthest point on the odour contour.

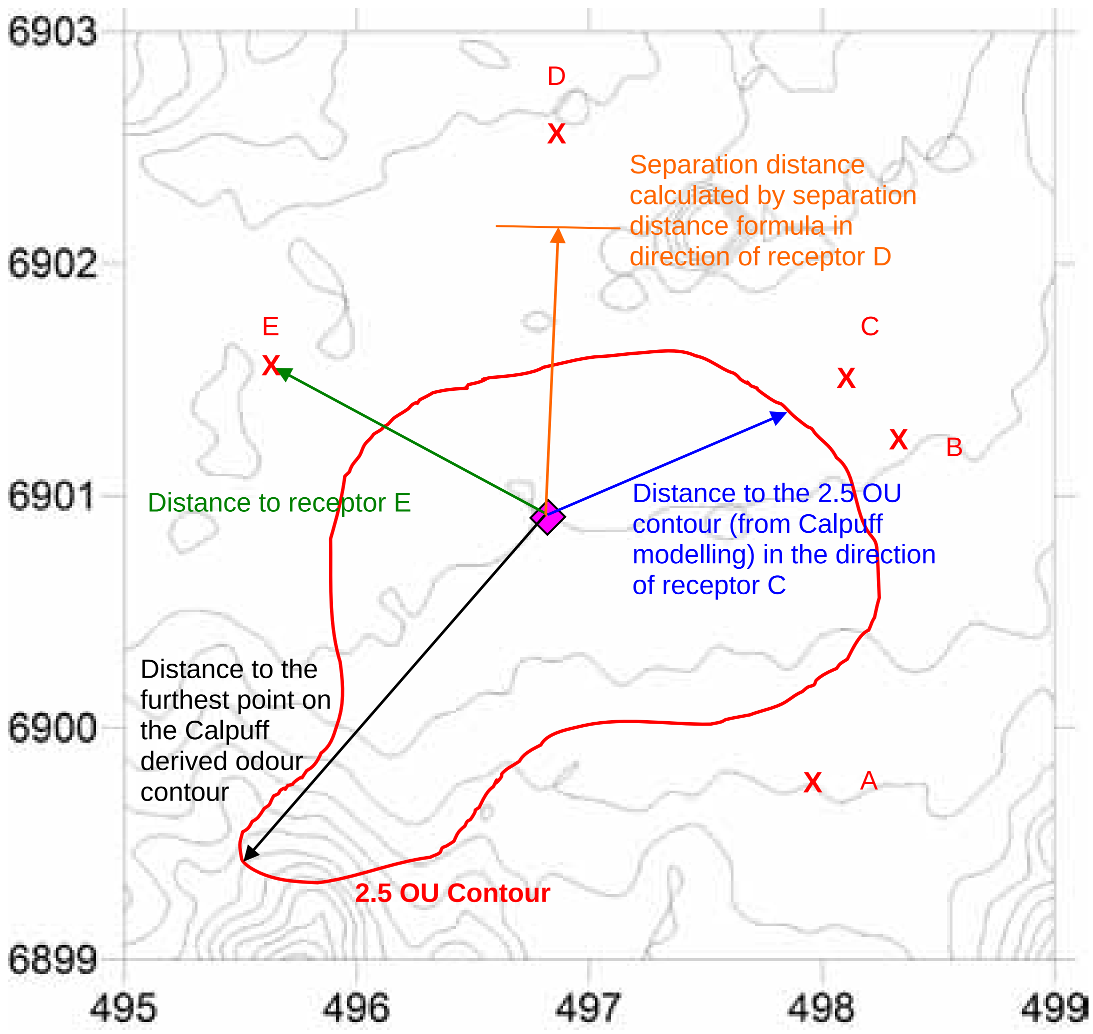

Figure 50: An example of the information used during the assessment between Calpuff modelling (using Qld odour impact criteria) and separation distance formulas

When applying the proposed Queensland separation formula, it was necessary to calculate a farm rating in order to determine the value for *S1* (see Equation 3). Each of the five farms represented the best available design and management (i.e. best available design, nipple drinkers with evaporation trays, automated shed environment control with alarms, litter inspected and topped up daily, average litter depth greater than 45 mm at the start of the batch and maximum shed airspeed exceeding 2.5 m/s). Consequently, each farm had an *S1* value of 1.0. Values for *S2* to *S4* are presented in the spreadsheet summaries in Appendix 8.

Modelling hypothetical broiler farms with Calpuff and calculating separation distances

In a separate exercise to the comparison between CFD and Calpuff models, Calpuff was used to model hypothetical broiler farms using a variety of different inputs and configurations. Odour impact contours were prepared according to the Queensland odour impact criteria (2.5 OU, 1 hr, 99.5th percentile). This contour was compared with distances calculated using the proposed Queensland separation distance formula. Two experienced Calpuff modelling consultants were engaged to undertake this work. Detailed reports from these modellers have been included in Appendix 6 and Appendix 7.

The hypothetical farms included sheds that were 153 m long, 15 m wide (internal), with 2.7 m tall walls and 4.5 m high roof apex. Each shed housed 43,750 birds. Maximum shed ventilation rate was

112 m³/s (403,200 m³/hr), which would deliver a maximum in-shed airspeed of 3 m/s (assuming that ceiling baffles were installed at 2.4 m above the floor). The farm was modelled with four and eight sheds (175,000 birds and 350,000 birds respectively) to assess the changes in predicted odour impacts with farm size. It should be noted that 350,000 birds exceeds the recommended limit of 320,000 birds stated in the proposed Qld separation distance formula, but was chosen to test the limits of the formula in light of the fact that new broiler farms are likely to be larger rather than smaller.

Odour emission rates were estimated using the method described by Ormerod and Holmes (2005). A K-factor of 2 (as described by these authors) was chosen to represent a modern farm using 'best practice' design and management. A thinning regime was adopted where birds were harvested from the shed on day 35, and again on another day until all birds were harvested on day 56.

Modelling domains relating to the major broiler production regions in southeast Queensland were chosen. These domains included areas to the south, west and north of Brisbane (near Beaudesert, Esk, Redland Bay and Caboolture). Some of the hypothetical farms were modelled in two different locations within the domain, with the farms surrounded by different terrain and land uses, to assess the influence of these on odour dispersion and calculations using the separation distance formula.

As there is no standard, commonly agreed methodology for modelling odour dispersion from broiler farms, each of the hypothetical farms was modelled with Calpuff using the following configurations:

1. point source with emission temperature estimated using ambient temperatures (to simulate no plume buoyancy);

2. point source with emission temperature estimated using production target temperatures (to simulate plume buoyancy); and

3. volume source (no plume temperature inputs leads to no buoyancy).

Separation distances determined using each of these three configurations were tabulated for comparison with the proposed Qld separation distance formula because each configuration was expected to produce a different, but equally acceptable result.

The proposed Qld separation distance formula was used to calculate separation distances from the hypothetical farms. No 'receptors' surrounded the farm. Instead, points on the 2.5 ou contour were selected for comparison with the formula. These points were selected wherever the contour was at an extended distance from the sheds or where terrain or surface roughness may have resulted in very short distances calculated with the formula. These two conditions were chosen because they represented the most likely situations for the separation distance formula to calculate shorter (less conservative) separation when compared with Calpuff. The distances to the 2.5 ou contour were measured from the centre of the odour centroid (between the two middle sheds and 25 m downstream of the tunnel ventilation fans). This is slightly different to the way that the proposed Queensland separation distance formula is supposed to be measured (from the odour centroid closest to the receptor); consequently, separation distances should not be considered as absolute values, rather an approximate value.

Results and Discussion

Comparison of Calpuff and separation distance formulas for existing farms

Table 11 presents the results from the assessment of the five broiler farms using the proposed Qld separation distance formula as well as the formulas used by NSW, Vic and SA. Based on data provided by the modelling consultant, the distance from the centre of the sheds to the 2.5 ou boundary (from Calpuff modelling) was compared to the proposed Qld separation distance formula. While the estimations of separation distance from the formulas have been compared against Calpuff, it must be remembered that dispersion modelling must not be considered as a ‘pass’ or ‘fail’ test of odour impact potential due to uncertainties and limitations in the modelling (Environmental Protection Agency (Queensland Government), 2004)

Cells have been shaded in Table 11 to highlight situations when the proposed Qld formula calculated a shorter distance than the Calpuff modelling. Assuming that Calpuff’s prediction of odour impact potential is correct, underestimation by the separation distance formula may result in reduced protection for receptors. This situation occurred for Farm B (in the direction of five of eight receptors, although the difference for one of the receptors was negligible) and for Farm E (in the direction of only one of the receptors).

While the proposed Queensland separation distance formula underestimated the required separation distances in a limited number of cases (compared to Calpuff predictions), it predicted larger, more conservative estimations for the majority of the receptors (75%). In some instances, the estimated separation distance was nearly four times greater than the distance predicted by Calpuff; which would help to ensure minimal odour impacts would be likely to occur.

Also in Table 11, distances to the receptor have been highlighted using a ‘##’ symbol when the distance to the receptor was less than the distance required by the proposed Queensland formula. This occurred for one receptor at Farm A, one receptor at Farm C, three receptors at Farm D and one receptor at Farm E. Had the proposed Queensland separation formula been used to assess these broiler farms, the separation distance to the receptors would have been inadequate, prompting the developer to find an alternative site, reposition the sheds on the property, or engage a consultant to perform site specific odour modelling (possibly with Calpuff).

Comparing the separation distances calculated using the various interstate methods, the proposed Qld formula predicted similar distances to the SA formula, larger (sometimes much larger) distances than the Vic formula, but shorter distances than the NSW formula.

Table 11: Separation distances between broiler farms and receptors calculated using various methods

Farm	Receptor	Distance to receptor	Distance to Calpuff 2.5 odour unit boundary	Separation distance formulas			
				Queensland	New South Wales	South Australia	Victoria
Farm A	1	1330	276	625	1268	553	472
	2	1650	143	625	1268	553	472
	3	1750	143	625	1268	553	472
	4	1900	255	999	1268	885 (553*)	472
	5	1580	337	999	1268	885	472
	6	1040	306	999	1268	885	472
	7	740##	255	999	1268	885	472
Farm B	1	1780	895	531	888 (986*)	470	472
	2	1840	743	531	986	470	472
	3	2130	533	531	986	470	472
	4	1410	381	531	986	470	472
	5	1590	438	625	1268	553	472
	6	1650	914	625	1268	553	472
	7	1850	1105	531	986	470	472
	8	1630	1524	531	986	470	472
Farm C	1	1694	349	937	1268	829	472
	2	1860	358	937	1268	829	472
	3	1414	413	796 (531*)	986	705 (470*)	472
	4	1200	670	796	986	705	472
	5	837##	284	937	1268	829	472
Farm D	1	700	532	697	1010	611	520
	2	900##	944	1045	1732	917	520
	3	740##	667	1045	1732	917	520
	4	740##	651	1045	1732	917	520
Farm E	1	370##	162	581 (625*)	804 (893*)	514	472
	2	1030	267	531	695	470	472
	3	926	448	531	695	470	472
	4	1623	714	531	695	470	472
	5	1075	610	937 (625*)	893	829	472

Notes: * indicates alternative separation distance due to the project team selecting a 'more appropriate' description of the terrain than was suggested by the consultant.
SHADED **cells indicate that the proposed Qld separation distance formula was less conservative than the Calpuff predicted odour separation requirement.**
indicates that the proposed Qld separation distance formula required a larger separation distance than was available (between the farm and receptor)

If the proposed Qld separation distance formula had been used for the odour impact assessment of these five farms:

- Four of the five farms (A, C, D and E) would be unlikely to have been immediately approved due to at least one receptor being closer than the separation distance calculated by the formula (Qld). This would have prompted the developer to undertake a site specific odour impact assessment (with dispersion modelling) or reconsider the location or orientation of the farm/sheds. Repositioning the sheds and repeating the assessment with the separation distance formula may have been sufficient for the farm to comply. **Regardless of what action was chosen, the formula would have provided adequate protection for the receptors at these farms.**

- Farm B could have been approved on the basis of the formula, simply because the receptors were located at sufficient distance from the sheds. With the benefits of having Calpuff modelling predictions, it can be seen that for six of the eight receptors, the formula estimated a shorter separation distance than was required by the Calpuff simulation. Potentially, receptors could have been much closer to the sheds (closer to the shed than the 2.5 ou contour) and the farm could still have been approved on the basis of the formula. If this occurred the receptors may have been put at increased risk of odour impacts (but this assumes that the Calpuff modelling accurately simulated the potential for odour impacts).

- The formula provided conservative estimates of separation distances for 75% of the receptors.

- Alternate interpretation of the inputs to the formula (terrain and land use factors in particular) would have had no bearing on the outcomes of an odour impact assessment.

Other important conclusions that can be drawn from this exercise include:

- Despite the fact that the shed design/management rating was the lowest possible value (*S1 = 1.0*), separation distances calculated by the proposed Queensland formula in the majority of cases were similar or more conservative than the separation distances predicted using Calpuff, sometimes more conservative by a factor of up to four times. Combined with the fact that new intensive broiler farms are built and operated to standards that exceed many of the options in the proposed method (Queensland Chicken Growers Association, 2005) (i.e. new facilities use only nipple drinkers; only automatic control systems with alarms; only adequately insulated and sealed sheds; and maximum airspeed exceeding 2.5–3.0 m/s), it seems that there is no requirement for *S1* to exceed a value of 1.0.

- The method used in NSW calculates much greater separation distances than the proposed Qld method. This method was designed to meet the air quality objectives in NSW, but calculates excessive separation distances when compared with dispersion modelling to the odour impact criterion in Qld. The SA method appears to be relatively comparable with the proposed Qld method. The Vic method is completely insensitive to terrain and other natural features that will influence odour dispersion, and tends to under-estimate separation requirements in many cases (compared to Calpuff modelling performed against the Qld odour impact criterion).

- Farm B appeared to be an unusual case. Despite all of the receptors being at the same or higher elevation to the sheds, which is usually associated with reduced possibility of odour impacts, Calpuff predicted relatively long separation distances. Even the NSW formula, which calculated much larger distances than the proposed Qld method, did not produce sufficient separation distances for two of the receptors.

  A wind rose for this farm (see Appendix 6) shows that a relatively high proportion of low speed winds (0.1–2.0 m/s) may have contributed to the extensive 2.5 ou contour. Inclusion of a low wind speed frequency factor (which is different to the prevailing wind/wind frequency factor in the NSW method) may improve estimation of separation distances when using the separation distances formulas in cases like Farm B; however, this would reduce the usability of formula because specific wind data would need to be acquired.

- Comparison of the proposed Queensland separation distance formula with the furthermost point on the Calpuff 2.5 ou contour demonstrated that, with the exception of Farm B, the formula predicted a similar (within 20%) or larger separation than Calpuff.

Comparison between Calpuff and separation distance formulas for hypothetical farms

Full details of the Calpuff modelling of hypothetical Farms A to E, including comprehensive results, are given in Appendix 6 and Appendix 7.

Transects were drawn in each domain to correspond with particular features on the 2.5 ou contour line. Along each transect, the distance from the odour centroid (nominated to be 25 m downwind from the tunnel ventilation fans) to the 2.5 ou contour was measured. The proposed Qld separation distance formula was applied along each transect for comparison to the Calpuff modelling. Aerial pictures of the hypothetical farms showing the position of transects, as well as the separation distances derived from Calpuff and separation distance formulas are summarised in the following sections (and full details are provided in Appendix 9).

Each of the hypothetical farms was modelled in Calpuff using three different, yet equally acceptable Calpuff configurations (point source with ambient emission temperatures, point source with target production temperature emissions and volume source) and the resulting separation distances have been tabulated in the following sections for comparison with the proposed Qld separation distance formula. Emission temperatures were estimated using ambient and target production temperatures to evaluate the difference when modelling without thermal buoyancy and with thermal buoyancy respectively. Each of the three Calpuff configurations must be independently and equally compared with the proposed Qld formula because there is no singular, preferred modelling methodology.

Domain A

Domain A represents a broiler growing area located approximately 60 km west of Brisbane. Figure 51 shows the hypothetical farm in position 1, including terrain contours, an example of the Calpuff outputs and six transects for comparison between the different separation distance methods. Figure 52 shows the farm in position 2.

Full details of Domain A are provided in Appendix 6.

Full details of the separation distance formula calculations and Calpuff outputs for Domain A are provided in Appendix 9 (refer to Appendix 9 Figure 1 to Appendix 9 Figure 6 for position 1 and Appendix 9 Figure 7 to Appendix 9 Figure 12 for position 2).

Figure 51: Hypothetical farm in Domain A, position 1: including terrain contours; odour contours (modelled with 175,000 birds with ambient emission temperature) using Qld odour guidelines; and the six transects for application of the separation distance formula

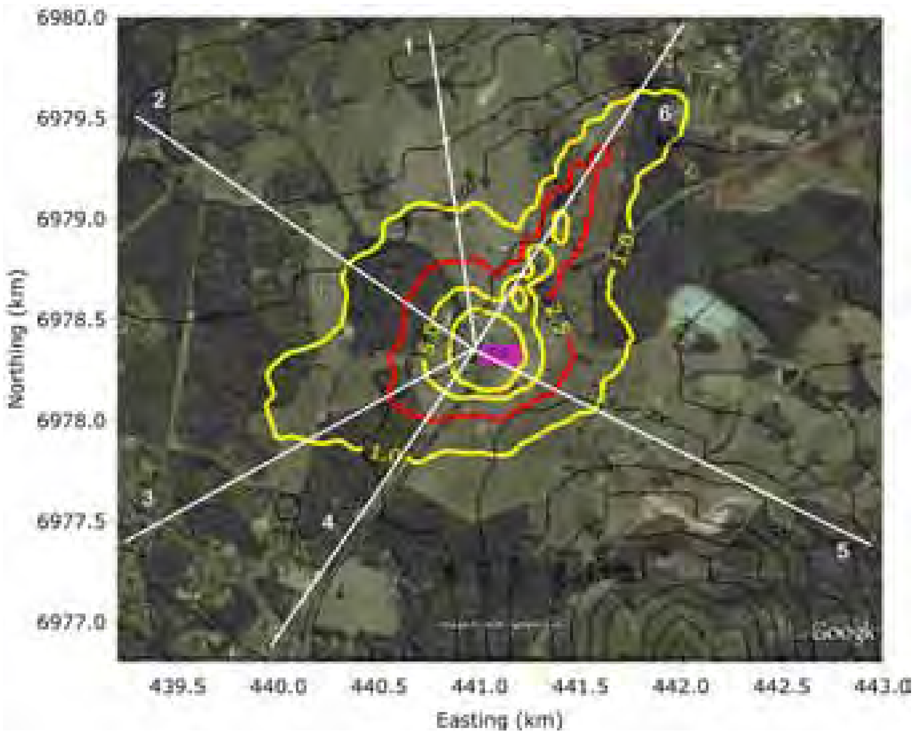

Figure 52: Hypothetical farm in Domain A, position 2: including terrain contours; odour contours (modelled with 175,000 birds with ambient emission temperature) using Qld odour guidelines; and the six transects for application of the separation distance formula

The distances measured along each transect from Calpuff modelling (using different emission temperatures and volume source configuration) and the separation distance formula are summarised in Table 12.

In Table 12, cells have been shaded where the distances calculated by the separation distance formula were shorter than those predicted by Calpuff; potentially indicating that the formula would provide less protection against odour nuisance for neighbours oriented in that direction from the farm.

Table 12: Domain A: Separation distances for hypothetical farms in along defined transects; calculated using Calpuff (using different emission temperatures and source description) and the proposed Qld separation distance formula

Farm	Number of birds	Transect	Direction (°)	Separation distance along transect (m)			
				Calpuff			Proposed Qld separation formula
				Ambient Emission Temperature	Production Emission Temperature	Volume source	
Position 1	175,000	1	326	1320	535	945	490
		2	302	630	505	690	735
		3	254	630	566	470	865
		4	155	708	504	945	865
		5	99	440	409	410	576
		6	42	315	283	380	576
	350,000	1	326	1732	1640	1200	743
		2	302	1670	725	1010	1114
		3	254	1025	787	790	1311
		4	155	1135	692	1070	1311
		5	99	567	535	535	874
		6	42	503	472	520	874
Position 2	175,000	1	352	450	395	380	865
		2	305	415	415	360	666
		3	242	495	450	395	490
		4	215	415	375	790	490
		5	116	377	470	450	576
		6	33	1205	520	880	576
	350,000	1	352	720	630	540	1311
		2	305	630	610	520	1009
		3	242	720	630	630	743
		4	215	555	470	935	743
		5	116	555	560	540	874
		6	33	1490	1205	1295	874

Notes: ***SHADED*** **cells indicate that the proposed Qld separation distance formula was less conservative than the Calpuff predicted odour separation requirement.**

Summary for Domain A

In Domain A, the proposed separation distance formula worked well at calculating more conservative separation distances than Calpuff (for five of the six transects at both farm positions). For one transect at each farm position (transect 1 at position 1 and transect 6 at position 2), the separation distance formula consistently calculated shorter distances than Calpuff. Reasons for the odour contour extending for such a long distance cannot be confirmed, but are most likely related to the terrain and dominant low wind speeds in the directions of these transects.

Distances predicted by Calpuff varied according to the emission temperature assumptions and volume source configuration. In general, the assumption that emission temperature was equal to ambient temperature resulted in longer separation distances compared to production temperatures.

Domain B

Domain B represents a broiler growing area located south of Brisbane. Figure 53 shows the hypothetical farm in position 1, including terrain contours, an example of the Calpuff outputs and six transects for comparison between the different separation distance methods. Figure 54 shows the farm in position 2.

Full details of Domain B are provided in Appendix 6.

Full details of the separation distance formula calculations and Calpuff outputs for Domain B are provided in Appendix 9 (refer to Appendix 9 Figure 13 to Appendix 9 Figure 18 for position 1 and Appendix 9 Figure 19 to Appendix 9 Figure 24 for position 2).

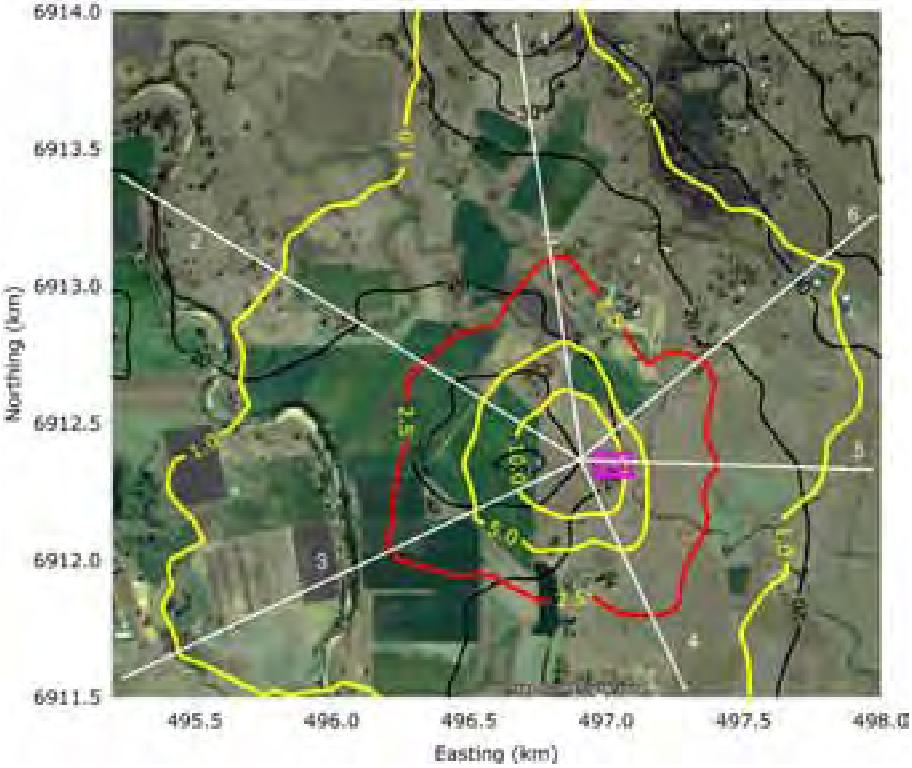

Figure 53: Hypothetical farm in Domain B, position 1: including terrain contours; odour contours (modelled with 175,000 birds with ambient emission temperature) using Qld odour guidelines; and the six transects for application of the separation distance formula

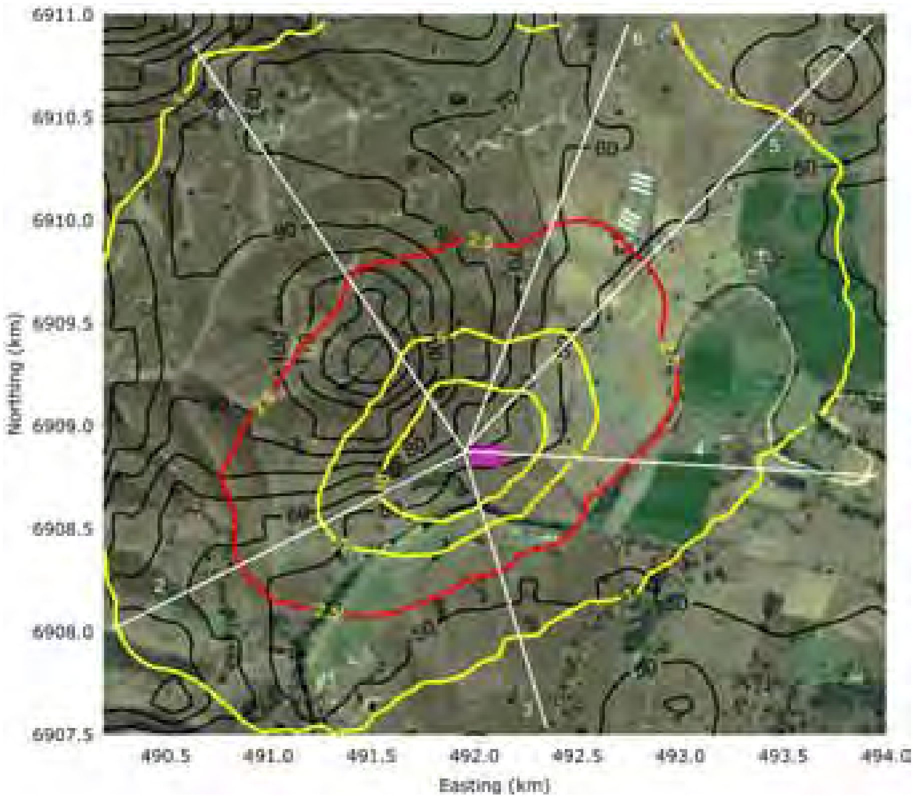

Figure 54: Hypothetical farm in Domain B, position 2: including terrain contours; odour contours (modelled with 175,000 birds with ambient emission temperature) using Qld odour guidelines; and the six transects for application of the separation distance formula

The distances measured along each transect from Calpuff modelling (using different emission temperatures and volume source configuration) and the separation distance formula are summarised in Table 13.

In Table 13, cells have been shaded where the distances calculated by the separation distance formula were shorter than those predicted by Calpuff; potentially indicating that the formula would provide less protection against odour nuisance for neighbours oriented in that direction from the farm.

Table 13: Domain B: Separation distances for hypothetical farms in along defined transects; calculated using Calpuff (using different emission temperatures and source description) and the proposed Qld separation distance formula

Farm	Number of birds	Transect	Direction (°)	Separation distance along transect (m)			
				Calpuff			Proposed Qld separation formula
				Ambient temperature	Production temperature	Volume source	
Position 1	175,000	1	353	725	430	820	865
		2	300	635	410	860	576
		3	241	780	465	875	576
		4	155	670	335	931	576
		5	94	505	280	745	576
		6	52	560	225	820	576
	350,000	1	353	1695	1770	1625	1311
		2	300	1080	782	1920	874
		3	241	1190	690	1420	874
		4	155	1045	390	1120	874
		5	94	840	560	1025	874
		6	52	1005	465	1175	874
Position 2	175,000	1	327	1000	900	975	576
		2	242	1180	1000	1155	576
		3	161	615	410	770	576
		4	94	820	565	975	576
		5	44	1285	1205	1282	576
		6	22	1205	1155	1075	576
	350,000	1	327	1845	1745	1665	874
		2	242	1720	1745	1665	874
		3	161	820	641	925	874
		4	94	1280	871	1230	874
		5	44	2051	1975	1925	874
		6	22	1975	1925	2050	874

Notes: ***SHADED* cells indicate that the proposed Qld separation distance formula was less conservative than the Calpuff predicted odour separation requirement.**

Summary for Domain B

In Domain B, the separation distance formula seemed to be less effective at calculating conservative separation distances when compared to Domain A. For Domain B, position 1, the separation distance formula worked reasonably well when compared with the Calpuff predictions when using production temperatures for emission temperatures. Even when using ambient emission temperatures, the separation distance formula calculated separation distances within 100-200 m of the Calpuff predictions. In position 2, however, the separation distance formula predicted comparable separation distances along two of the six transects (transects three and four), but fell short on the remaining four).

As with Domain A, there was considerable variability in the separation distances estimated by Calpuff, especially in position 1. Also, the use of production emission temperatures resulted in slightly shorter separation distances compared with using ambient emission temperatures.

Domain C

Domain C represents a broiler growing area located north of Brisbane. Figure 55 shows the position of the hypothetical farm, including terrain contours and six transects for comparison between the different separation distance methods.

Full details of Domain C are provided in Appendix 7.

Full details of the separation distance formula calculations and Calpuff outputs for Domain C are provided in Appendix 9 (refer to Appendix 9 Figure 25 to Appendix 9 Figure 30).

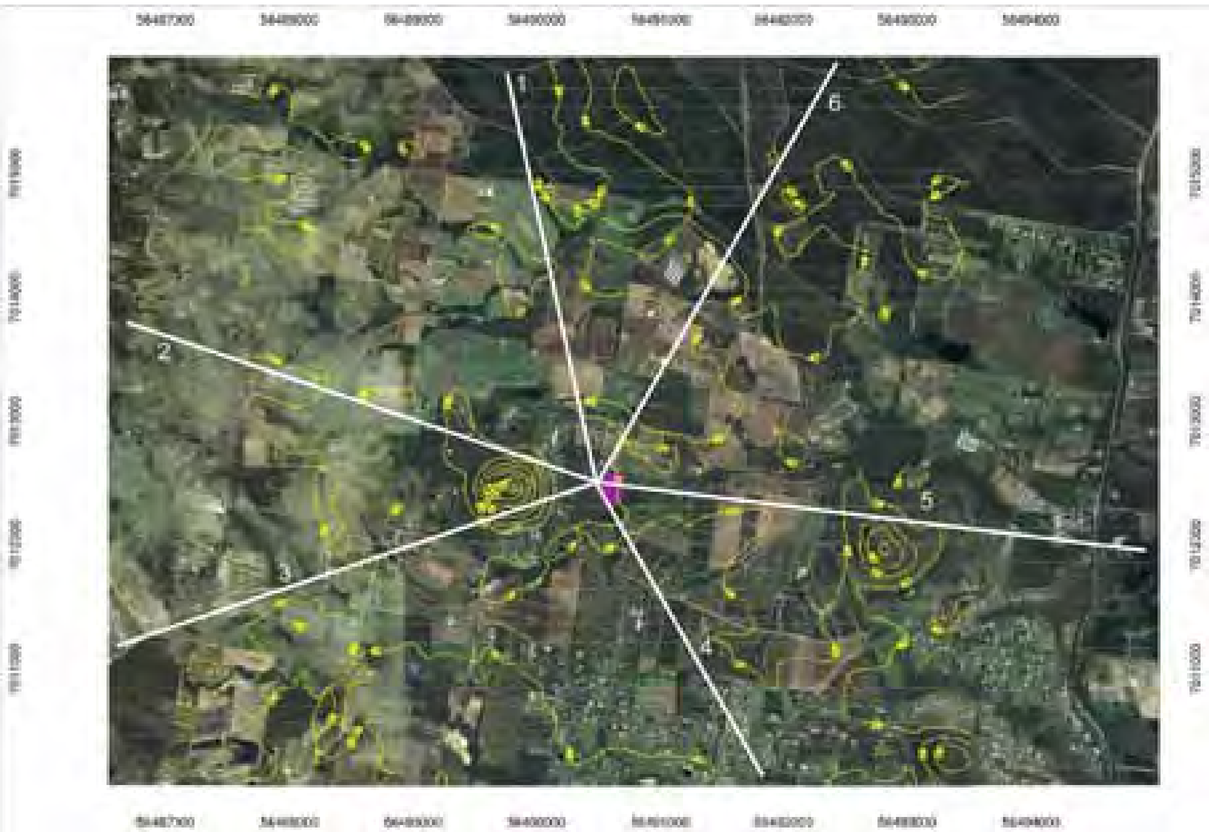

Figure 55: Hypothetical farm in Domain C: including terrain contours and the six transects for application of the separation distance formula

The distances measured along each transect from Calpuff modelling (using different emission temperatures and volume source configuration) and the separation distance formula are summarised in Table 14.

In Table 14, cells have been shaded where the distances calculated by the separation distance formula were shorter than those predicted by Calpuff; potentially indicating that the formula would provide less protection against odour nuisance for neighbours oriented in that direction from the farm.

Table 14: Domain C: Separation distances for hypothetical farms in along defined transects; calculated using Calpuff (using different emission temperatures and source description) and the proposed Qld separation distance formula

Number of birds	Transect	Direction (°)	Separation distance along transect (m)			
			Calpuff			Proposed Qld separation formula
			Ambient temperature	Production temperature	Volume source	
175,000	**1**	**348**	1045	1008	185	490
	2	**289**	1005	1045	185	444
	3	**251**	1045	930	225	444
	4	**151**	970	1005	205	490
	5	**98**	785	560	185	490
	6	**30**	1195	1005	185	490
350,000	**1**	**348**	1305	1305	525	743
	2	**289**	1567	1605	375	673
	3	**251**	1830	1790	375	673
	4	**151**	1530	1380	305	743
	5	**98**	1305	1120	225	743
	6	**30**	1865	1565	450	743

Notes: ***SHADED*** **cells indicate that the propose Qld separation distance formula was less conservative than the Calpuff predicted odour separation requirement.**

Summary for Domain C

In Domain C, the separation distance formula did not appear to be effective at calculating conservative separation distances. Along all transects, the formula calculated distances that were approximately half the size of the ones predicted by Calpuff.

There was considerable variability between the separation distances predicted by Calpuff using the volume source configuration and short stacks configurations, with the volume source configuration requiring substantially shorter distances. As with Domains A and B, the use of production emission temperatures generally resulted in slightly shorter predictions of separation distance compared with using ambient emission temperatures.

Domain D

Domain D represents a coastal broiler growing area located just south of Brisbane. Figure 56 shows the position of the hypothetical farm, including terrain contours and six transects for comparison between the different separation distance methods.

Full details of Domain D are provided in Appendix 7.

Full details of the separation distance formula calculations and Calpuff outputs for Domain D are provided in Appendix 9 (refer to Appendix 9 Figure 31 to Appendix 9 Figure 36).

Figure 56: Hypothetical farm in Domain D: including terrain contours and the six transects for application of the separation distance formula

The distances measured along each transect from Calpuff modelling (using different emission temperatures and volume source configuration) and the separation distance formula are summarised in Table 15.

In Table 15, cells have been shaded where the distances calculated by the separation distance formula were shorter than those predicted by Calpuff; potentially indicating that the formula would provide less protection against odour nuisance for neighbours oriented in that direction from the farm.

Table 15: Domain D: Separation distances for hypothetical farms in along defined transects; calculated using Calpuff (using different emission temperatures and source description) and the proposed Qld separation distance formula

Number of birds	Transect	Direction (°)	Separation distance along transect (m)			
			Calpuff			Proposed Qld separation formula
			Ambient temperature	Production temperature	Volume source	
175,000	1	0	515	430	60	490
	2	308	371	285	60	490
	3	248	460	315	60	490
	4	163	540	371	285	490
	5	100	400	315	285	490
	6	28	485	460	315	490
350,000	1	0	660	515	457	743
	2	308	485	485	455	743
	3	248	828	600	660	743
	4	163	660	660	742	743
	5	100	715	630	742	743
	6	28	630	571	685	743

Notes: ***SHADED*** **cells indicate that the propose Qld separation distance formula was less conservative than the Calpuff predicted odour separation requirement.**

Summary for Domain D
In Domain D, the separation distance formula appeared to be very effective at calculating conservative separation distances. Along all transects, the formula calculated longer separation distances than those predicted by Calpuff (except for a few instances when ambient temperatures were used as the emission temperature). As with Domains A, B and C, the use of production temperatures to estimate emission temperatures resulted in slightly shorter separation distances.

Effect of emission temperature and source configuration on predicted odour impacts using Calpuff at hypothetical farms

Selection of emission temperature (when representing the source using stacks) had a considerable influence on the prediction of separation distances when using Calpuff. Setting the emission temperatures equal to target production temperatures had the effect of shortening the required separation distances compared to using ambient emission temperatures for 80–90% of the transects. Figure 57 is a histogram summarising the percentage *increase* in separation distances when emission temperature was set to production temperatures rather than ambient temperature. The average reduction in separation distance by using production temperatures was 18%, but in some instances the reduction in separation distance was by 50–60%.

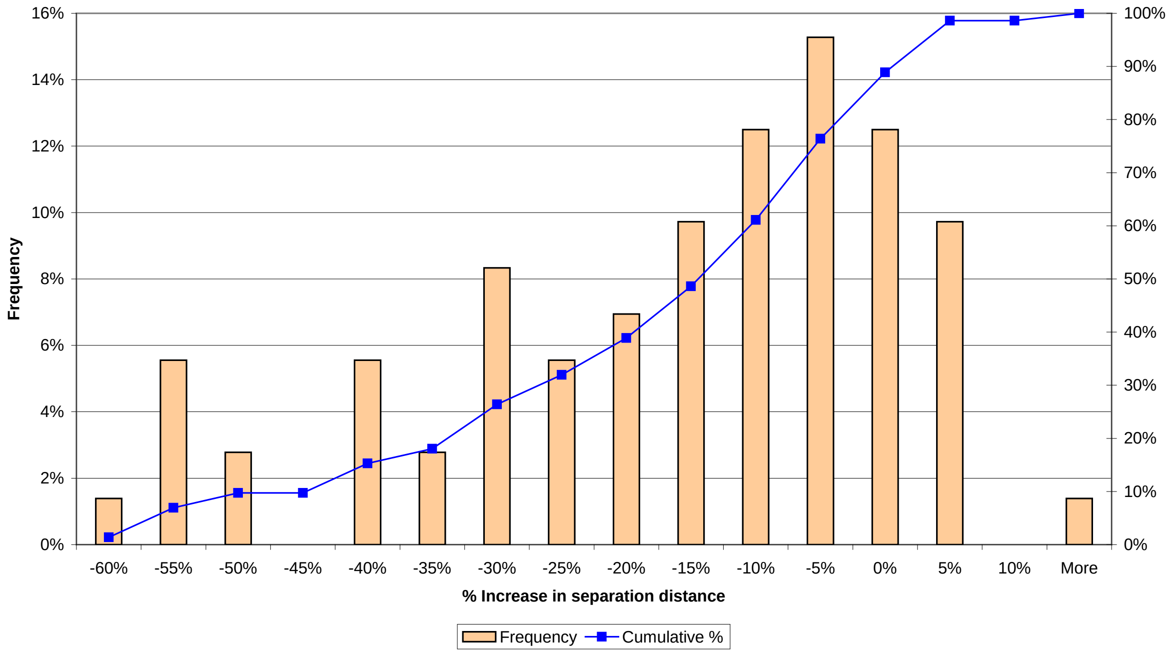

Figure 57: Histogram summarising the percentage increase in separation distances due to modelling with emission temperatures equal to production temperature rather than ambient temperature.

Source configuration also had an effect on the prediction of separation distances. The use of a volume source configuration produced a more uniform (circular) buffer zone around the farm compared to when the farm was modelled using point sources.

These findings demonstrate that model configuration is critical to accurately simulate odour plumes to predict the likelihood of odour nuisance, and begs the question as to which configuration most likely represents ‘true’ odour impacts.

In this exercise, odour emission rates used in Calpuff were estimated using the method described by Ormerod and Holmes (2005). An assumption has been made that these emission rates are typical for modern broiler farms. Selection of an alternate method for estimating emission rates, or better still using actual broiler shed emission rates (if they were available), is likely to result in different Calpuff predictions of separation distances.

There was a large range of separation distances observed in the Calpuff modelling (see Table 16). For farms with 175,000 birds, separation distances ranged from 60–1285 m and for farms with 350,000 birds, separation distances ranged from 225–2050 m. Since farms of the same size were modelled using similar emission rates, variability in separation distances was most likely due to terrain and weather influences.

Table 16: Minimum and maximum separation distances for each hypothetical farm (for the separation distance formula, the maximum range was recorded (Farm rating S1=1, sensitive receptors and excluding upslope valley drainage)

Farm Size	Farm	Range of separation distances (m)			
		Qld separation formula (Max range)	Calpuff (to 2.5 ou contour)		
			Ambient emission temp	Production emission temp	Volume source
175,000	A1	444 – 922	315 – 1320	283 – 566	380 – 945
	A2		377 – 1205	375 – 520	360 – 880
	B1		505 – 780	225 – 465	820 – 931
	B2		615 – 1285	410 – 1205	770 – 1282
	C		785 – 1195	560 – 1080	185 – 225
	D		371 – 540	285 – 460	60 – 285
350,000	A1	673 – 1398	503 – 1732	472 – 1640	520 – 1200
	A2		555 – 1490	470 – 1205	520 – 1295
	B1		840 – 1695	390 – 1770	1025 – 1920
	B2		820 – 2051	641 – 1975	925 – 2050
	C		1305 – 1865	1120 – 1605	225 – 525
	D		485 – 828	485 – 660	457 – 742

The range of separation distances that can be calculated with the separation distance formula generally covered the range of separation distances determined using Calpuff, but the formula did not correspond to the most extreme values.

Assessment of the effect of farm size on prediction of separation distances

Effect of farm size on separation distance

When the farm size was doubled (for each hypothetical farm) the separation distance requirement increased. Using the separation distances predicted by Calpuff, the magnitude of this increase was calculated using a ratio of the separation distances along each transect.

Figure 58 shows that when the farm size was doubled, the separation distance increased by a factor of 1.2 to 2.0 in the majority of cases. The average of these results was a ratio of 1.51 (ratios above 2 were excluded to prevent high values from having strong leverage on the data). Coincidently, this is the same as $2^{0.6}$, which is the same exponent used in the proposed Qld separation distance formula (see Equation 3). This finding supports the use of the 0.6 exponent in the proposed formula and demonstrates that doubling the emission source is unlikely to double the required separation distance.

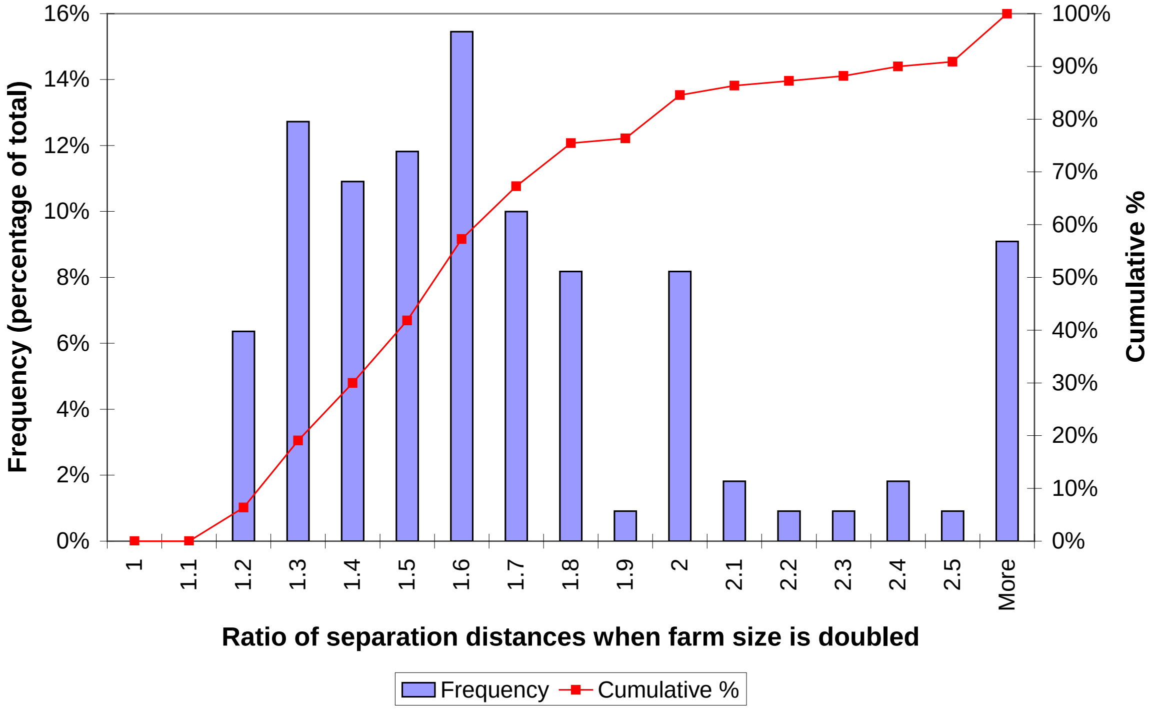

Figure 58: Histogram of the ratio between Calpuff separation distances when farm size was doubled

Effect of farm size on the comparison between Calpuff and the proposed Qld separation distance formula

Overall, the proposed Qld separation distance formula calculated longer separation distances than Calpuff in 49% of cases when using ambient emission temperatures, 66% of cases when using production emission temperatures and 58% of cases when the shed was configured as a volume source. The data was then divided according to farm size.

Rather than simply being a pass-fail test for the separation distance formula (where pass indicated that the formula calculated a larger separation distance than Calpuff), the ratio between the separation distances was calculated along each transect at each hypothetical farm. A ratio of 1.0 implies that the separation distance formula and Calpuff produced the same separation distance. Below 1.0, the separation distance formula calculated a smaller distance than Calpuff and above 1.0, the formula calculated a greater separation distance.

Figure 59 is a histogram summarising these ratios for the hypothetical farms with 175,000 birds and Figure 60 is for the hypothetical farms with 350,000 birds. Comparison of these two figures reveals only minor differences due to farm size. The histogram for 350,000 birds appears to be more heavily weighted for ratios less than 1.0, indicating more instances of the formula calculating smaller separation distances; however, at the critical point (ratio = 1.0), the percentage of failure (by the formula) for farms with 175,000 birds ranged from 31–53% (depending on Calpuff configuration) whilst for farms with 350,000 birds ranged from 36–56%. This demonstrates that the separation distance formula performed the same for the 350,000 bird farm despite this farm size being outside the recommended capability of the proposed Qld separation distance formula.

Based on this finding, the proposed Qld separation distance formula appears to be no less suitable for application to a proposed broiler farm with 350,000 birds as it is for 175,000 birds.

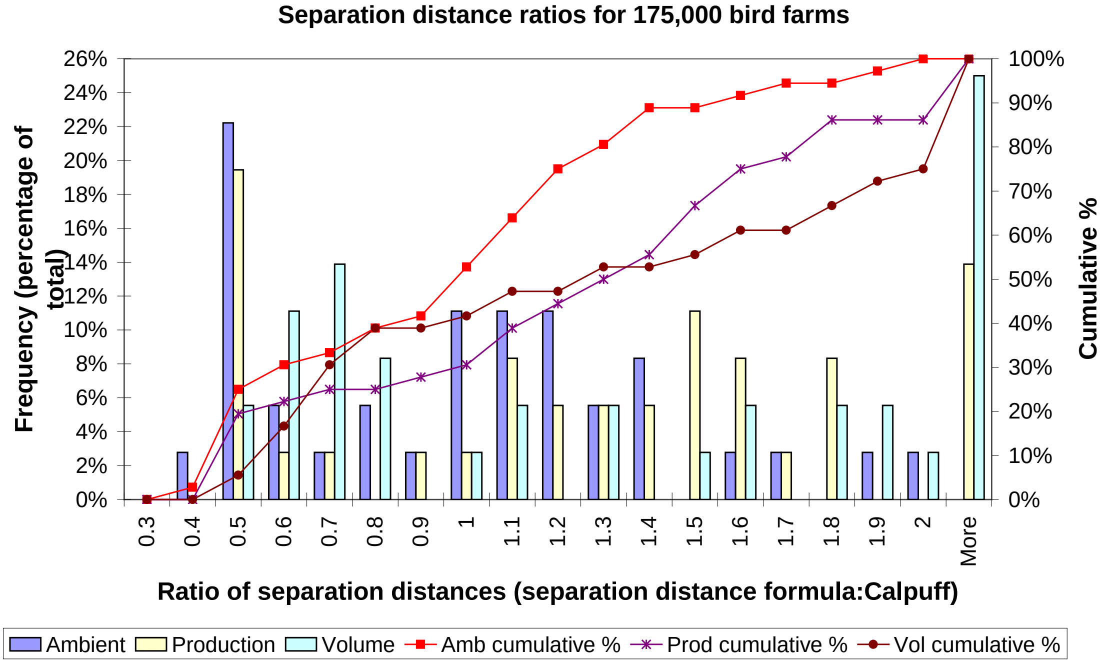

Figure 59: Histogram of the ratio between separation distances calculated from the proposed Qld separation distance formula and Calpuff for hypothetical farms with 175,000 birds

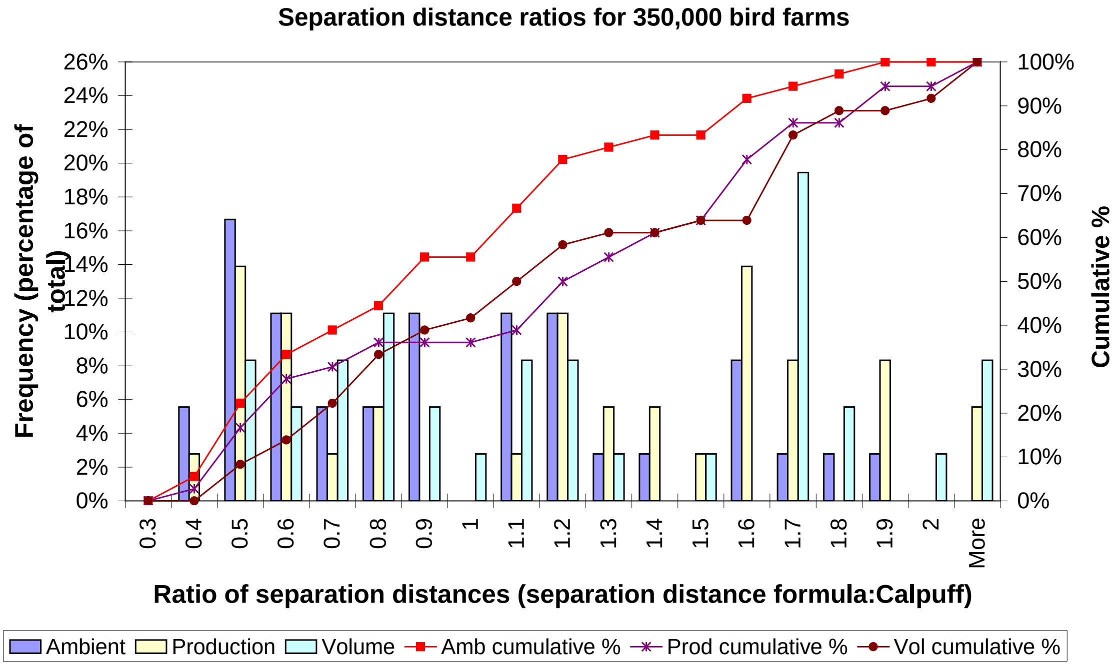

Figure 60: Histogram of the ratio between separation distances calculated from the proposed Qld separation distance formula and Calpuff for hypothetical farms with 350,000 birds

Could the proposed Queensland separation distance formula be improved?
During the comparison with existing and hypothetical broiler farms, the separation distance formula tended to under-estimate separation distances when:

- The farm was located on the side of a hill, in which case the 2.5 ou contour tended to extend around the hill (on the same elevation as the farm) rather than down the slope.
- When the surface roughness of the land surrounding the farm was considered to be grassy or 'long grass/few trees'.

To improve the calculation of separation distances using the formula in these situations, an alternative methodology was trialled whereby:

- The description of "Sloping terrain – down slope" was changed to include the cross-slope direction (for any receptor on the same or lower elevation, regardless of the position around a hill). For receptors meeting this condition, the multiplier assigned was 1.5.
- Surface roughness values were arbitrarily increased according to the following table:

Descriptor	Original multiplier	Alternative multiplier
Long grass/few trees	1	1.2
Level wooded country	0.85	1
Heavy timber	0.77	0.85

Applying this methodology reduced the number of the occurrences when the separation distance formula calculated shorter separation distances than Calpuff.

Figure 61 is a histogram summarising the ratio of separation distances using the original methodology and Figure 62 summarises the ratios with this alternate methodology. The peak at a ratio of 0.5 in Figure 61 was reduced with the alternate methodology, as was the percentage of occurrences when the separation distance formula calculated shorter separation distances than Calpuff (reduced from 33–54% with the original methodology to 22–35% with the alternate methodology). On the other hand, there was a substantial increase in the number of occurrences when the separation distance calculated by the formula was more than twice as large as the separation distance determined by Calpuff. This is a less than encouraging outcome and demonstrates that the methodology for the proposed Qld separation distance formula should not be flippantly adjusted without further testing and development.

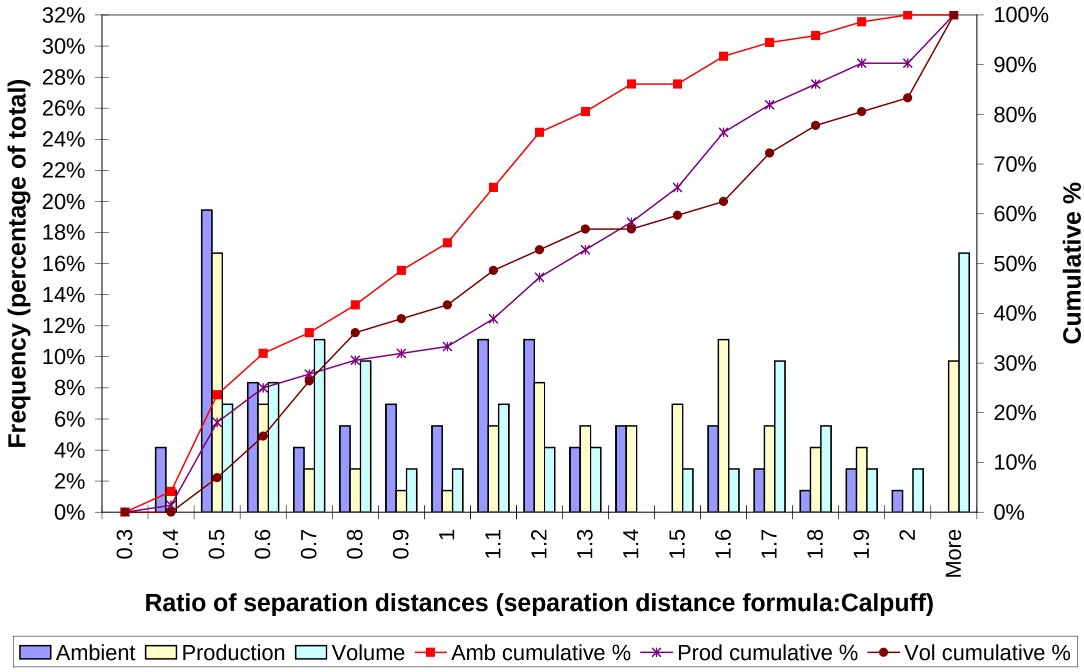

Figure 61: Histogram of the ratio between the separation distances calculated using the separation distance formula and Calpuff (Original methodology with various Calpuff emission temperatures and volume source configuration)

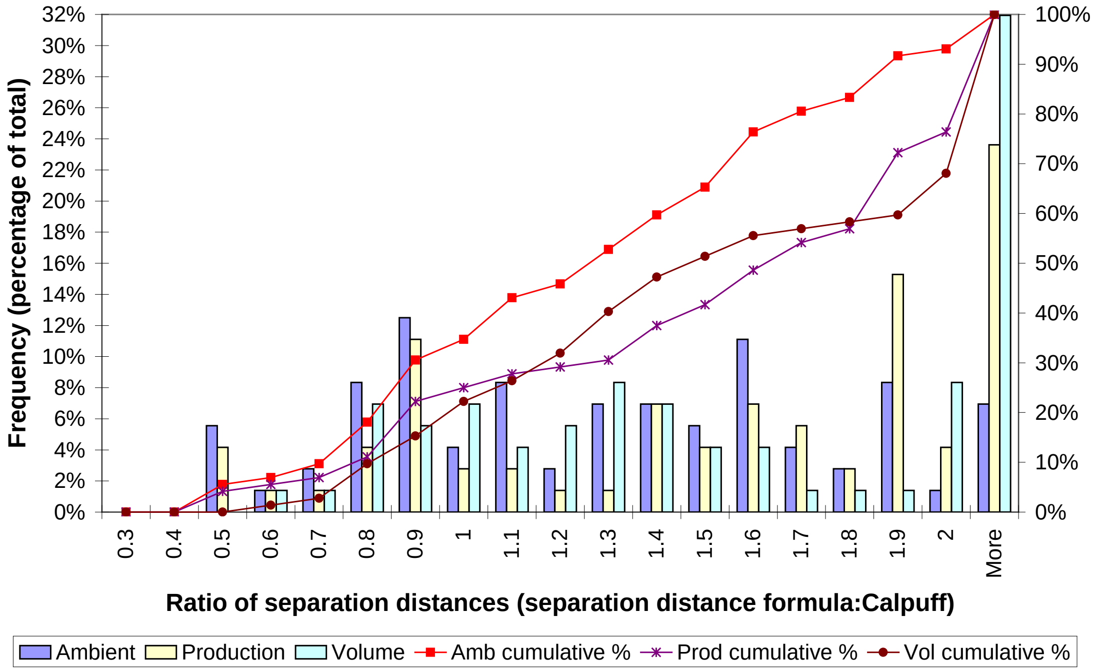

Figure 62: Histogram of the ratio between the separation distances calculated using the separation distance formula and Calpuff (Alternative methodology with various Calpuff emission temperatures and volume source configuration)

In addition to terrain and surface roughness effects, the separation distance formula tended to under-predict separation distances for farms that frequently experience low wind speeds and very stable atmospheric conditions. The wind roses and stability class information supplied with existing Farm B and hypothetical Farms A1, A2, B1, B2 and C (see Appendix 6 and Appendix 7) demonstrated greater occurrences of these conditions, corresponding to a greatly extended 2.5 ou contour (from Calpuff) in the direction of the low wind speeds. Consequently, the separation distance predictions by the separation distance formula may potentially be improved by including a low wind speed factor. However, based on the limited weather data supplied for the farms in this exercise, we are unable to recommend exactly what criteria should be used to define this factor, but a multiplier of 1.5 (as used in the NSW separation distance formula method) in the directions of dominant low wind speeds may improve the separation distance estimations by the proposed Qld separation distance formula. Unfortunately, the inclusion of a low wind speed factor would reduce the usability of the current formula because specific wind data would need to be acquired.

Summary of comparison between Calpuff and separation distance formulas for hypothetical farms

- The proposed Qld separation distance formula provided a relatively simple and transparent method to estimate separation distance requirements.
- For this exercise, Calpuff was chosen as a ‘superior’ modelling tool, against which the proposed Qld separation distance formula was assessed, but there was substantial variability in the Calpuff outputs due to selection of modelling inputs or configuration.
- In the majority of cases, the proposed Qld separation distance formula calculated larger, more conservative separation distances than Calpuff.
- In some instances, the proposed Qld separation distance formula calculated much shorter separation distances than Calpuff.
- Low wind speeds (interpreted from wind roses) tended to elongate the 2.5 ou contour in the Calpuff modelling, to which the separation distance formula calculated shorter separation distances.
- The separation distance formula tended to under-estimate separation distances (compared to Calpuff) when low wind speeds, low surface roughness and complex terrain (especially cross-slope wind fields) combined.
- The proposed Qld separation distance formula can be applied to farms up to 350,000 birds.

Conclusions

KEY FINDINGS

- The air exhausted from broiler sheds is frequently warmer than the ambient air (often by 2–10 °C).
- Poultry shed plumes that are warmer than ambient air are buoyant and rise.
- Calpuff does not appear to accurately model plume rise from broiler sheds (when compared to CFD modelling).
- When modelling hypothetical farms (using real terrain and weather data), emission temperature (ambient or production temperatures) influenced separation distances.
- The proposed Queensland separation distance formula calculated more conservative separation distances than Calpuff modelling in many instances, but also calculated shorter separation distances.

Thermal Buoyancy

- CFD modelling demonstrated that:
  - poultry shed plumes will rise, even when the exhausted air is only slightly warmer than ambient (e.g. 2 °C). This finding questions the practice of neglecting the effects of thermal buoyancy when modelling broiler shed plumes;
  - when the exhausted air was 6–10 °C warmer than ambient, the plumes rose by 30–50 m, at a position 300 m downwind (assuming wind speed of 2 m/s); and
  - plume rise will be affected by temperature differential, wind direction, wind speed and ventilation rate.
- In contrast to CFD, Calpuff did not demonstrate any plume rise, even when the exhausted air was 10 °C warmer than ambient air.
- As Calpuff did not appear to simulate plume rise, there was virtually no difference in downwind impact when the emission source was modelled as short stacks with no vertical momentum; short stacks with low vertical velocity of 0.01 m/s; or as a volume source.
- The CFD model predicted narrower plumes than Calpuff, due to inherent turbulence and puff splitting formulations in Calpuff and because Calpuff reports an average plume concentration rather than the instantaneous plume concentration reported by CFD.
- Minimal plume rise predicted by Calpuff will result in higher ground level concentrations, and consequently longer, more conservative separation distances for receptors at ground level. For elevated receptors, the inability of Calpuff to predict plume rise may under-predict odour impacts.
- Calpuff appeared to under-predict ground level concentrations (relative to CFD) during conditions when plume buoyancy was unlikely and during stable atmospheric conditions. Calpuff outputs may need to be adjusted for these conditions. The differences between the two models may have

been due to modelling ‘constant’ wind conditions, for which Calpuff automatically includes turbulence adjustments while CFD does not.

- When smoke flares were used to visualise shed exhaust air, it was observed that:
    - the exhaust plume was buoyant and rose vertically, even when the exhausted air was only 1–2 °C warmer than ambient air;
    - when the exhausted air was warmer than ambient by 5–8 °C, plume rise was almost immediate, with the plume rising within 20 m of the shed;
    - for several smoke releases conducted around sunrise (and presumably stable atmospheric conditions), the smoke dispersed horizontally at a height of 15–20 m, despite rapid and almost immediate plume rise of the exhausted air;
    - for smoke releases conducted an hour or more after sunrise (presumably neutral or unstable atmospheric conditions), plumes rose and dispersed vertically when the plume was thermally buoyant; and
    - the distance at which the plume began to rise was influenced by wind speed, wind direction, temperature differential (exhaust air versus ambient air) and fan activity (this observation supports the CFD model predictions).
- Measurement of temperature profiles immediately downwind from the shed demonstrated that:
    - the temperature of the exhausted air approached ambient air temperature very rapidly, typically within 40 m from the shed;
    - when the exhausted air temperature was similar to ambient temperature, exhaust plume shape was difficult to distinguish from the collected temperature data; and
    - when the exhausted air was 3 °C (or more) warmer than ambient air, temperature recordings indicated that the plume rose within a short distance of the shed.
- When Calpuff was used to model hypothetical broiler farms using different emission temperature inputs and source configuration (volume source):
    - separation distance varied with emission temperature. In general, modelling broiler sheds with emission temperatures equal to ambient temperature resulted in longer separation distance compared to when broiler sheds were modelled using target production temperatures as the emission temperature; and
    - dominant low wind speed directions corresponded with significant elongation of the 2.5 ou contour.

Separation distance formula

- When the proposed Queensland separation distance formula was applied to five existing broiler farms for comparison to approved Calpuff modelling outputs:
    - receptors surrounding four out of five farms would have been adequately protected by the use of the formula (compared against Calpuff modelling). At the fifth farm, the formula calculated shorter distances than those estimated using Calpuff;
    - four out of five farms would not have been immediately approved on the basis of the separation distance formula due to receptors being within the calculated distance. This would have required site specific dispersion modelling or alternatively, re-siting or re-

sizing of the farm. **Nevertheless, at these four farms, the receptors were protected by the use of the separation distance formula as a first stage assessment tool; and**

    - the proposed Queensland formula calculated similar distances to the South Australian method, shorter distances than the New South Wales method and larger distances than the Victorian method. These other methods, however, are designed to address different air quality objectives as legislated in those states.

- When the proposed Queensland separation distance formula was applied to hypothetical broiler farms (located in broiler growing regions in southeast Queensland) for comparison against Calpuff:

    - the separation distance formula calculated longer separation distances than Calpuff in the majority of cases;

    - the separation distance formula calculated shorter distances than Calpuff in some instances;

    - the separation distance formula tended to under-estimate separation distances (compared to Calpuff) when low wind speeds, low surface roughness and complex terrain (especially cross-slope wind fields) combined; and

    - selection of inputs/factors used in the formula is unambiguous, and readily available for review and alternate interpretation. On the other hand, the selection of inputs for the Calpuff modelling and reasons for variability between modelling outputs are not as clear.

  (It should be remembered that comparisons between the two methods at these hypothetical farms were made along transects where the Calpuff predicted odour contour was elongated, and therefore the most likely situations where the separation distance formula would be relatively shorter.)

- There was substantial variability between Calpuff outputs due to the selection of modelling configuration (source configuration and emission temperatures). The overall performance of the separation distance formula was dependent on the chosen Calpuff modelling configuration.

Implications

Outcomes from this report may change the way that separation distances are currently estimated for broiler farms. In particular, the adoption of a single methodology for modelling odour emissions from broiler sheds, using realistic shed emission temperatures (not ambient), will result in a more consistent approach to modelling odour impacts. This will reduce contention of modelling outcomes, and decrease the frequency of appeals during the development assessment process.

Recommendations

Recommendations regarding Calpuff modelling of broiler farms and inclusion of thermal buoyancy

- Air exhausted from broiler sheds is usually warmer than the ambient air. Consequently, broiler sheds should be modelled with the exhaust air temperature approximated using target production temperatures or other suitable estimate of exhaust temperature (for example, by using Equation 2).
- A single methodology regarding source configuration and the selection of emission temperature inputs needs to be adopted to ensure consistency in modelling results when using Calpuff.
- Receptors that are located at a higher elevation than the farm need to be considered cautiously. If Calpuff is not adequately simulating plume rise (as suggested in this report), it is likely that impacts on elevated receptors are not being adequately addressed.
- Calpuff demonstrated significant elongation in the 2.5 ou contour in the directions of low wind speed. This resulted in separation distances ranging from 1300–2050 m. Existing Calpuff modelling outputs similar to these should be checked against complaint records to assess the occurrence of odour complaints at these distances.

Recommendations for the proposed Queensland separation distance formula

- Adoption of the proposed Qld separation distance formula should be strongly considered.
    - In the majority of cases tested during this exercise, the formula calculated greater separation distances than Calpuff, which would improve protection for residents; however, in 33–50% of cases examined in this project, the separation distance formula under predicted separation distances when compared with Calpuff.
    - Parameters used when applying the formula are immediately available for peer review; and the method can be consistently applied from farm to farm.
    - The multiplier for the ‘Farm design/management factor”, S1 should be fixed at 1.0, as new farms will only be operated using best available design and management. (Broiler production has evolved since the formula was proposed in 2005.) Use of this multiplier resulted in conservative estimates of separation distances in the majority of cases examined in this exercise.
- Changes to the methodology should be considered to reduce occurrences when the separation distance formula under predicted separation distances (when compared to Calpuff modelling).
    - Small changes to the definitions and multipliers for terrain and surface roughness factors may improve the reliability of the formula; however, care must be taken to ensure that increasing the multipliers does not make the separation distance formula excessively conservative.
    - Inclusion of a low wind speed factor should be investigated; however, improvements in prediction of separation distances would need to be balanced with useability of the formula, especially the requirements to acquire detailed weather data.
    - The formula should be tested for many broiler farms before changes to the methodology are made.
    - The formula can be applied to farms up to 350,000 birds.
- The exercise of applying the proposed Qld separation distance formula to existing broiler farms, approved on the basis of Calpuff modelling, should be expanded to include a greater number of examples covering a wider range of environmental and farm variables.

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Appendix 1: CFD modelling report

Pacific Air and Environment, 2009. Modelling Plume Rise from Poultry Sheds. Job No. 2655, 1 June 2009. Pacific Air and Environment, Brisbane.

REPORT

MODELLING PLUME RISE FROM POULTRY SHEDS

Department of Primary Industries and Fisheries

DATE 1 June 2009

JOB NO. 2655

PACIFIC AIR & ENVIRONMENT

A PEL Company

PROJECT TITLE: MODELLING PLUME RISE FROM POULTRY SHEDS

JOB NUMBER: 2655

PREPARED FOR: Department of Primary Industries and Fisheries

STATUS: Final

PREPARED BY: E. Anglo/ F. Rahaman

APPROVED FOR RELEASE BY: P.D'Abreton

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TABLE OF CONTENTS

List of Figures

1 INTRODUCTION

Pacific Air & Environment (PAE) was contracted by the Department of Primary Industries and Fisheries (DPI&F) to perform a modelling investigation of the behaviour of plumes from poultry sheds and compare the predictions of a regulatory dispersion model with the results of a computation fluid dynamics (CFD) model.

1.1 Background

The prediction of odour impact from poultry operations and similar facilities through dispersion modelling has borrowed heavily from principles originally designed for the modelling of plumes from industrial stacks – despite the obvious differences between these two types of sources. Unlike emissions from poultry sheds, emissions from industrial sources are emitted well above ground level, are typically warm and buoyant being by-products of combustion, and possess strong vertical velocity. Two main reasons explain this practice:

- First, dispersion modelling principles that make use of the Gaussian formulation are conceptually simple and are easily translated into free or inexpensive computer programs that can run on any computer by non-specialist users with sufficient training and expertise.
- Second, Gaussian models have a long-standing and widespread acceptance as regulatory tools. In many cases they over-predict actual impact, and in complex situations where assumptions of the models may be grossly simplistic, it is often considered too difficult to obtain a more accurate result, or not worthy of the additional effort, in which case conservative inputs might be used to compensate for the uncertainty of model results in such circumstances.

Two important assumptions of the Gaussian plume models are steady meteorology and flat terrain. To accommodate the influences of deviations from these assumptions, users and regulators have since adopted various adjustments in model parameters. For instance, varying wind direction over time arising from a turbulent atmosphere is incorporated by enhancing the degree to which concentrations are spread out around the plume centreline. The impact of terrain is partly accounted for by keeping the ground flat but reducing the height of the plume while keeping the plume direction constant. Spatial wind variations caused by terrain effects are not readily addressed by adjustments in Gaussian plume models, which assume wind is constant over the model domain during any given time step.

Another complication to the process of dispersion arises from the influence of building downwash. Gaussian models account for this influence by reducing plume rise by a degree determined from empirical relationships between the dimensions of buildings adjacent to a source and discharge properties such as stack height, temperature and velocity. These building wake effects also influence *near-field* dispersion. Because downwash tends to increase ground level concentrations, stacks are designed to avoid or reduce these effects.

These modifications are simplistic compared to the current understanding of the atmosphere, but their outcomes have been accepted as minor adjustments to what are presumed to be essentially reliable predictions of the Gaussian model. Modellers and regulators also assume that with their tendency to over-predict concentrations especially when run with conservative inputs, the objectives of most applications of dispersion models are adequately satisfied by these simple methods.

1.2 CFD vs. Regulatory Models

CFD models simulate environmental flow based on a first-principles understanding of the mathematics and physics of fluids. This means that their formulations are closer to a "true" understanding of the phenomena surrounding flow and dispersion, compared to the practical-empirical approach used in regulatory models. This implies that CFD models should be more accurate, and, were it not for their large computational requirements, should be in much more common use.

One problem with this assertion is that published studies demonstrating the ability of CFD models to simulate concentrations arising from real sources have been few. This is partly due to the difficulty of running CFD models, and the lack of resolve in their use when simpler methods are available. While it is also possible that most applications of CFD models are commissioned works that are not publicly available, the superiority of CFD models is mainly unproven in this field. However, CFD models are widely relied on for a wide variety of exacting requirements involving fluid flows, such as aircraft design, ventilation system design, industrial process design, amongst others.

By contrast, the performance characteristics of regulatory models such as CALPUFF and its predecessors are reasonably well-known. In simulating industrial stack emissions, these models have been progressively improving in their predictions.

The value of this study is therefore not in challenging regulatory models as they are used in industrial stack emissions, but only in their specific application to dispersion from poultry sheds where conditions are well outside the range of parameters on which plume rise schemes in regulatory models were based.

1.3 Plume Rise in Meat Chicken Farms

The primary aim in this project is to determine whether plume rise from poultry sheds is a significant feature, and if so, estimate the parameters for plume rise and plume dispersion in the near- and mid-field. Plume rise from poultry sheds could significantly affect downwind odour concentrations but have been assumed to be insignificant in most modelling applications.

Photographic and anecdotal evidence as well as observations indicate that plumes from animal facilities do tend to rise, at least under certain conditions. A LIDAR scan from Prueger *et al.* 2008 showed ascending plumes of particulate matter from swine facilities, with part of the rise due to heating and turbulence induced by shed roofs.

Chicken sheds represent an extreme application of Gaussian models, outside the range of original design intentions. First, chicken sheds emit through horizontal vents with no, or negligible, vertical velocity. Second, plume buoyancy is relatively low due to the small difference between in-shed and outdoor temperature (compared to most stack release temperatures, which are usually much greater than ambient). Third, building downwash is almost always a major factor in the dispersion process. But the absence of alternative solutions with equal ease of use, and the confidence that their predictions would remain realistic or conservative, have allowed models like AUSPLUME and CALPUFF to remain the main tools in the prediction of the air quality impact of poultry operations.

Although AUSPLUME and CALPUFF permit the use of plume rise formulae, and it is possible – in line with recommended approaches in the US and other places – to simulate in rough fashion a horizontally directed release, there has been a reluctance in some quarters to incorporate plume rise into poultry shed modelling.

It has been suggested that the most appropriate way to model their emissions is by assuming them to be (non-buoyant) volume sources (e.g., Jiang & Sands, 1998, 2000). This approach neglects both the momentum and buoyancy of the plume since volume sources in current regulatory models are not assumed to possess these properties. Such a misrepresentation is assumed to have little influence on the predicted far-field downstream concentrations but there has been no clear reason for doing so, apart possibly from the relative simplicity of using the approach.

It is also not clear whether the representation of a shed as a volume source is superior, in terms of accuracy or conservativeness, to using a downwashed horizontal point source. This project will test the influence of this assumption on predicted odour concentrations by comparing the results arising from changing the assumed geometry of the source.

This study therefore aims to evaluate the limits of a Gaussian puff model in simulating emissions from chicken sheds. This evaluation will compare two different modelling approaches: Computational Fluid Dynamics (CFD) modelling, and a sensitivity study using CALPUFF. The outcome is a set of recommendations on how to improve the use of the conventional approaches to the modelling of emissions from chicken sheds.

1.4 Input Parameters to be Tested

The Gaussian plume model has two key components:

1. the plume rise formulation, which calculates the height of the plume centreline from stack parameters such as stack height, discharge temperature, discharge velocity and stack diameter, and
2. the dispersion parameter, a meteorology- dependent variable that quantifies how pollution is spread out from the plume centreline.

Together these components define the concentration of a pollutant at ground level downwind of the source under specific atmospheric flow conditions.

A parcel of air leaving a typical industrial smokestack possesses both upward momentum and buoyant energy. These properties are gradually lost to the environment as the outer edges of the parcel mix with the surrounding air in a process called entrainment. At the same time, the plume is being transported horizontally by the wind. The net effect is for the plume to take a bent-over shape which starts as vertical at the stack, becoming horizontal with distance. The plume also expands with distance from the source as turbulence mixes it into the ambient flow.

Plumes from chicken sheds are governed by the same principles, except that the discharge is typically horizontal. The discharge diameter is also large since the discharge is through several fans that typically cover much of the endwall of a shed. Some shed designs are more complex, with sidewall fans as well.

The use of a horizontal point source to stand for a chicken shed allows sensitivity experiments to be conducted on the discharge temperature, which is dependent on the temperature of the interior of the shed. This temperature is directly related to the age of the birds and therefore varies with time. Because the odour emission rate also rises as the birds mature, its changing value may also be considered as another parameter to test.

The influence of the vertical discharge velocity will also be tested. Results with a speed of 0.01 ms^{-1}, a value recommended by some agencies as a minimum to use for horizontal discharges, will be compared to the control results which assume no vertical velocity. Note that the arbitrary use of a non-zero minimum velocity has been made redundant by recent changes to CALPUFF, which permits a zero vertical velocity to reflect the conditions of a horizontal release.

The model to be used in these sensitivity studies is CALPUFF. This model represents the state-of-the-art in regulatory modelling, but its plume rise formulations are still based on conventional Gaussian models. Hence, any conclusions drawn from CALPUFF regarding plume rise and building downwash should apply to other Gaussian models as well.

1.5 Building Downwash

Plume downwash is a complex interaction among the flow, the plume and the surrounding structures. Downwash introduces turbulence close to the source that enhances the initial diffusion of the plume. Such interaction is best understood with CFD models, but owing to their considerable computational requirements they have been rarely used in regulatory modelling. Instead, the role of building downwash in modelling meat chicken farms is currently simulated by many modellers by assuming that each shed is a volume source whose dimensions are proportional to the size of the shed.

There is a need to test and compare the simple downwash formulations used in dispersion models with the results generated by CFD modelling. In particular, the common practice of modelling meat chicken farms as volume sources rather than horizontally discharging point sources needs to be reviewed in terms of its accuracy and conservatism.

1.6 Objectives of Study

The objectives of the study are as follows:

- To determine whether plume rise from poultry sheds is a significant feature.
- To determine the applicability of conventional Gaussian plume rise equations in describing weakly buoyant plumes from poultry sheds.
- To apply a Computational Fluid Dynamics (CFD) model to investigate the influence of building downwash on plume rise from poultry sheds.

- To compare plume rise, dispersion and predicted ground level concentrations using default CALPUFF parameters with those derived from CFD model results.
- To suggest possible modifications to plume rise and dispersion parameters that can improve predictions of odour impact from poultry sheds using regulatory dispersion models.

2 STUDY APPROACH AND METHODOLOGY

2.1 Modelling with CFD

The CFD model used is AVL/SWIFT Version 3.3. The model will be run for a tunnel-ventilated poultry shed with a set of fans discharging horizontally at a direction parallel to its long axis.

With suitable depiction of a limited set of scenarios defining meteorological and shed ventilation conditions, the CFD model will be used to provide the basis for either confirming that current plume rise methods are appropriate or refining plume rise equations specifically for application to poultry sheds. In addition, the CFD model is expected to provide insight into how the shed structure affects the flow and the plume.

The plume trajectory will be extracted from the three-dimensional odour concentration fields by tracing the location of the maximum odour concentration. The height of the plume as a function of distance will be calculated from the trajectory. Finally, dispersion parameters at various points along the trajectory will also be estimated from the lateral distribution of the concentration around the trajectory.

2.2 Model Configuration

The commercial CFD code AVL-Swift, version 8.41 employs a finite-volume discretisation method to solve the fundamental physical conservation laws (mass, momentum, energy) in their integral form. In the finite volume approach, the conservation equations for the fluid entering and leaving the volume are integrated over the finite control volumes.

The k-ε turbulence model, the most widely used approach, was used in the simulation. It is numerically robust and is generally accepted to yield realistic predictions of major mean flow features in most situations.

The flow was treated as incompressible. An upwind differencing scheme was used for the solution of the energy, turbulence and scalar transport equations, while the momentum and continuity equations use a central differencing scheme.

A 1200-m long, 600-m wide and 100-m high domain was used. The shed building was centred at ground level of the domain 300 m from the inlet. In order to reduce the complexity of the geometry, the exhausts were modelled as a single rectangular fan. The domain was meshed with over 500,000 cells with highest cell density immediately around, above and downwind of the shed. An image of the meshing configuration on the domain boundaries is presented in **Figure 2.1**.

The exhaust and the domain delimitation on the upwind side were modelled as inlet velocity boundaries. Atmospheric velocity turbulence and temperature profiles were applied to the domain inlet flow boundary. Pressure and zero gradient boundary conditions were applied in upper delimitation and downwind side delimitation of the model. A wall boundary condition was applied for ground surface and shed walls. The surface roughness of the ground was kept constant at 0.25 m for these studies. The side boundaries, parallel to the primary flow direction were configured as symmetrical.

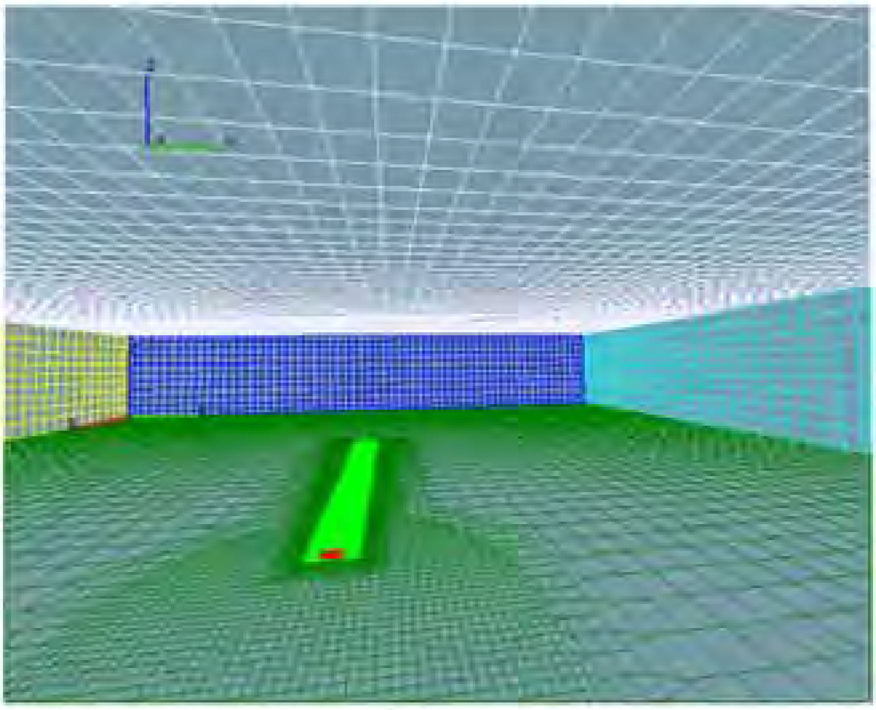


Figure 2.1: Image of the modelling domain. Red rectangle indicates the discharge.

2.3 Sensitivity Studies with CALPUFF

The CALPUFF model was set up with the same domain dimensions as with the CFD model. Horizontal grid point spacing was set at 40 m, and all other values were set to default values typically used in regulatory modelling for similar facilities. An artificial 8-hour meteorological input file containing constant values was used to define the flow. Concentrations were then drawn as the 1-hour average of the last hour of the simulation.

CALPUFF will be used to test how predicted downwind concentrations are affected by changing the assumed geometry of the source and small changes in the assumed vertical discharge velocity, temperature and other parameters described in Section 1.4. Actual measurements of differences between temperatures inside and outside the shed will be used as input.

The experiments herein will only model a typical chicken farm in flat terrain. It has been suggested that an actual farm be used in the experiments, but there is confidence that sufficient insights can be obtained with a flat terrain assumption without having to deal with the huge number of possible terrain configurations.

2.4 Comparisons between CFD and CALPUFF

Three parameters will be compared between the CFD and CALPUFF models: plume rise with distance, dispersion parameters (graphically depicted through concentration profiles), and ground level concentrations. Based on the comparison, the study will quantify the weaknesses of CALPUFF when applied to the prediction of meat chicken farm impact.

The key aim of the proposed CALPUFF modelling scenarios is to illustrate whether, and to what extent, plume rise influences the predicted ground level concentrations of odour downwind of poultry sheds. The CALPUFF modelling will therefore involve scenarios with and without plume rise incorporated.

At the end of the CALPUFF modelling phase, results will be compiled and recommendations will be made on the preferred approach to modelling odour dispersion from poultry sheds. More importantly, the study will recommend possible modifications to a CALPUFF setup that could improve its consistency with the results of CFD models. Such modifications may involve artificial adjustments to building dimensions and plume parameters in order to improve forecasts of odour impact from poultry facilities and similar sources. These recommendations could also be adopted in other regulatory Gaussian models such as AUSPLUME or AERMOD.

2.5 Cases to be Modelled

Table 2.1 lists the cases to be studied and the parameters in each case. These cases are based on ranges of observed values from typical farms.

The shed was assumed to be 150 m long, 15 m wide and 4.5 m at its highest point, based on a typical tunnel-ventilated chicken shed.

Atmospheric stability was held at neutral (class D under the Pasquill-Gifford scheme) for two main reasons. First, CFD models are more computationally stable in neutral conditions. Second, results obtained for the neutral case are expected to be extendable to other atmospheric conditions and can be guided by existing standard algorithms once the behaviour in neutral conditions is established.

The temperature difference of 6°C used in several cases was based on average observed values from a meat chicken farm. The other temperatures tested are approximately the 25th (2°C) and 75th (10°C) percentiles. Values of the other parameters are based on the ranges typically encountered in actual modelling studies.

The wind directions in the experiment represent the angle of the discharge relative to the ambient flow. A value of zero means that the discharge is in the same direction as the wind (co-flowing).

Because the study cannot capture all possible configurations of the terrain, only flat terrain conditions were tested in all the experiments.

Table 2.1 Cases to be Modelled (CFD and CALPUFF)

Case	Parameter Tested	Temperature Difference (C°)	Ventilation Rate (%)	Vertical Velocity (ms^{-1})	Wind Direction	Wind Speed (ms^{-1})
1	Control (horizontal point source)	**6**	**7 fans (50%)**	**0.0**	**0 (co-flowing)**	**2**
2	Fan Activity	6	**1 fan (7%)**	0.0	0	2
3		6	**14 fans (100%)**	0.0	0	2
4	Temperature difference (discharge minus ambient)	**10**	50%	0.0	0	2
5		**2**	50%	0.0	0	2
6		**0**	50%	0.0	0	2
7		**-6**	50%	0.0	0	2
8	Source geometry (**volume source**)	N/A	50%	0.0	0	2
9	Source geometry (**quasi-stacks**)	6	50%	**0.01**	0	2
10	Wind direction (co-flowing = 0)	6	50%	0.0	**45**	2
11		6	50%	0.0	**90**	2
12		6	50%	0.0	**135**	2
13		6	50%	0.0	**180**	2
14	Wind speed	6	50%	0.0	0	**0.5**
15		6	50%	0.0	0	**10.0**

Note: Items in boldface indicate the parameter being tested.

3 MODELLING RESULTS

The results of the two models were analysed and compared using the following diagrams:

- concentration isopleth maps along the vertical and horizontal plane
- concentration profiles with height at 300 m (unless indicated otherwise) from the source
- ground-level concentration profiles with distance along the plume centreline, and
- lateral (crosswind) ground-level concentration profiles at 300 m (unless indicated otherwise) from the source

The concentrations expressed here are in units of g/m^3. The emission rates and resulting concentrations are arbitrary. For maps generated by the CFD model, concentrations are depicted as relative to the discharge concentration in the control case. The emission rates are consistent between the CFD and CALPUFF to allow a comparison of their results.

3.1 Case 1 (ΔT = 6°C, 7 Fans, Control)

The results of the control case generated by the CFD model are shown in Figure 3.1. What is clear from these diagrams is significant plume rise, even at a shed temperature of only 6°C above the ambient. After a horizontal jet stage, the plume rises along a straight trajectory with an approximate slope of 10 percent (Figure 3.1, top). Wind speed for this case is 2 m/s.

CALPUFF simulations of the same case are shown in Figure 3.2. Unlike the CFD results, there is no apparent plume rise and maximum concentrations remain at the surface. A quick test (not shown here) with the SCREEN3 model whose plume rise formulations are identical to those in CALPUFF reveals that final plume rise is less than 2 m, with or without building downwash included. (There is in fact only one case among the 15 in which CALPUFF exhibits any plume rise, and still well below those predicted by the CFD model. CALPUFF plume rise is significant only when windspeed is much less than 2 m/s.)

A comparison of ground-level concentrations along the plume centreline extracted from CALPUFF and CFD models shows remarkable equivalence (Figure 3.6, middle). However, this agreement is largely a coincidence, since plume cross-sections are very different between the two. As shown in maps of ground surface concentrations in Figure 3.3 and Figure 3.4, concentrations across the plume centrelines show that the plume generated by CALPUFF is much wider than that of the CFD model. This result is true for nearly all the cases considered.

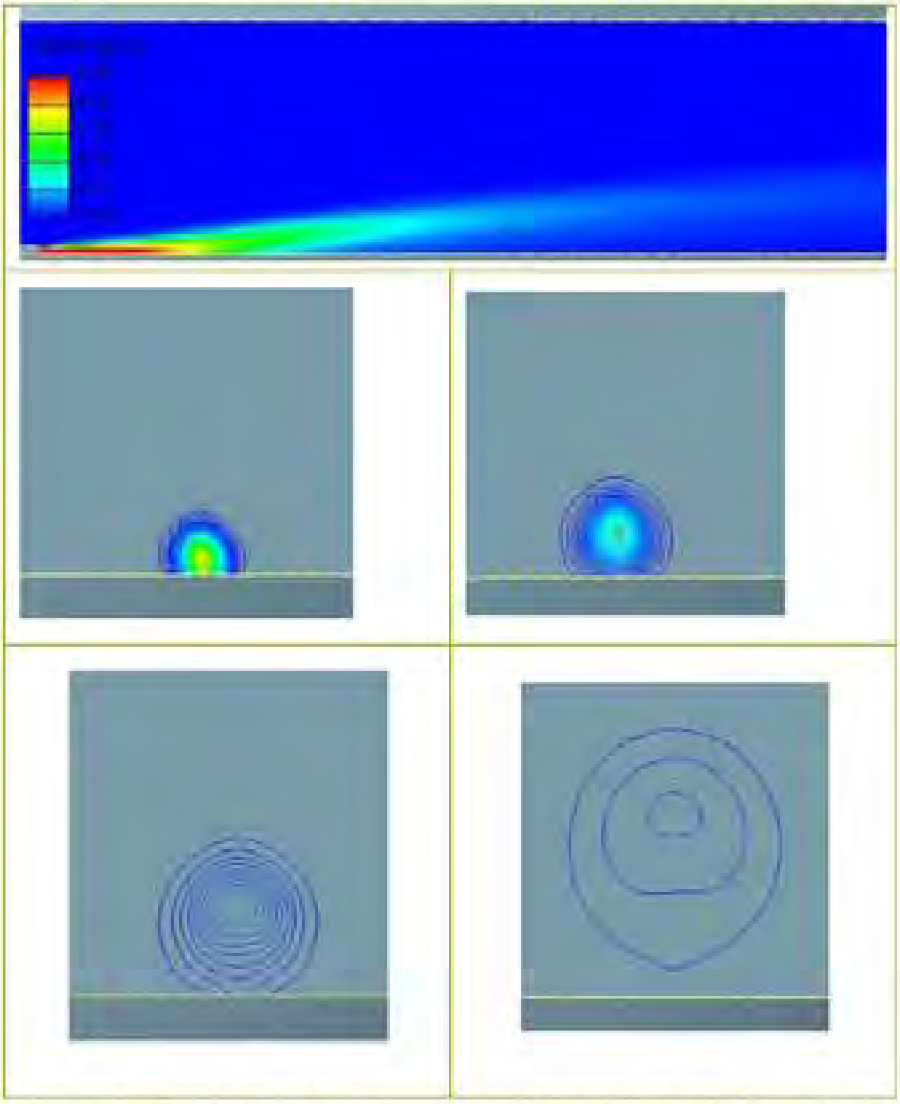


Figure 3.1: Isopleths of odour concentration (relative to discharge) for Case 1 (ΔT = 6°C, Control). Top: elevation view across plume centreline; plume cross sections at 50 m (middle left), 100 m (middle right), 200 m (bottom left) and at 400m.

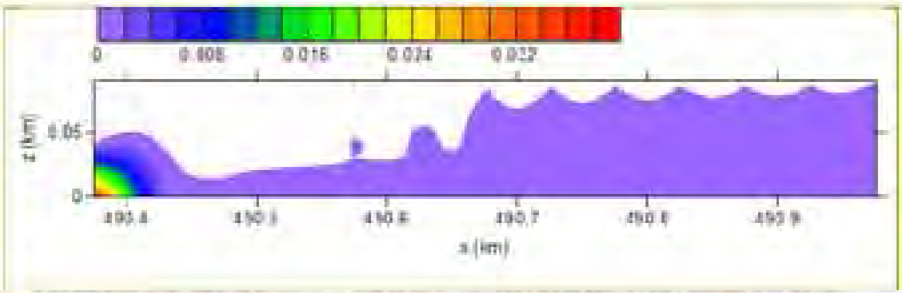


Figure 3.2: Predicted odour concentrations using CALPUFF for Case 1 (ΔT = 6°C, Control). Wave-like contours are artefacts of interpolation used to generate the grid map. Note that vertical scale is different from horizontal.

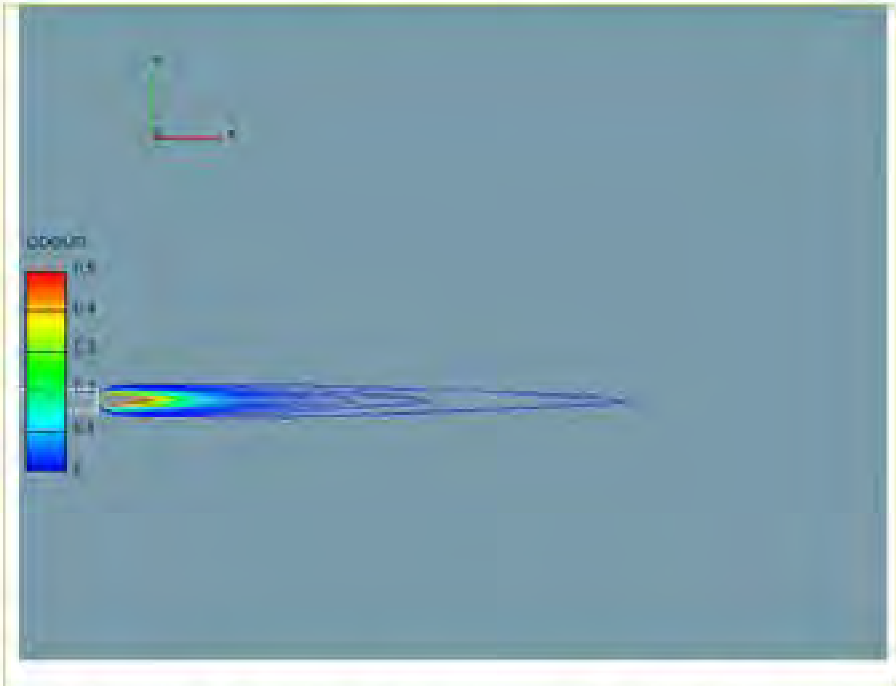


Figure 3.3: Predicted ground-surface concentrations (relative to discharge concentrations) using CFD for Case 1 (ΔT = 6°C, Control).

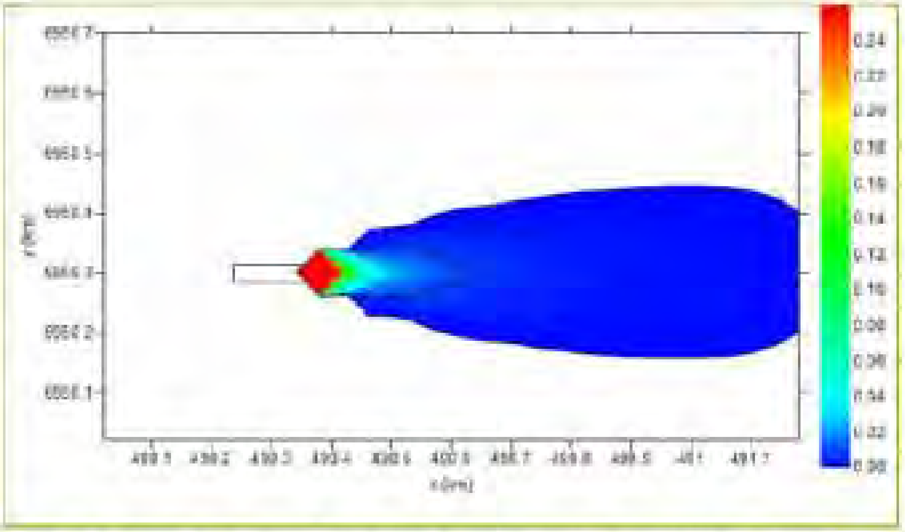


Figure 3.4: Predicted ground-surface odour concentrations in g/m3 using CALPUFF for Case 1 (ΔT = 6°C, Control).

3.2 Case 2 (1 Fan)

Reducing the number of fans to 1 fan or 7 percent of the maximum imparts much less horizontal momentum on the discharge, causing the plume to rise almost immediately according to the CFD model. As a result, concentrations at the locations selected for comparison register near-zero values (Figure 3.6).

As with the control case (2 m/s wind speed), CALPUFF continues to model the plume as a ground-based source with negligible tendency to rise.

The CFD results for this case showed a very stiff plume rise compare to all other cases. A detailed investigation of the plume for this scenario was performed and reverse flow was observed at the outlet. The reverse flow may have restricted the plume movement downwind. To further evaluate the CFD results, Plume rise calculation were made using Brigg's equation. Calculations from Brigg's equation showed a 25 m plume rise, 11 m downwind from the source*. The CFD predicted a similar rise at the same location. However we note that the CFD modelling did show a continued plume rise to greater than 100 metres without achieving final plume rise. From this it is concluded that the CFD model prediction does not represent a reasonable representation of the plume behaviour for this particular scenario as the CFD does not include micro entrainment of ambient air resulting from turbulence.

3.3 Case 3 (14 Fans)

At twice the discharge volume, the plume rises slightly more quickly than the control because it loses buoyancy less rapidly. At 300 m, the centreline will have

* The Briggs plume rise equations were developed from elevated sources with considerable mechanical and thermal buoyancy. The applicability of these equations to this extreme scenario is unknown. Therefore this calculation is for indicative purposes only.

climbed to 45 m compared to 30 m in the control. Ground-level concentrations in Figure 3.7 therefore fall off faster with distance.

CALPUFF results however do not show any appreciable differences among the first three cases since the same emission rate was assumed, and horizontal fan speeds do not influence in its initial dispersion. Windspeed is also 2 m/s.

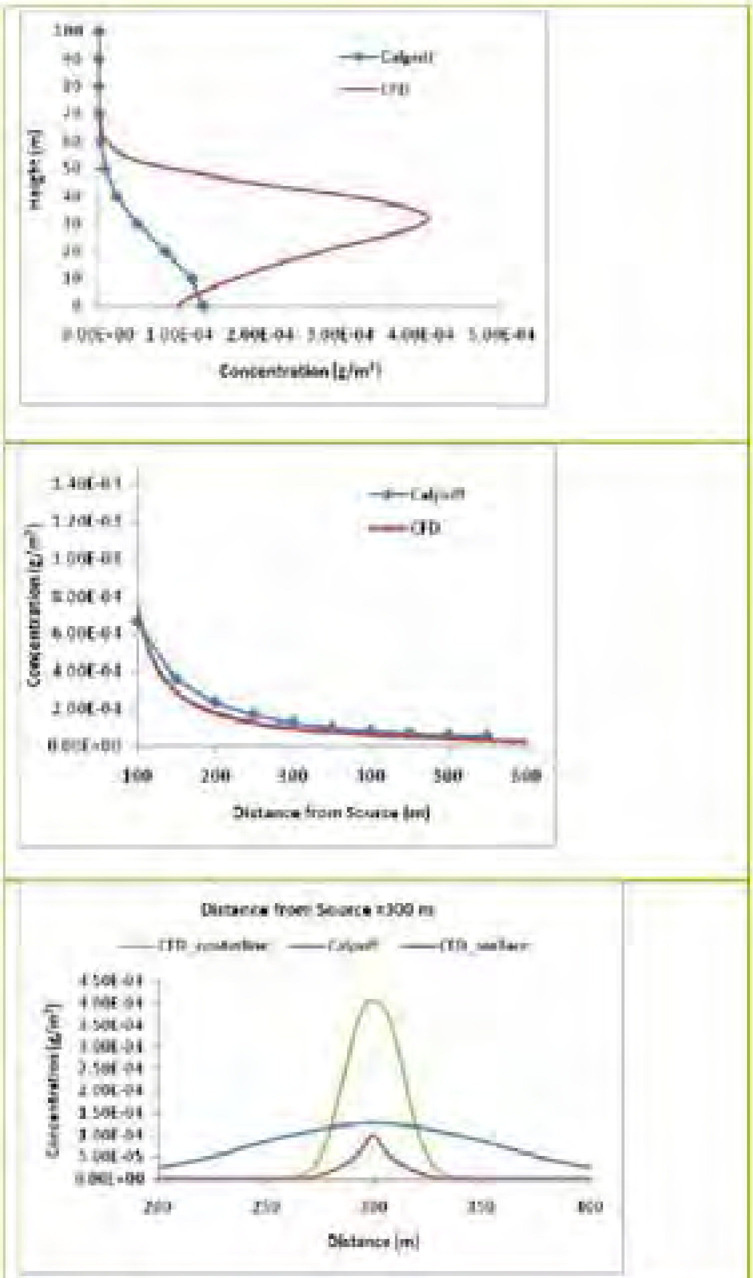


Figure 3.5: Profiles of predicted odour concentrations for Case 1 (control). Top: concentration vs. height 300 m from source; middle: ground-level concentrations along plume centreline; and crosswind concentrations 300 m from the source.

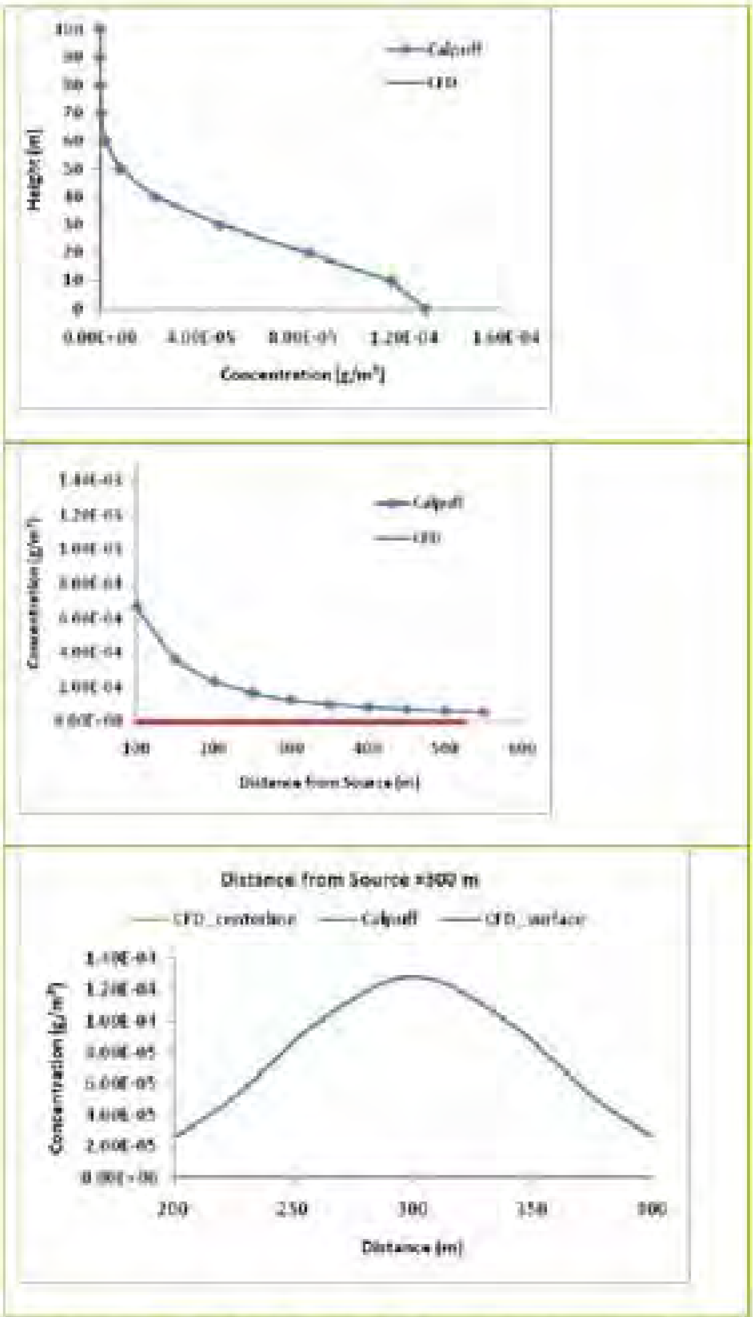


Figure 3.6: Profiles of predicted odour concentrations for Case 2 (one fan). Top: concentration vs. height 300 m from source; middle: ground-level concentrations along plume centreline; and crosswind concentrations 300 m from the source.

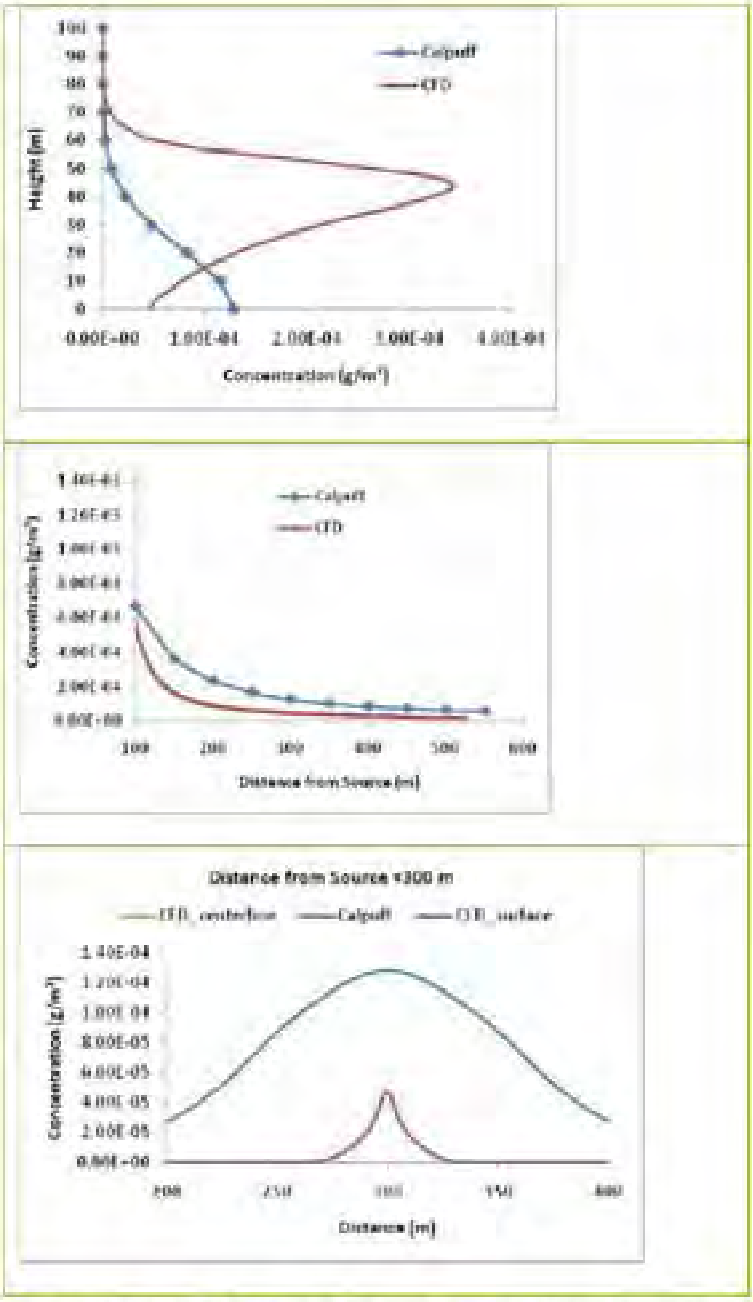


Figure 3.7: Profiles of predicted odour concentrations for Case 3 (14 fans). Top: concentration vs. height 300 m from source; middle: ground-level concentrations along plume centreline; and crosswind concentrations 300 m from the source.

3.4 Case 4 (ΔT = 10°C)

This case represents a condition in which the chickens are older and larger, causing shed temperatures to be warmer. With this increase buoyancy, the plume rises more quickly than in the control, as predicted by the CFD model. As shown in Figure 3.8, ground-level concentrations at 300 m decrease by about 75 percent compared to the control case.

For CALPUFF, the temperature of the discharge has no impact on its predictions. Wind speed is set at 2 m/s.

3.5 Case 5 (ΔT = 2°C)

Additional details into plume behaviour emerge when the discharge temperature is only 2°C warmer than the ambient (Figure 3.9). Initially, as with the control case, the plume registers a slow ascent, rising no more than 6 metres up to about 200 m downwind (Figure 3.10, bottom). However, in contrast to the other cases, the plume stabilizes at 6.5 m. At about 400 m downwind, the level of maximum concentration begins to drift downwards.

As explained earlier, plume rise is due to the buoyancy of the discharge. Plume rise stops when the plume's temperature becomes equal to that of the environment or when its buoyancy can no longer support further rise. The plume then continues to diffuse at this elevation. The apparent downward drift of the plume is likely a result of differential advection, wherein the upper part of the plume is entrained into the ambient air faster than its bottom due to wind shear, causing the maximum to be found at a progressively lower layer.

This qualitative behaviour of this plume is likely to be true for the previous other cases had the domains in these cases been extended farther downwind.

3.6 Case 6 (ΔT = 0°C)

In absence of buoyancy, the plume remains at ground level at all downwind locations. Although both CALPUFF and CFD predict no plume rise, the CFD model results at the surface are an order of magnitude higher than CALPUFF results. As shown in Figure 3.11, CFD model predictions exceed those of CALPUFF owing to the much lower horizontal dispersion in the CFD model, even if their vertical diffusion coefficients are nearly equal based on the 40-m depth in both models where top of bulk of concentrations are found (top of Figure 3.11).

3.7 Case 7 (ΔT = -6°C)

This case assumes that the plume is colder than the environment, a condition that is rare but possible during very warm conditions, when the birds are in early growth stages, and air is cooled in the shed through passive shading or active evaporation. As might be expected the plume exhibits no buoyancy and confines its dispersion to a lower elevation than that in Case 6.

The results are somewhat unexpected in the sense that the plume does not simply stay closer to the surface than in Case 6. In fact, ground-level downwind concentrations in Case 7 are less than 30 percent of those in the previous case (middle of Figure 3.12). At 300 meters, the plume cross-section loses its bellshaped profile (bottom of Figure 3.12). A comparison of the spread of this plume with those in the previous cases shows this plume to be the widest.

This plume behaviour results from its density, which is higher than the ambient. After being discharged, the air tends to build up at the side of the shed instead of freely flowing downwind as in the control. The building's wake then shelters this mass of dense air. The added time spent inside the wake allows diffusion to equalize the concentration within. At the same time, air at the sides of the plume are forced out beyond the protective wake zone of the building and are quickly mixed into the ambient flow. The net result is what is termed a "top-hat" concentration profile describing that illustrated at the bottom of Figure 3.12.

CALPUFF is not formulated to simulate negative buoyancy.

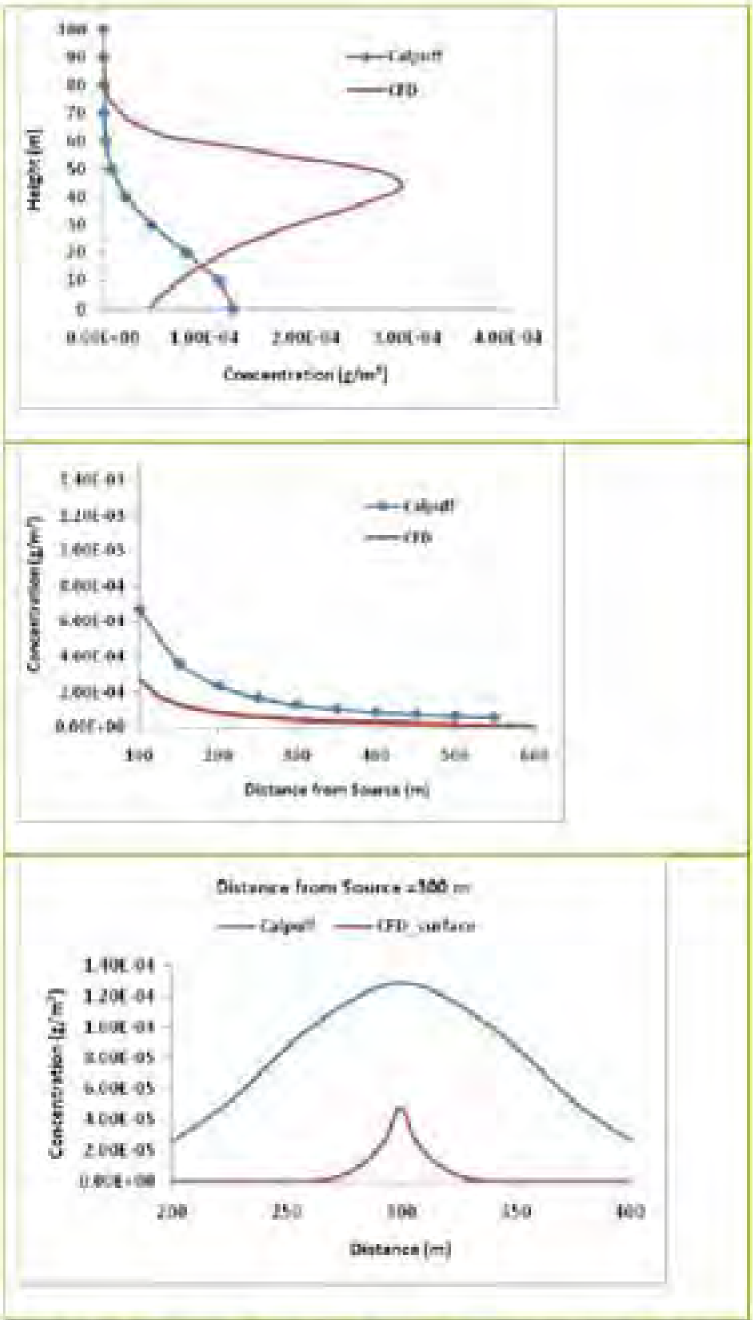


Figure 3.8: Profiles of predicted odour concentrations for Case 4 (ΔT = 10°C). Top: concentration vs. height 300 m from source; middle: ground-level concentrations along plume centreline; and crosswind concentrations 300 m from the source.

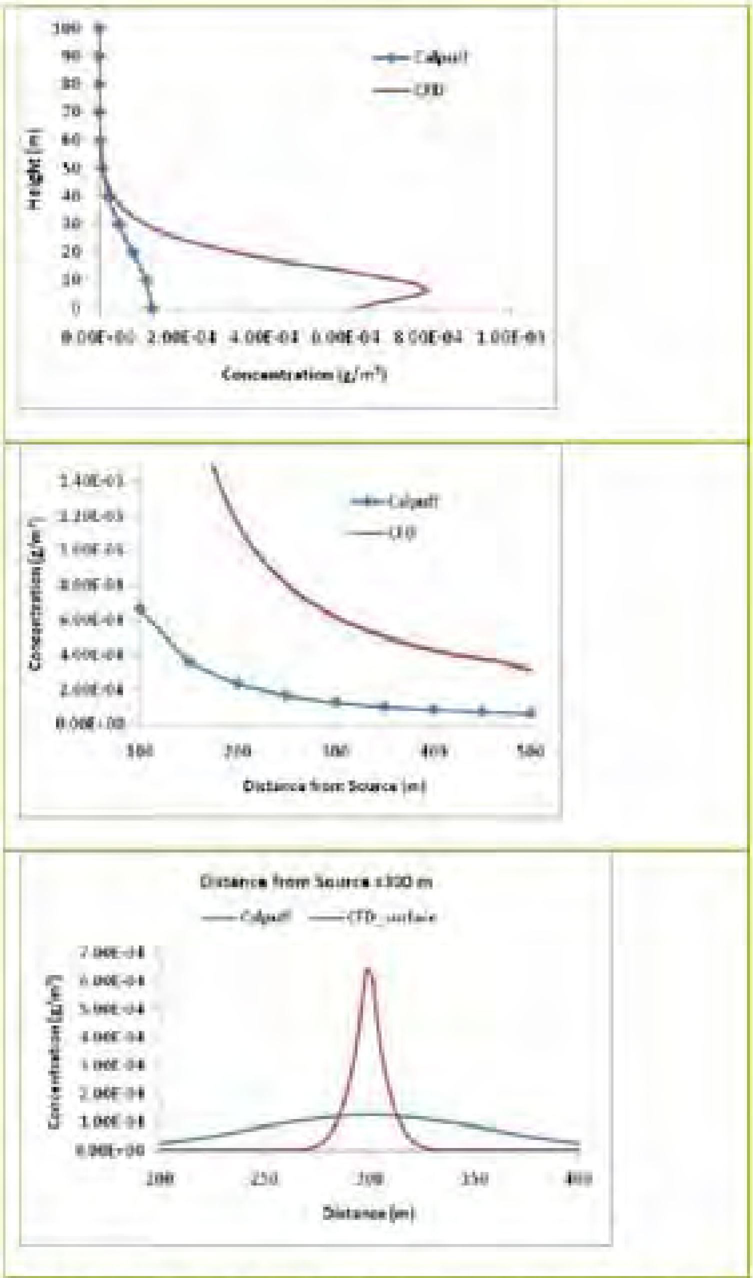


Figure 3.9: Profiles of predicted odour concentrations for Case 5 (ΔT = 2°C). Top: concentration vs. height 300 m from source; middle: ground-level concentrations along plume centreline; and crosswind concentrations 300 m from the source.

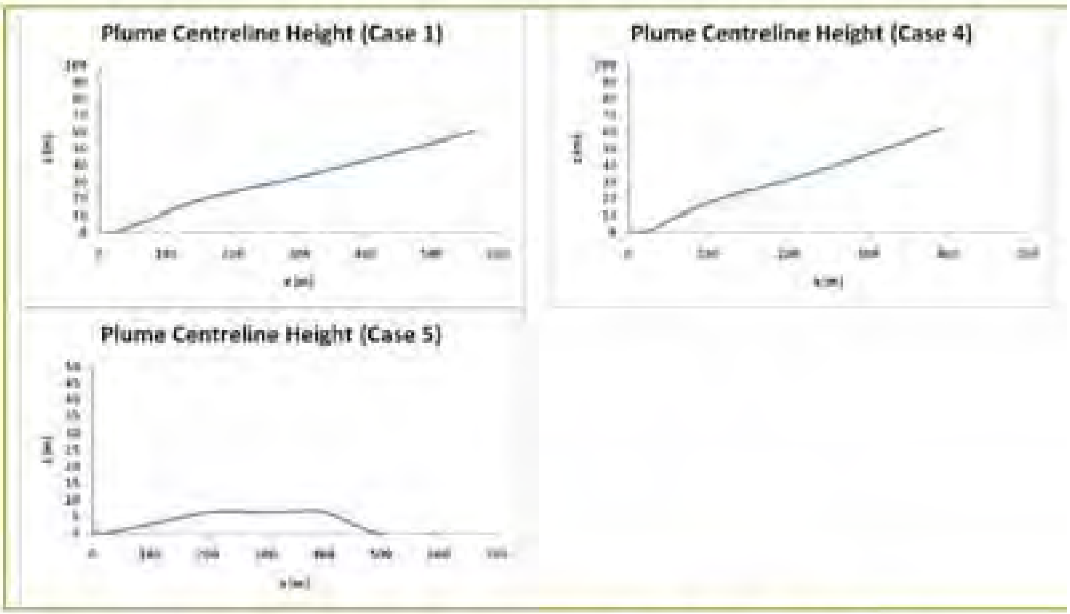


Figure 3.10: Predicted Plume Heights with Distance using CFD. Top left: Case 1 (ΔT = 6°C, Control); top right: Case 4 (ΔT = 10°C); bottom: Case 5 (ΔT = 2°C)

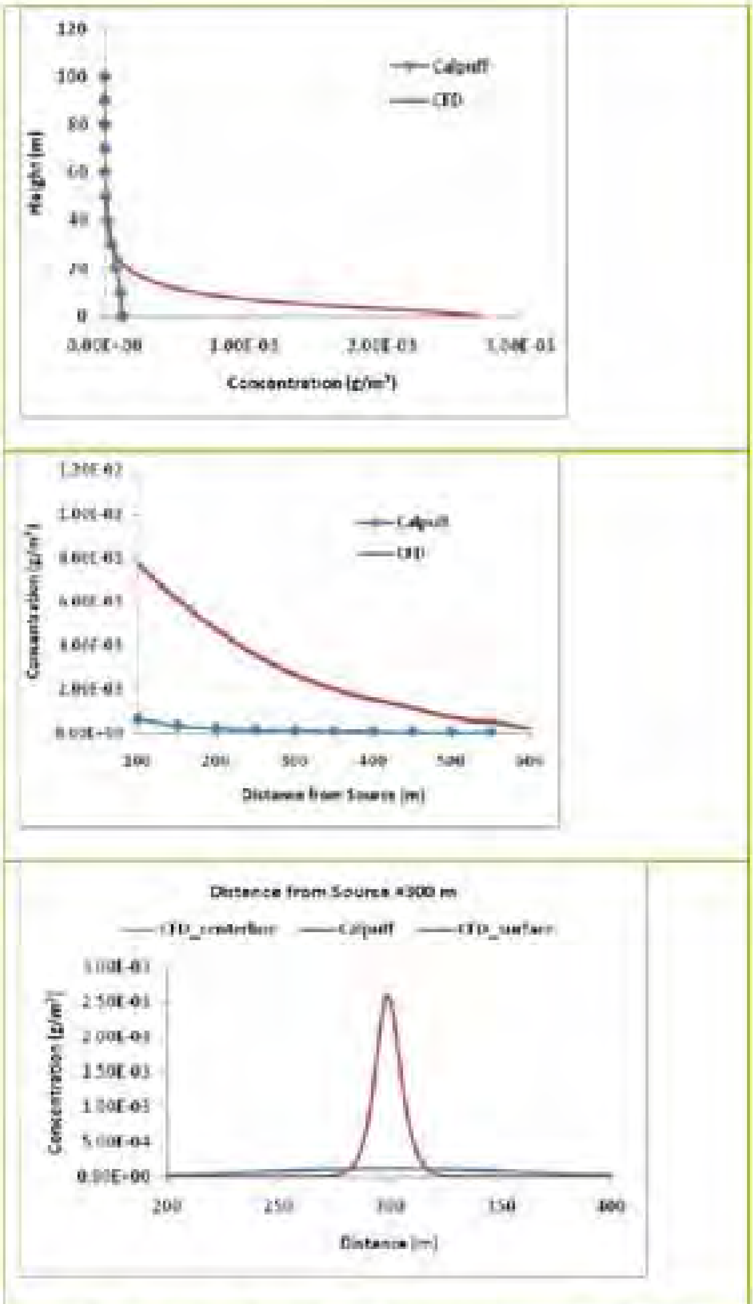


Figure 3.11: Profiles of predicted odour concentrations for Case 6 (ΔT = 0°C). Top: concentration vs. height 300 m from source; middle: ground-level concentrations along plume centreline; and crosswind concentrations 300 m from the source.

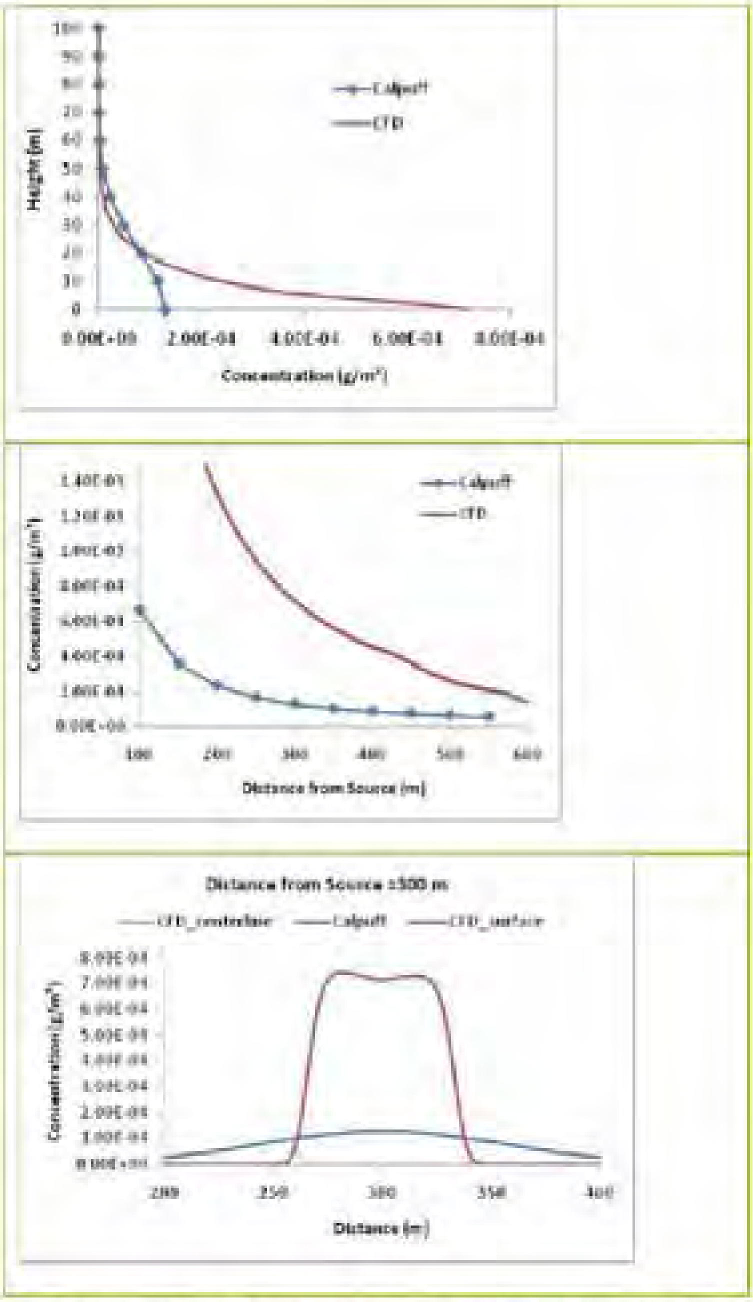


Figure 3.12: Profiles of predicted odour concentrations for Case 7 (ΔT = -6°C). Top: concentration vs. height 300 m from source; middle: ground-level concentrations along plume centreline; and crosswind concentrations 300 m from the source.

3.8 Case 8 (Volume Source) and Case 9 (Quasi-Stacks)

These cases aim to determine the effect of modelling the shed as a volume source and as a point source with a small (1 cm/s) vertical discharge velocity, and to compare their results to the control case (point source with no vertical discharge velocity). We note that when modelling volume sources, the effect of temperature of the plume cannot be evaluated.

A comparison of concentration profiles with height, downwind and along cross-sections found virtually no differences among the three CALPUFF runs (Figure 3.13). Note that differences between these cases could appear when CALPUFF is run with much lower wind speeds.

In addition to the limitations of the plume rise formulation in CALPUFF noted earlier, another reason for the similarity of these results is the overriding influence of building downwash, which erases the differences among the three discharge characteristics.

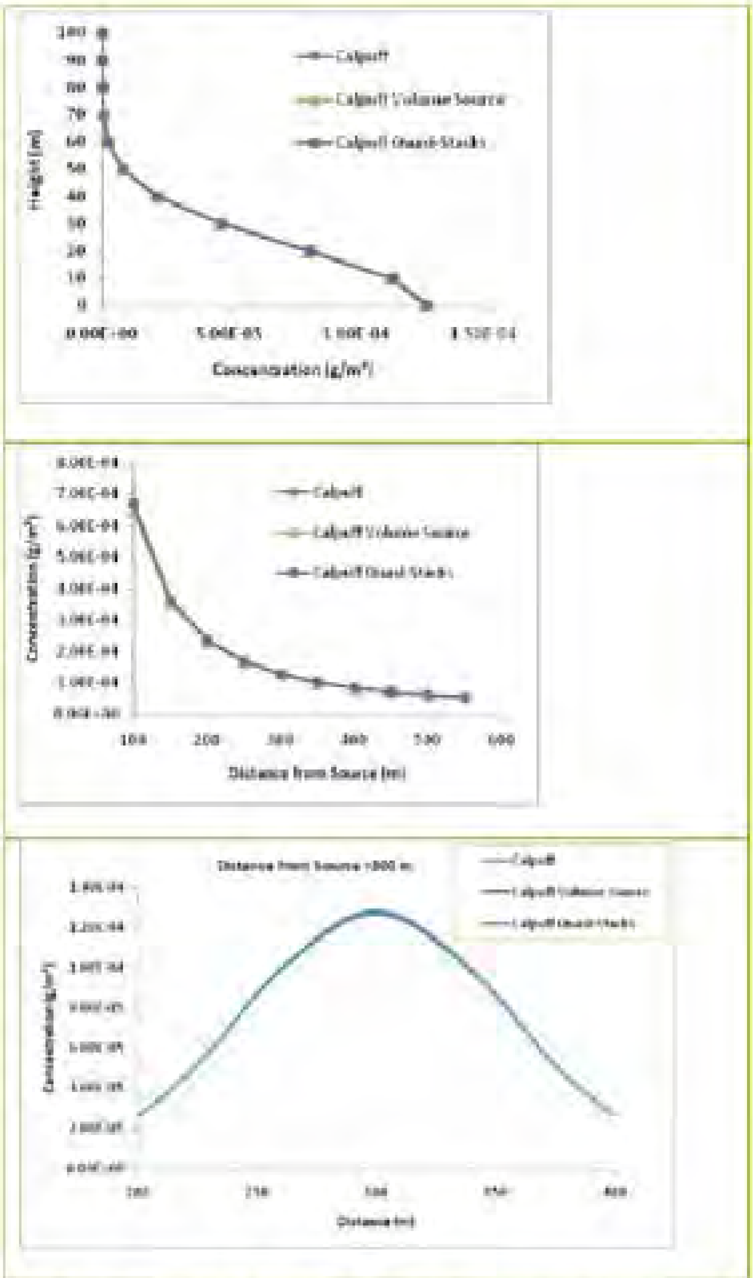


Figure 3.13: Profiles of predicted odour concentrations for Case 8 (volume source) and Case 9 (Quasi-stacks). Top: concentration vs. height 300 m from source; middle: ground-level concentrations along plume centreline; and crosswind concentrations 300 m from the source.

3.9 Case 10 (45° Angle between Discharge and Wind Direction)

The effect of imposing an angle between the discharge and the wind is to create a complicated interaction between the plume and flow. From its original direction, the discharge bends towards the wind flow tens of metres from the source. At the same time, its buoyancy begins to bring about lifting as its horizontal momentum weakens. Unlike the control, in this case the ambient flow provides less enhancement of the horizontal discharge when an angle between the two exists.

The interaction between the discharge and the ambient flow goes beyond a change of direction, as may be seen in the irregular vertical profile of concentration shown in Figure 3.14. What occurs is a radical deformation of the plume's conical shape resulting from the unequal effect of building downwash on different parts of the plume. As the plume weakens and begins to take on the direction of the wind, the influence of building downwash becomes weaker on the far end of the turning plume than the near end. This causes plume to be split or horizontally sheared, in addition to the vertical deformation caused by the wind profile. Among the cases investigated by the CFD model, it was in this case where plume distortion was most pronounced.

None of these effects are reproduced by CALPUFF, which retains the same simple concentration profile obtained in earlier results.

3.10 Case 11 (Discharge Perpendicular to the Wind Flow)

In this flow configuration, a wake region forms along the length of the lee side of the building. The low pressures in the wake limits plume rise, causing ground-level concentrations to increase compared to the control (Figure 3.15). By contrast, CALPUFF predicts this configuration to cause a decrease in ground-level concentrations by increasing the size of the initial dispersion.

Because the wind does not enhance the horizontal jet, the plume should be able to rise more readily. However, the effect of the wake dominates this factor.

3.11 Case 12 (135° Angle between Discharge and Wind Direction)

This case depicts a wind blowing at a 45-degree angle into or against the discharge. The plume is again deformed by the interaction, but there appears to be less asymmetry because the influences of the wind and the building wake more evenly impact different parts of the plume.

Also, because the building profile facing the wind is smaller compared to that in the previous case, the effect of building downwash is also smaller. This reduced influence of the building is reflected in both the CALPUFF and CFD model results.

The net effect is lower concentrations from both models compared to the control (Figure 3.16). For the CFD model, the reduction is due to (i) the plume being forced partially up the side of the discharge wall and (ii) the suppression of the horizontal jet, which allows the buoyancy to initiate plume rise sooner.

3.12 Case 13 (Discharge into the Wind)

Wind blowing against the discharge results in convergence and strong uplift at the fan wall. Concentrations at the discharge side are higher than normal due to accumulation of the discharge, but after the plume is forced over the shed the enhanced rise will have caused ground level concentrations to fall to levels lower than in the control (Figure 3.17). The horizontal jet stage completely disappears in this case.

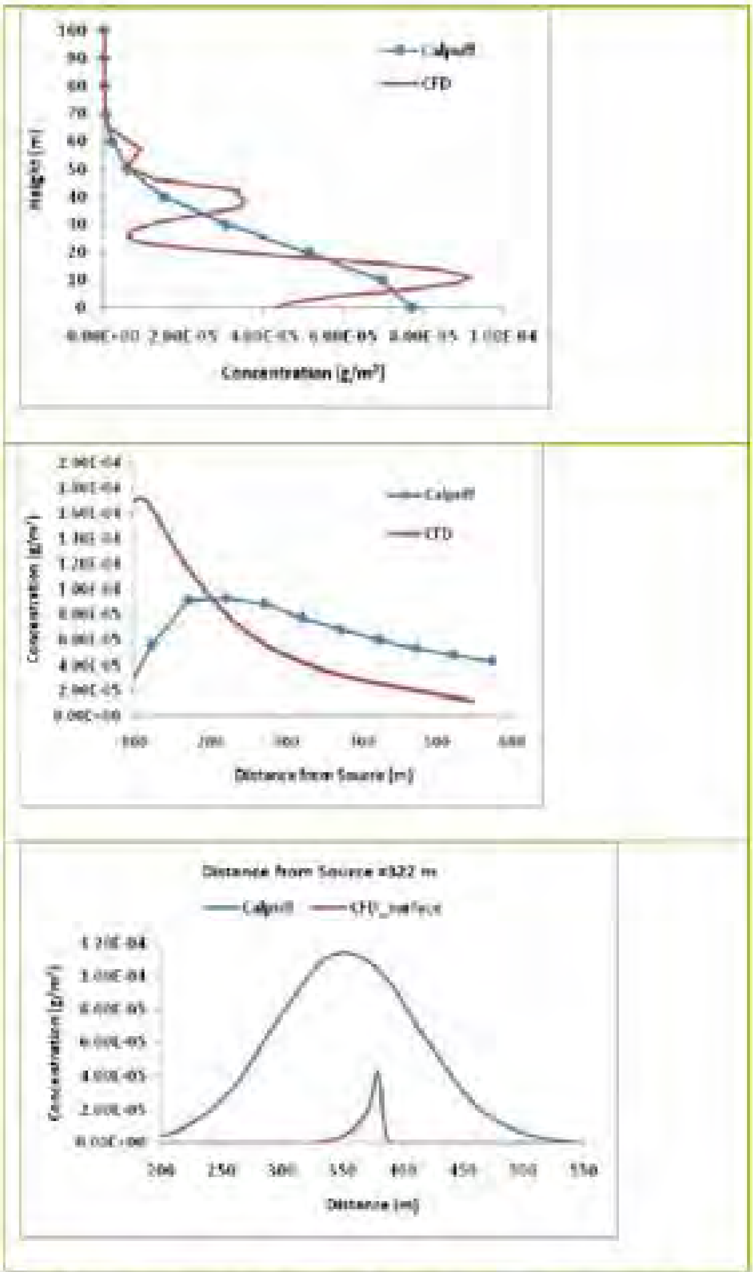


Figure 3.14: Profiles of predicted odour concentrations for Case 10 (45° wind). Top: concentration vs. height 300 m from source; middle: ground-level concentrations along plume centreline; and crosswind concentrations 300 m from the source.

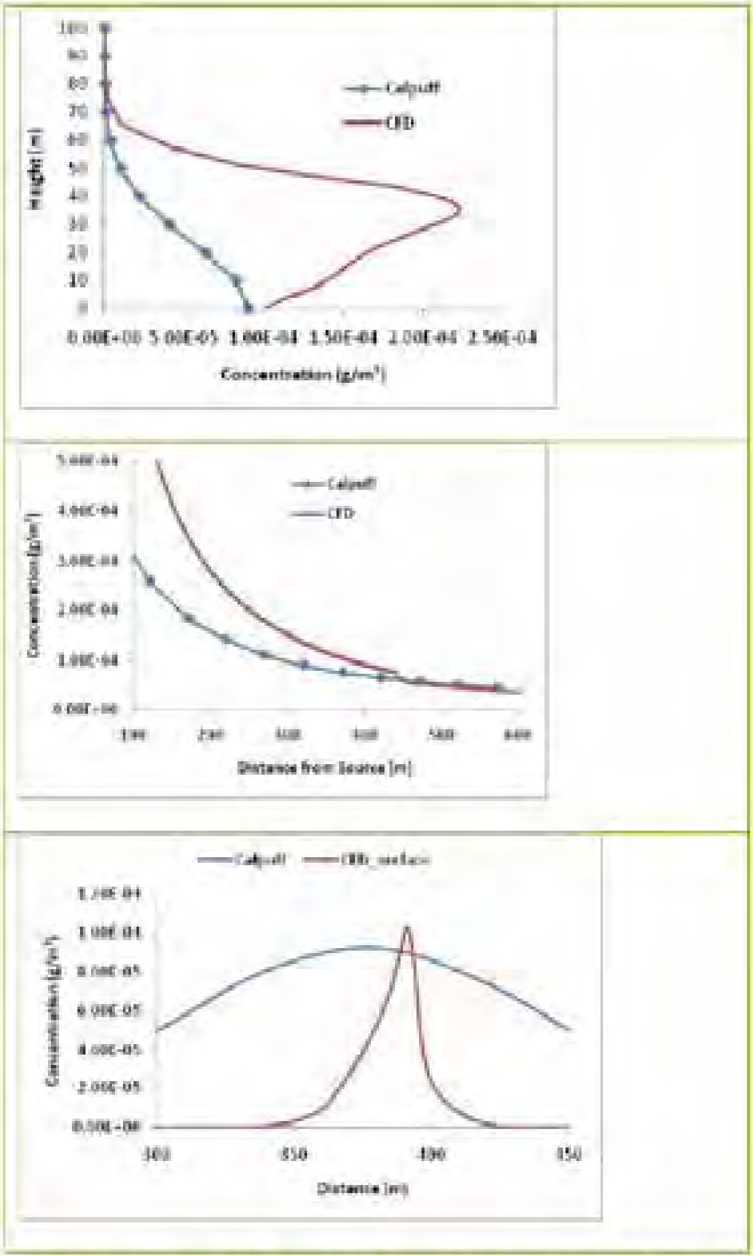


Figure 3.15: Profiles of predicted odour concentrations for Case 11 (90° wind). Top: concentration vs. height 300 m from source; middle: ground-level concentrations along plume centreline; and crosswind concentrations 300 m from the source.

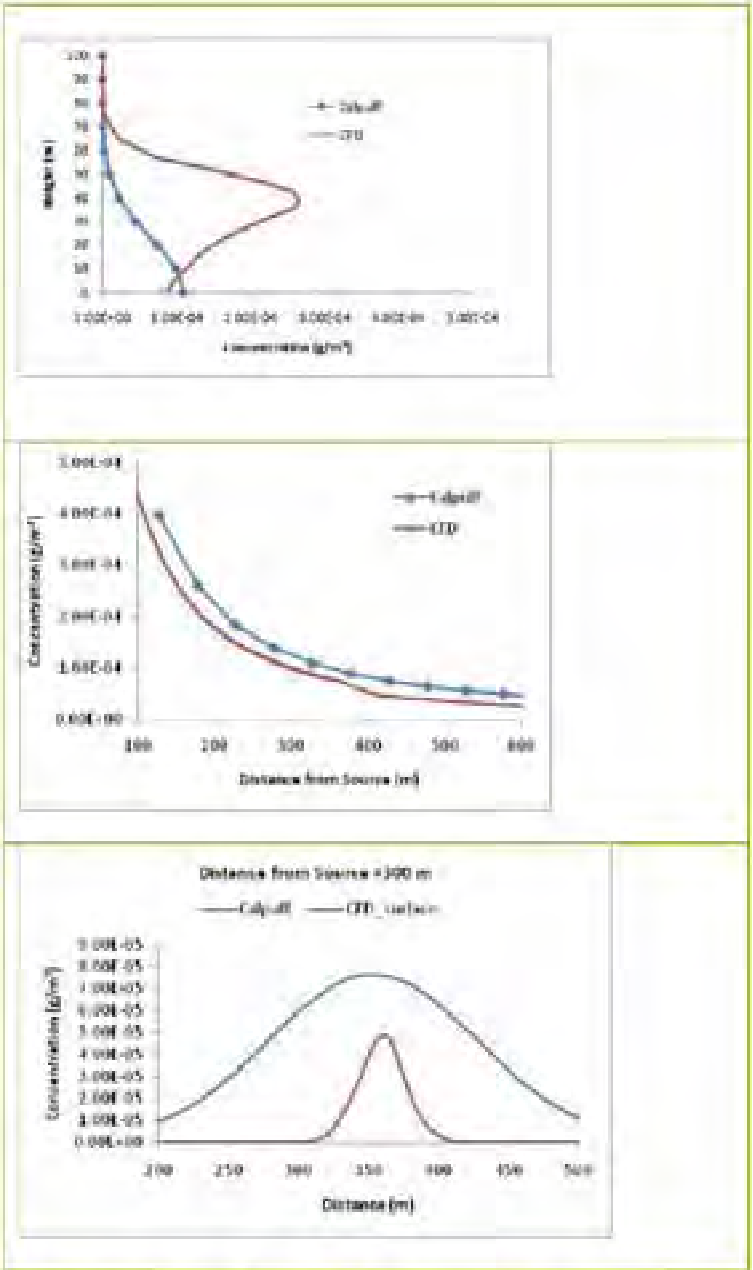


Figure 3.16: Profiles of predicted odour concentrations for Case 12(135° wind). Top: concentration vs. height 300 m from source; middle: ground-level concentrations along plume centreline; and crosswind concentrations 300 m from the source.

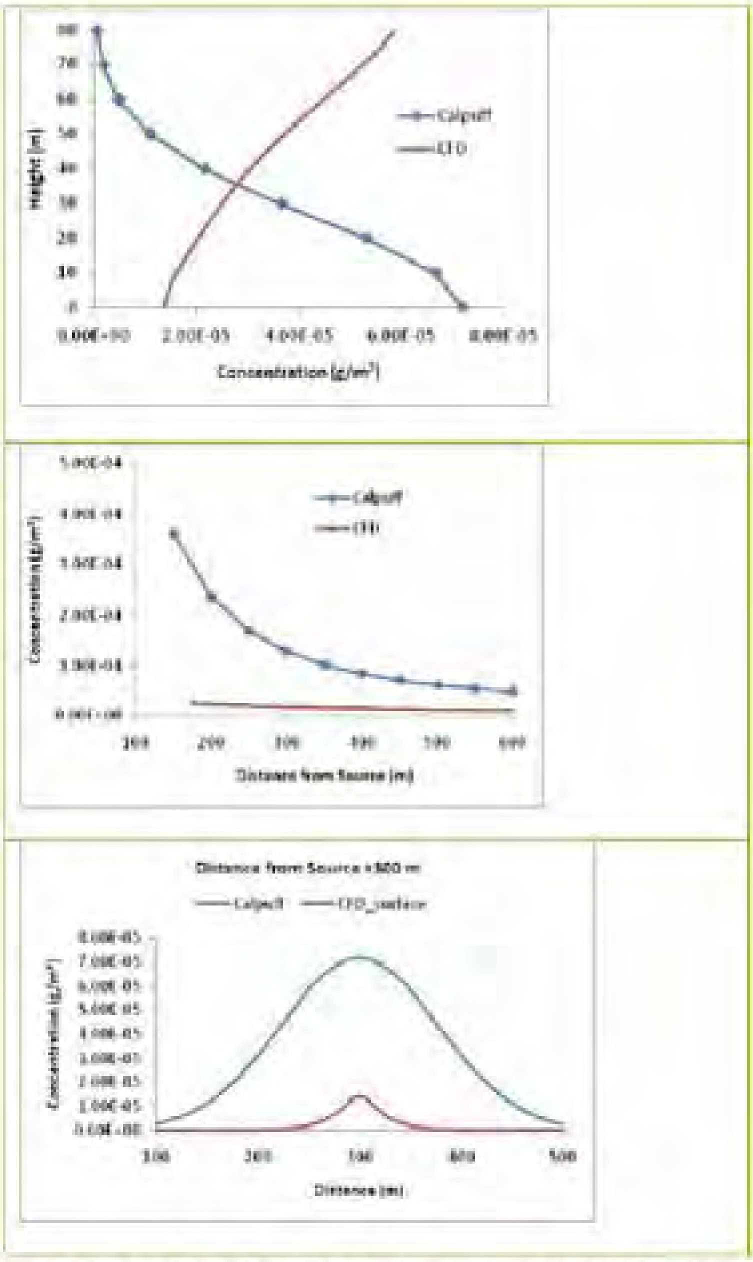


Figure 3.17: Profiles of predicted odour concentrations for Case 13 (180° wind). Top: concentration vs. height 300 m from source; middle: ground-level concentrations along plume centreline; and crosswind concentrations 300 m from the source.

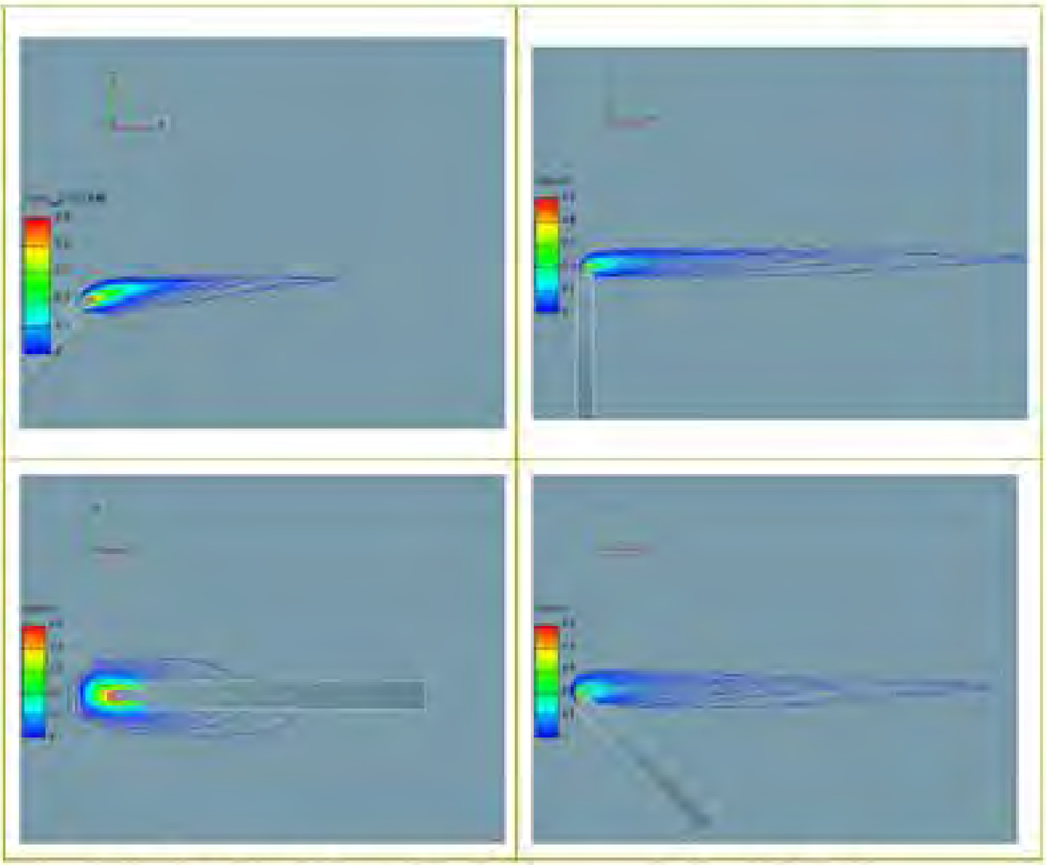


Figure 3.18: Plan view of of ground-level odour concentrations (relative to discharge concentration) predicted by CFD model for Case 10 (upper left), Case 11 (upper right), Case 12 (lower right), and Case 13.

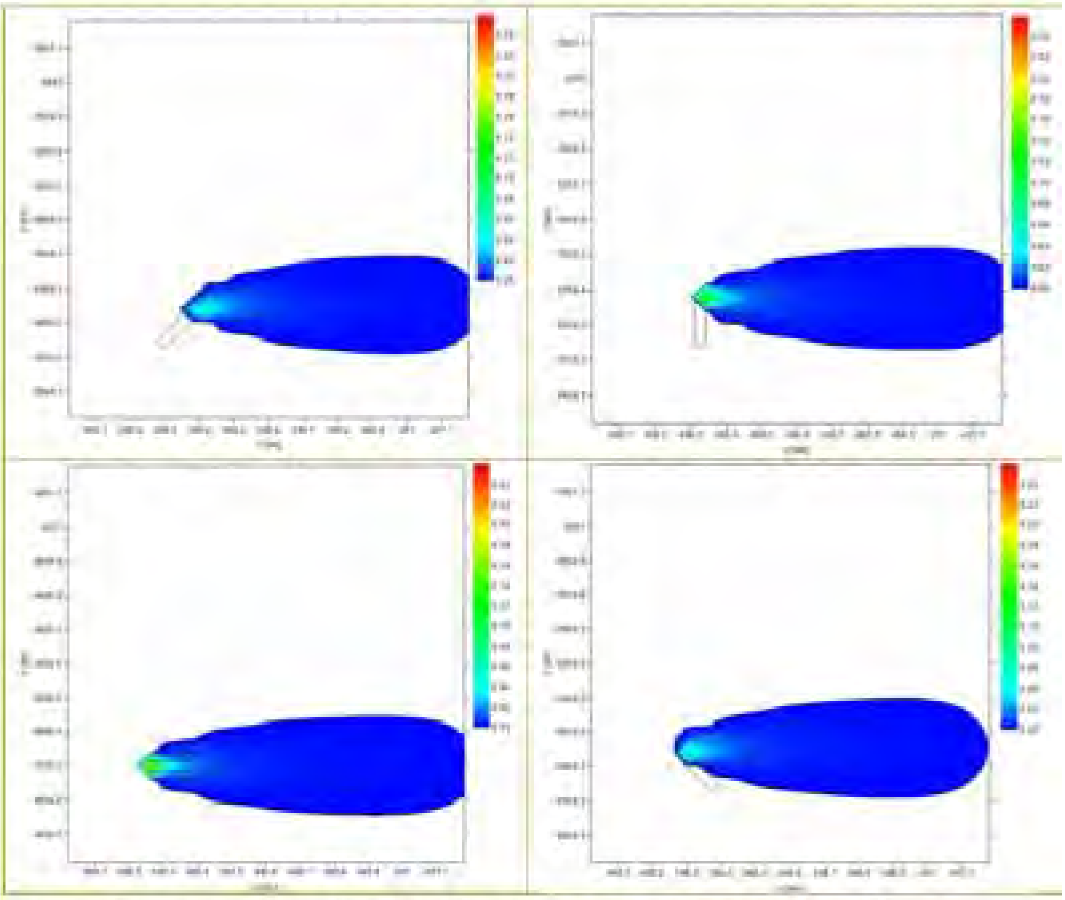


Figure 3.19: Plan view of ground-level odour concentrations (g/m^3) predicted by CALPUFF for Case 10 (upper left), Case 11 (upper right), Case 12 (lower right), and Case 13.

3.13 Case 14 (Light Wind)

A wind of 0.5 m/s causes the discharge to rise sharply into the upper boundary of the domain. As a result, ground level concentrations generated by the CFD model were found to be lowest in this case (Figure 3.20).

This case is noteworthy for CALPUFF because only under this condition was significant plume rise detected from the model. At the reference distance of 675 m, the plume reaches about 10 m. This behaviour also causes peak ground level concentrations to appear farther downwind (250 m) from the fans (middle ofFigure 3.20, in contrast to all other CALPUFF setups that predict the maximum at the side of the shed.

3.14 Case 15 (Strong Wind)

As might be expected, strong winds suppress plume rise and cause both CFD and CALPUFF models to predict highest ground level concentrations at the shed (Figure 3.21). No plume rise was seen in the CFD prediction. However, it is possible that the CFD model would have predicted the plume to ascend after its horizontal momentum is dissipated had the model boundary been long enough. This ascent will however be smaller than in the control since the strong advection will have reduced plume buoyancy more quickly.

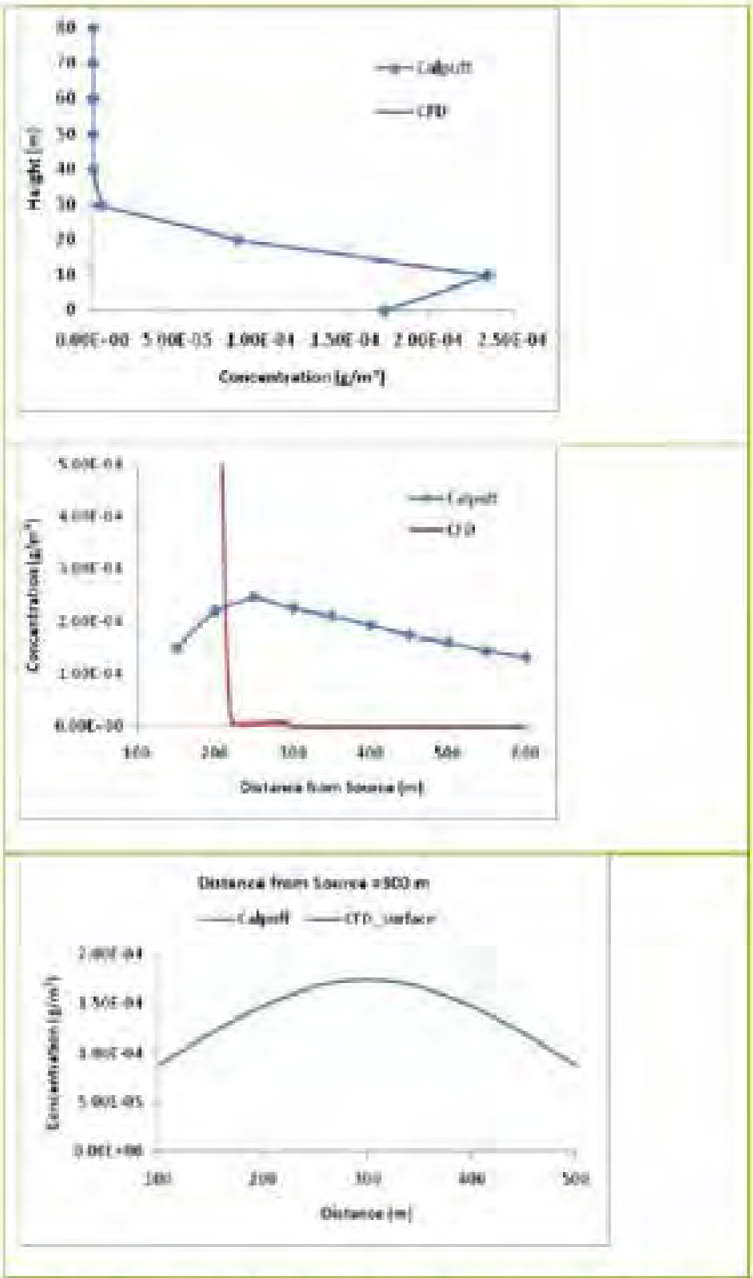


Figure 3.20: Profiles of predicted odour concentrations for Case 14 (wind speed = 0.5 m/s).Top: concentration vs. height 300 m from source; middle: ground-level concentrations along plume centreline; and crosswind concentrations 300 m from the source.

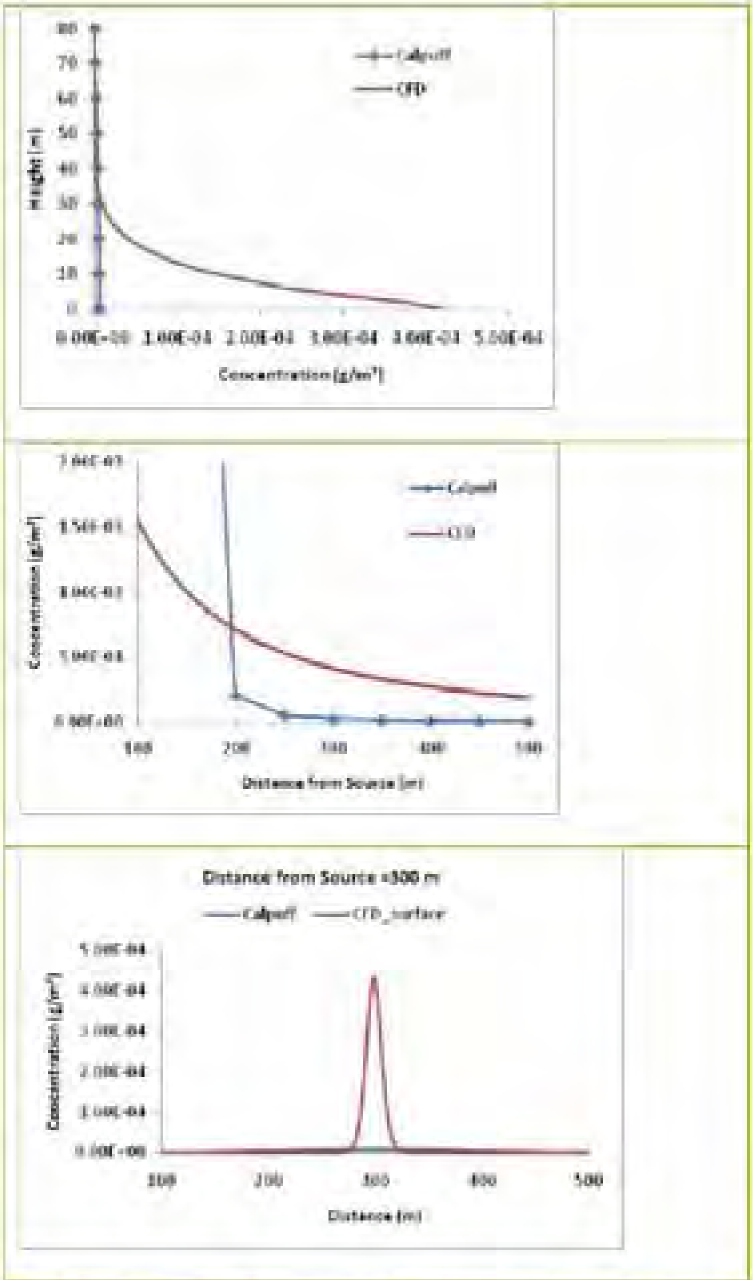


Figure 3.21: Profiles of predicted odour concentrations for Case 15 (wind speed = 10 m/s).Top: concentration vs. height 300 m from source; middle: ground-level concentrations along plume centreline; and crosswind concentrations 300 m from the source.

4 REGULATORY IMPLICATIONS

A key objective of the study is to determine, if possible, how to improve the results of regulatory models such as CALPUFF using the CFD findings. The previous chapter showed how CALPUFF fails to account for many aspects of the interaction between the discharge and the ambient flow. However, as a regulatory model CALPUFF aims less to simulate accurately this interaction than to ensure that a reasonable margin of safety through overprediction is maintained in the results. Improving CALPUFF should therefore identify whether conditions exist under which the model fails this aim.

In predicting odour impact from a chicken shed or any other facility, the most important output is the highest predicted offsite value of the 99.5th percentile of the 1-hour odour concentrations at ground level (using Queensland guidelines). However, this parameter cannot be used as a basis for comparing the results of the two models in this study since short hypothetical emissions and meteorological records were used as input in both models. Also, in CALPUFF the maximum concentrations were almost always found at the mouth of the discharge and cannot be meaningfully compared to the peaks predicted by the CFD model.

To compare the performance of CALPUFF and CFD in generating peak short-term ground-level concentrations, an index based on the farthest extent in metres of the 0.01OU concentration was used. The farther from the source this concentration isopleth extends, the higher the peak offsite concentrations. The focus of the analyses below is on the cases where CALPUFF results are lower than those of the CFD model, since these point to the possibility of CALPUFF failing to ensure a margin of safety.

Results of this comparison are shown in Figure 4.1. Several features may be drawn from this figure.

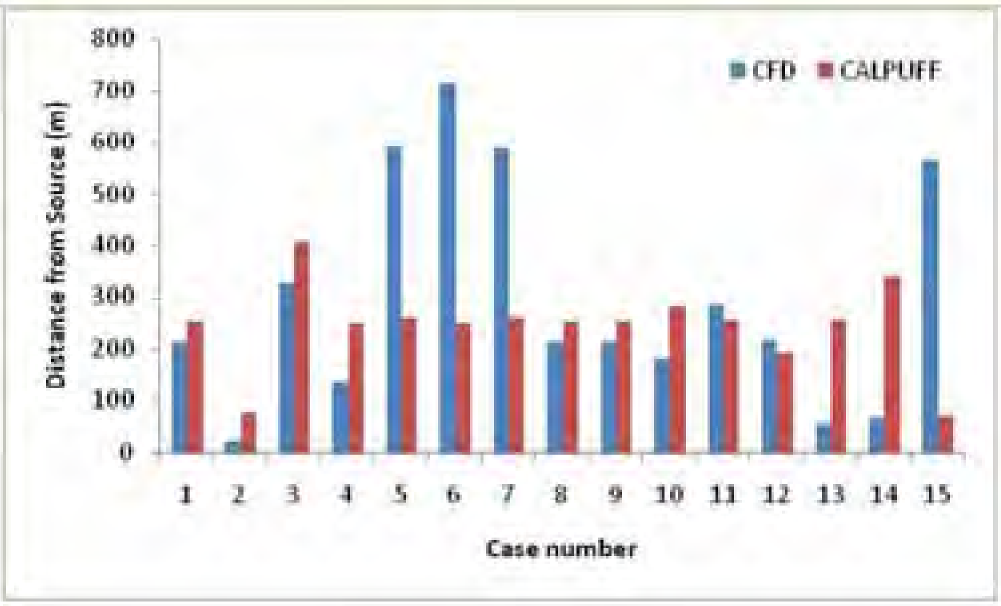
4.1 CALPUFF Underprediction

CALPUFF predictions consistently exceed those of the CFD model in those cases where the CFD model predicts significant plume rise. The difference is larger the higher the CFD plume rise; i.e., during warm shed temperatures (Case 4) or under weak winds (Case 14). For such cases, CALPUFF provides a margin of safety.

In those cases where the CFD model predicts little or no plume rise (Cases 5, 6 and 7), CALPUFF results (which also predict no plume rise) will always be lower than the CFD predictions. The reason is that the theoretical diffusion rate in the CFD model is lower than the empirical diffusion term used by CALPUFF. In other words, while the CFD model assumes the plume to be completely stationary within the averaging period, CALPUFF assigns stability-dependent puff spreading. As a result, peak concentrations at the affected receptors will always receive higher concentrations from the CFD model than from CALPUFF.

Since CALPUFF underpredicts the CFD results in these cases, the question arises whether there is a need to adjust either CALPUFF model inputs or outputs to retain the required margin of safety. But before any adjustments are recommended, it is critical to consider that the behaviour simulated by the CFD model in which the plume remains stationary is unrealistic, even under stable conditions. The CFD and CALPUFF results cannot be directly compared without first considering the differences inherent in the plume calculations regarding time-averaged turbulence effects. Assuming that a change in wind direction causes the plume to exhibit meandering equivalent to just the width of the plume within one hour, concentrations will drop by at least 50 percent. This will bring the predictions of the CFD model closer to those of CALPUFF (or even lower since the concentration curve is of exponential decrease).

Hence, these results do not point to need for adjusting CALPUFF to reproduce CFD results.



Case	Description	Case	Description
1	Control (7 fans, 6°C temperature difference, point source, co-flowing, 2 m/s wind)	8	Shed as volume source in CALPUFF
		9	Shed as quasi-stack
2	1 fan	10	Wind 45° from discharge
3	15 fans	11	Wind 90° from discharge
4	10°C difference	12	Wind 135° from discharge
5	2°C difference	13	Wind 180° from discharge
6	0°C difference	14	Wind speed 0.5 m/s
7	-6°C difference	15	Wind speed 10 m/s

Figure 4.1: Predicted Distances to 0.01-OU Concentration Isopleth, without accounting for necessary adjustments to CFD results for direct comparison to CALPUFF

A final point must be made regarding the frequency of the condition described in Case 7. DPI provided PAE with data on the temperatures inside and outside chicken sheds from three facilities taken every 15 minutes over a period of several months. The data showed that periods in which shed temperatures were cooler by 1°C than ambient or more occurred mainly during the summer months and during daytime. Presumably the shed interior was being cooled actively through evaporation, or passively through the shade provided by the shelter. In either case there is a limit to how much cooling can be achieved, and the negative temperature anomaly occurs less because the shed interior is cool but mainly because the outside air is very warm. This also means that these conditions occur principally during unstable conditions, making it every unlikely for the plume to behave in the stagnant manner described by the CFD model.

The only other case in which the CFD model overpredicts CALPUFF is Case 15, which assumes wind speeds of 10 m/s. Under such a case random plume behaviour should be even more pronounced, and 1-hour concentrations should be lower than predicted by the CFD model.

4.2 Effect of Wind Direction on Building Downwash

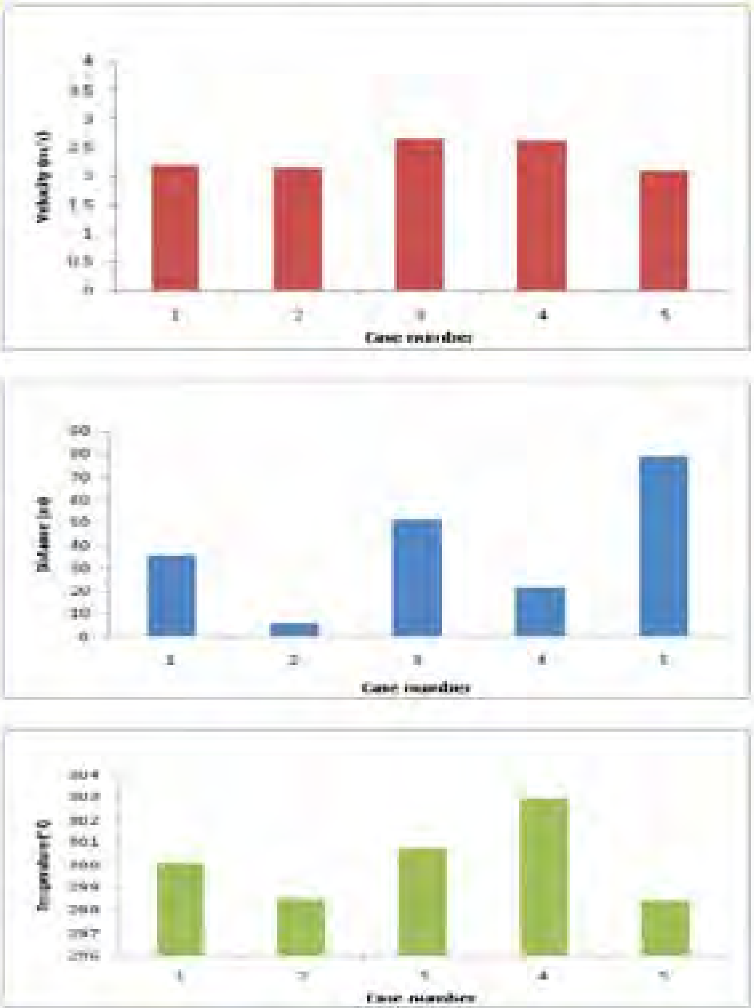
Certain wind directions result in higher concentrations with the CFD model than with CALPUFF. The CALPUFF and CFD models yield conflicting results when the angle between then discharge and the wind increases from 45° (Case 10) to 90° (Case 11), and from 135° (Case 12) to 180° (Case 13). Here the influence of the building and flow-plume interaction in the CFD model must be considered superior compared to the crude building downwash formulations used to account for these phenomena in CALPUFF. However, the underprediction by CALPUFF (in Case 11 and 12) is relatively small (about 10 percent below the comparable CFD prediction). Additional modelling runs will be needed to determine the maximum magnitude of this underprediction.

Comparing Cases 1, 8 and 9, it is seen that CALPUFF results are not sensitive to the assumed geometry of the source. In these tests, CALPUFF results are higher than the CFD's. However, these cases only consider co-flowing conditions. A reduction in CALPUFF predictions may result from a different source geometry with winds blowing at an angle.

Integrating these results, CALPUFF's inability to predict significant plume rise (with the settings used) is a shortcoming, but because it causes the model to remain conservative in its predictions, there is no need to correct this failure. In those cases where CALPUFF underpredicts the CFD model results, the CFD model is not seen to be realistic since it fails to account for plume meandering. CALPUFF also is weak in accounting for building downwash, but the result of this weakness appears to be minor, and underprediction is confined to specific angles between the wind and the building axis. Additional modelling runs would be needed to quantify this difference and eliminate the underprediction.

4.3 Effect of Shed Temperature and Ventilation Rate on Plume Rise

CFD prediction (Figure 4.2) shows that the distance to the point at which plume rise commences (x_r) and the plume temperature at which plume rise commences (T_r) are directly related to the shed temperature and ventilation rate. With similar shed temperature (Case2, Case1 and Case3), T_r and x_r increase with the increase of ventilation rate. With similar ventilation rate (Case4, Case1 and Case5) T_r increases with the increase of shed temperature. However with similar ventilation rate, x_r decreases with the increase in shed temperature. This behaviour of plume is expected, as the time required for discharge horizontal momentum to dissipate and become dominated by buoyancy depends on thermal buoyancy and ventilation rate.



Case	Description	Case	Description
1	Control (7 fans, 5°C temperature difference, point source, co-flowing, 2 m/s wind)	4	10°C difference
2	1 fan	5	2°C difference
3	15 fans		

Figure 4.2: Predicted plume velocity, distance from source (x) and plume temperature (T) of the point at which plume rise commences.

5 CONCLUDING REMARKS

5.1 Generalized Plume Behavior

Based on the results of the CFD model, the discharge of warm air from chicken sheds and similar facilities exhibits four separate stages:

1. Horizontal jet stage
2. Plume rise stage
3. Plume levelling stage
4. Plume decay stage

5.1.1 The Horizontal Jet Stage

The horizontal jet stage is due to the action of the fans. The length of time the plume stays in this stage is determined by the temperature difference, the number of fans, the ambient wind speed, and the angle between the wind and the discharge. The plume stays horizontal longer if the plume is cooler, if more fans are used, and if the wind is of such a direction that enhances the discharge. The direction also indirectly influences the length of this period by enhancing or suppressing building downwash: more downwash means weaker plume rise.

This stage ends when the plume's horizontal momentum weakens due to friction and turbulence.

5.1.2 Plume Rise

The CFD model distinctly simulates plume rise from the shed under most of the cases studied. Under neutral conditions, the plume appears to ascend in a straight line. By contrast, plume rise is not seen in the CALPUFF results except for the 0.5 m/s wind speed case, even where it assumes the shed to be a point source.

A rising trajectory is what would be expected of a plume with buoyancy. The main reason CALPUFF fails to reproduce this effect is that the Briggs plume rise formulations are not designed to handle plumes of chicken sheds, which are cooler and have little vertical momentum compared to industrial smoke stacks for which these formulas were originally designed. A test using the numerical plume rise option and with building downwash (BPIP) turned off in CALPUFF also showed no rise for the standard 2 m/s wind speed case that was used for most of the simulations.

Plume rise is a function of the discharge temperature and the ambient temperature. A warmer plume relative to the environment has more buoyant energy, while weak ambient flow means weaker entrainment which allows the plume to retain more of this energy. The flow and temperature profile also define the shape of the ascent.

The longer the plume stays in the horizontal jet stage, the weaker the plume rise. This is because the plume loses buoyancy continuously with time. All other things being equal, the sooner the plume begins to rise the more buoyancy it retains and the higher it can ascend.

5.1.3 Plume Levelling Stage

As the plume rises, it cools down adiabatically due to expansion under lower pressures at higher elevations. Theoretically, the plume will keep rising until its temperature intersects that of the environment (if the lapse rate is stable). However, the actual level will be lower since the plume's buoyancy will be eroded by entrainment with the ambient air. The maximum height at which the plume levels off is therefore a function of the temperature difference between the discharge and the ambient air at different levels. The length of time the plume stays at the same level depends on the ambient wind speed, which also determines the entrainment rate: lower winds speeds allow the plume to retain its temperature longer.

The effect of other values of the temperature lapse rate is discussed below.

5.1.4 Plume Decay

As the plume levels off, it continues to dissipate. This dissipation is manifested as the increase, with time and distance, of the diameter of the plume cross-section. The rate of this increase is expected to be dependent on the available turbulent energy in the atmosphere, which causes the plume to meander or become entrained into the ambient air.

A feature of this stage is the descent of the plume centreline. This subsidence to lower elevations is only apparent because in absence of a downdraft, the parcels of air making up the plume remain at the same mean elevations after plume levels off. What drifts downward is the height of maximum concentration. This height decreases because faster winds at higher elevations erode the upper half of the plume more quickly than the weaker winds at lower half. Since this descent is only apparent, it does not result in an increase in ground-level concentrations with increasing distance from the source.

5.2 Extensions to Other Stability Conditions

The study considered only neutral stability conditions because the results can be theoretically extended to other stability conditions. These two other conditions are discussed below.

5.2.1 Unstable Conditions

In meteorology, unstable conditions refer to a temperature profile that decreases faster with height than 1°C per 100 m, the neutral lapse rate used in the cases studied. In such a case, the plume will exhibit a different behaviour from what was found here. When the plume ascends to another height, it will have cooled down adiabatically as before. But unlike the neutral case, in an unstable atmosphere the temperature difference between the rising plume and the ambient air will increase with height. This will cause the plume to accelerate upwards, slowing down and eventually stopping its ascent only when it loses buoyancy due to diffusion. It will however reach a higher elevation than in the neutral case.

Unstable conditions will enhance plume rise in all the cases considered, even if the CALPUFF plume rise formulation may not adequately reproduce this effect. In light of this, CALPUFF will generate even more conservative predictions than it did in the neutral case. From a regulatory standpoint, there will therefore be no need to adjust its results or those of other models that make use of the same plume rise formulations.

5.2.2 Stable Conditions

A stable atmosphere is one where the temperature lapse rate is decreasing less quickly than neutral, or even constant or *increasing* with height. This occurs most often at night to early morning because air in contact with the ground cools down faster than air aloft. Stable atmospheric conditions will, as expected, have the opposite, suppressive effect on plume rise as unstable conditions. Because the plume starts out as warm, it will still rise after the horizontal jet stage. However, the atmosphere will be warmer at the same level than it would be had it been neutral. The temperature of the plume and the ambient air will thus equalize at a lower elevation than before. As shown in Figure 5.1, plume rise will therefore be more limited, and concentrations at ground level will be higher.

A test with the CFD model made use of a stable lapse rate of -0.25°C/100 m while keeping all other conditions identical to the control case. The results indicate that the 0.01 OU isopleth will extend to 233 m from the source, a value about 10 percent higher than the 214 m found for the control case. However, this value is still less than the 254 m predicted by CALPUFF under neutral conditions. Since running CALPUFF under stable conditions will certainly cause this value to increase, CALPUFF will remain more conservative than the CFD model even under stable conditions.

When the atmosphere is stable and the temperature of the discharge is not much warmer than the ambient, plume behaviour as predicted by the CFD model is likely to be more accurate than in CALPUFF. Because these concentrations are higher than those of CALPUFF, they raise the need for adjustments. Additional modelling runs will be needed to determine these adjustments to CALPUFF.

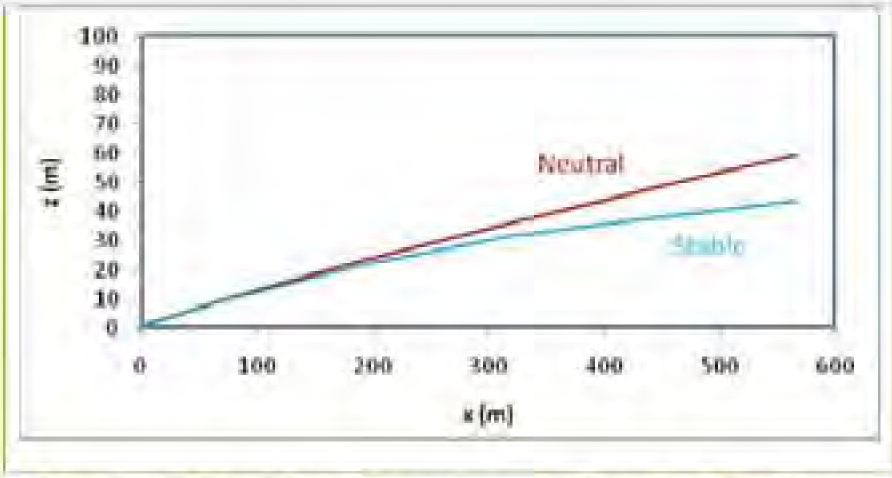


Figure 5.1: CFD prediction of Plume Rise under Neutral and Stable Lapse Rate, Case1.

5.3 CFD Model Performance

In general, plumes generated by the CFD model are narrower than those of CALPUFF. This explains much of differences in the results of the two models, and is an important difference that reflects the basic formulation of the models. Importantly, the predicted plume concentrations cannot be directly compared between the models: an adjustment of one or the other is necessary to provide an approximation that can be used for comparison.

In CALPUFF and in other Gaussian dispersion models, plume width is not a measure of the shape of the plume at a given time but is the time-averaged (usually hourly) distribution of concentrations across its mean position. The instantaneous plume width is actually narrower than in the Gaussian plume. Rather than quantify the plume's snapshot dimensions, dispersion coefficients instead account for the plume's meander in both the horizontal and vertical directions over the integration timestep.

The CFD model cannot incorporate the observed meander without introducing an artificial random component in the flow. Such a step radically increases both the computing demands and uncertainty in its results. Hence, the CFD results reflect more effectively the instantaneous plume dimensions when the flow is unperturbed by turbulent fluctuations that apply over longer time-scales.

In sum, as important are the insights provided by the CFD model in simulating the behaviour of plumes from poultry sheds, translating these insights into practical recommendations in CALPUFF applications is not a straightforward process and will require more work with both models.

5.4 Poultry Sheds as Buoyant Line Sources

CALPUFF cannot account for plume rise if poultry sheds are modelled as a volume source. An approach that could be worth testing is to model the sheds as buoyant line sources. Such a representation will still be imperfect since CALPUFF's plume rise algorithm for such sources is designed for industrial smelters with high source temperatures. However, given that the discharge does behave as a buoyant line source in its initial stage particularly under co-flowing conditions, the approach could be tested using the experiments conducted here.

5.5 Other Recommendations

The finding that significant plume rise can occur with poultry shed emissions is an important outcome that puts into question the widespread practice of ignoring this phenomenon. However, a monitoring campaign would be needed to verify whether the CFD model accurately predicts this ascent. Despite this finding, CALPUFF is sufficient if the aim is to maintain a margin of safety and overprediction in the modelling. It remains possible that there are source-receptor configurations, particularly in complex terrain, in which the inclusion of plume rise will yield more conservative results than with no plume rise. Additional modelling work will be needed in identifying such configurations.

6 REFERENCES

Jiang, J, and Sands, J, 1998, ***Report on Odour Emissions from Poultry Farms in Western Australia.*** Principal Technical Report", Centre for Water and Waste Technology, University of NSW, Sydney.

Jiang, J, and Sands, J., 2000. ***Odour and Ammonia Emission from Broiler Farms.*** RIRDC Project UNS-11A, Rural Industries Research and Development Corporation, Canberra. http://www.rirdc.gov.au/reports/CME/00-2.pdf

Prueger, J. H., W. E. Eichinger, L. E. Hipps, J. L. Hatfield and D. I. Cooper, 2008. Air-flow distortion and turbulence statistics near an animal facility. *Atmospheric Environment*, **42**, 3301-3314.

Appendix A
Isosurface plots of CFD Results

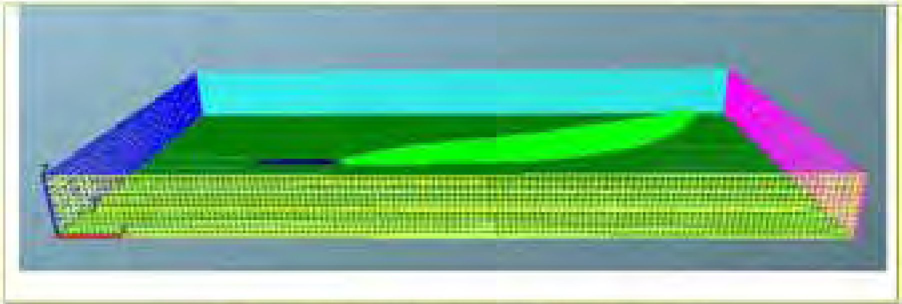


Figure A.1: Plume visualisations for Case 1

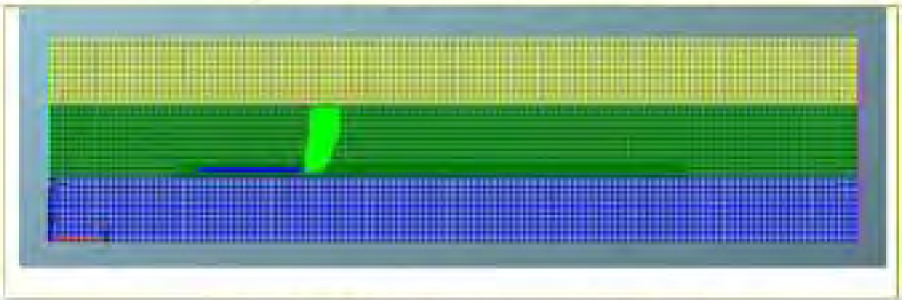


Figure A.2: Plume visualisations for Case 2

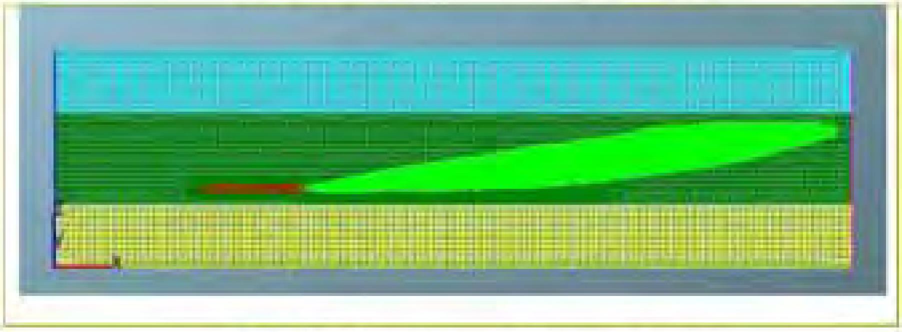


Figure A.3: Plume visualisations for Case 3

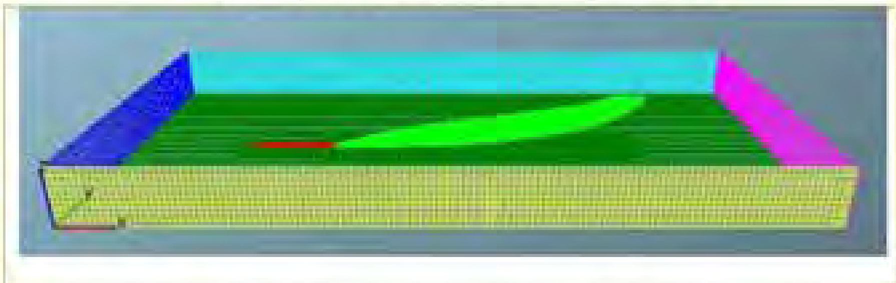


Figure A.4: Plume visualisations for Case 4

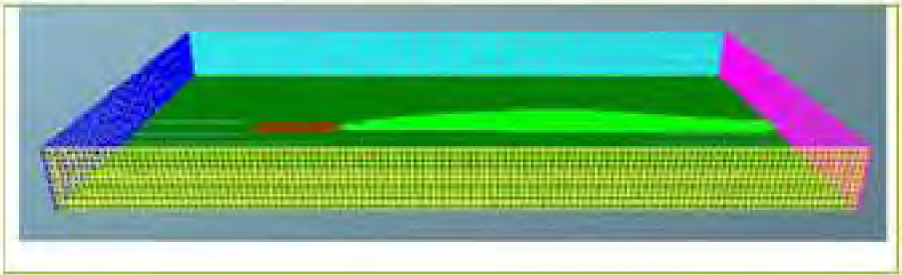


Figure A.5: Plume visualisations for Case 5

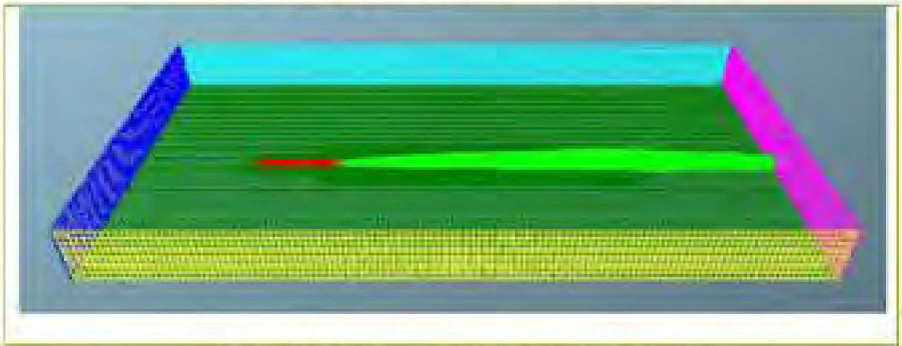


Figure A.6: Plume visualisations for Case 6

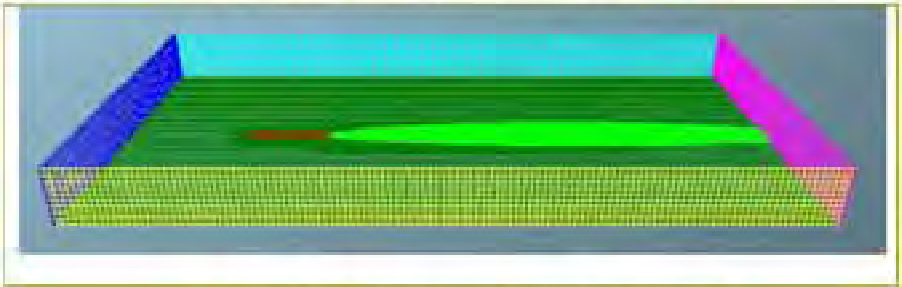


Figure A.7: Plume visualisations for Case 7

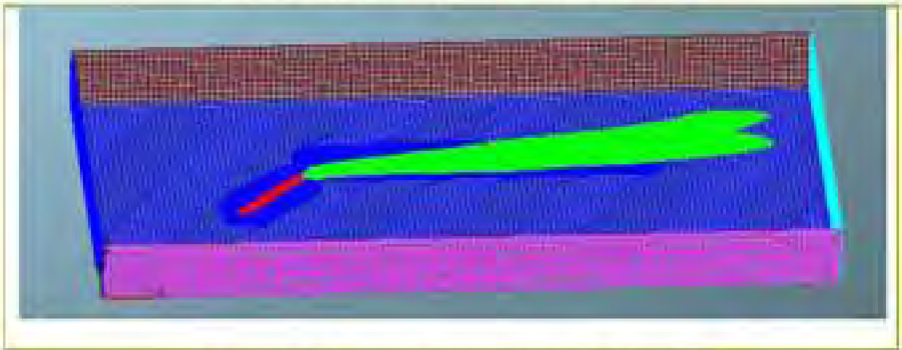


Figure A.8: Plume visualisations for Case 10

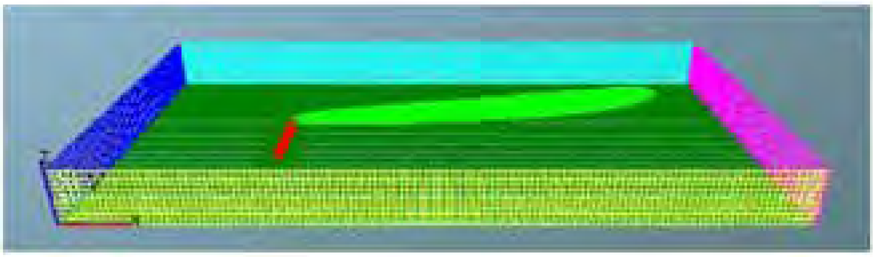


Figure A.9: Plume visualisations for Case 11

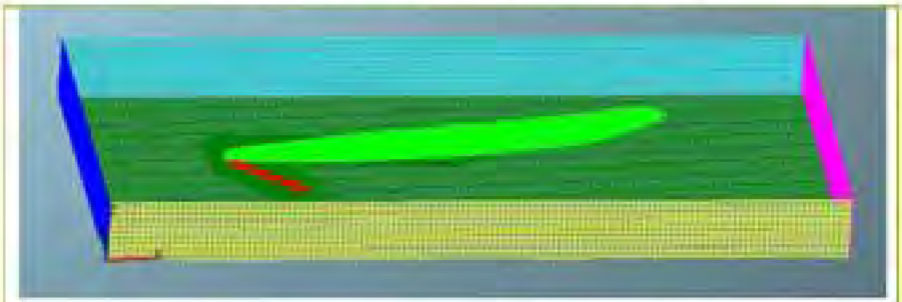


Figure A.10: Plume visualisations for Case 12

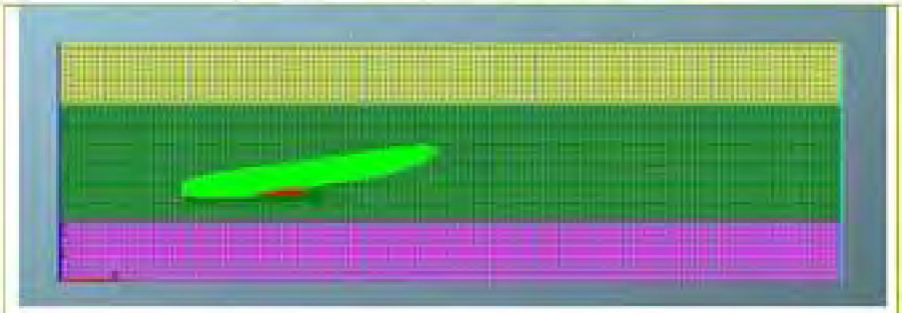


Figure A.11: Plume visualisations for Case 13

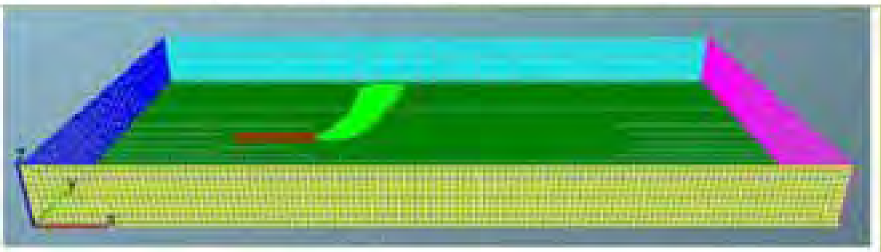


Figure A.12: Plume visualisations for Case 14

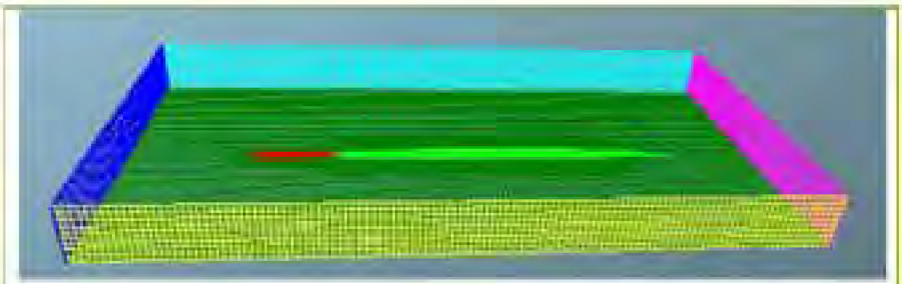


Figure A.13: Plume visualisations for Case 15

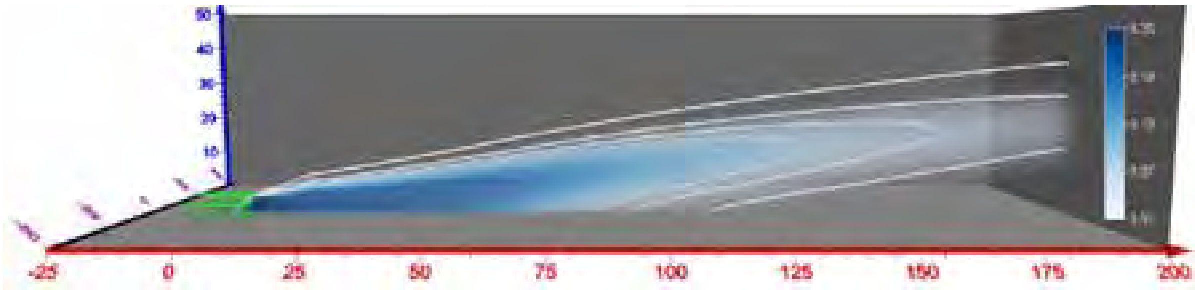
Appendix B
Calpuff model parameters

Table 8.1 Calpuff Model Parameters

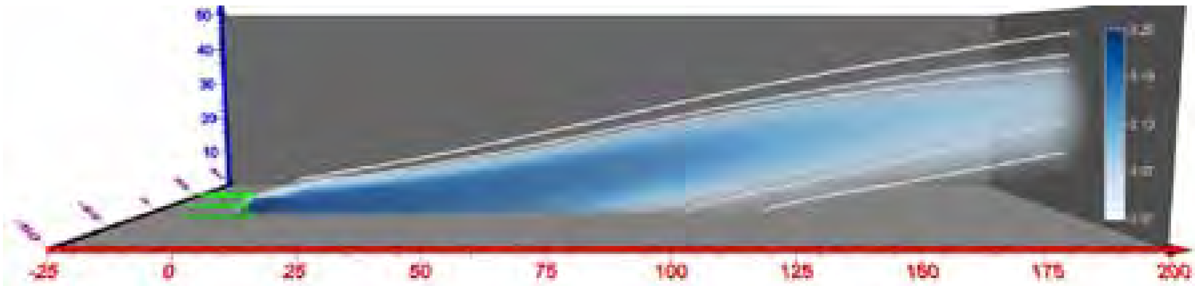
Case	Parameter Tested	Type of Source	Surface Roughness	Building Downwash	Temperature Difference (°C)	Ventilation Rate (%)	Neutral Stability (m/s)	Wind Direction	Wind Speed (m/s)
1	Control (horizontal point source)	Point	0.25	Yes	5	1 fans (50%)	S.C	0 (in flowing)	2
2	Fan Activity	Point	0.25	Yes	5	1 fan (7%)	S.C	0	2
3		Point	0.25	Yes	5	14 fans (100%)	S.C	0	2
4	Temperature difference (discharge - normal ambient)	Point	0.25	Yes	10	50%	S.C	0	2
5		Point	0.25	Yes	2	50%	S.C	0	2
6		Point	0.25	Yes	0	50%	S.C	0	2
7		Point	0.25	Yes	-5	50%	S.C	0	2
8	Source geometry (volume source)	Volume	0.25	No	N/A	50%	S.C	0	2
9	Source geometry (quasi-vertical)	Point source with vertical velocity	0.25	Yes	5	50%	S.C	0	2
10	Wind direction (in-flowing = 0)	Point	0.25	Yes	5	50%	S.C	45	2
11		Point	0.25	Yes	5	50%	S.C	90	2
12		Point	0.25	Yes	5	50%	S.C	135	2
13		Point	0.25	Yes	5	50%	S.C	180	2
14	Wind speed	Point	0.25	Yes	5	50%	S.C	0	0.5
15		Point	0.25	Yes	5	50%	S.C	0	10

Appendix 2: CFD outputs: Plume concentrations

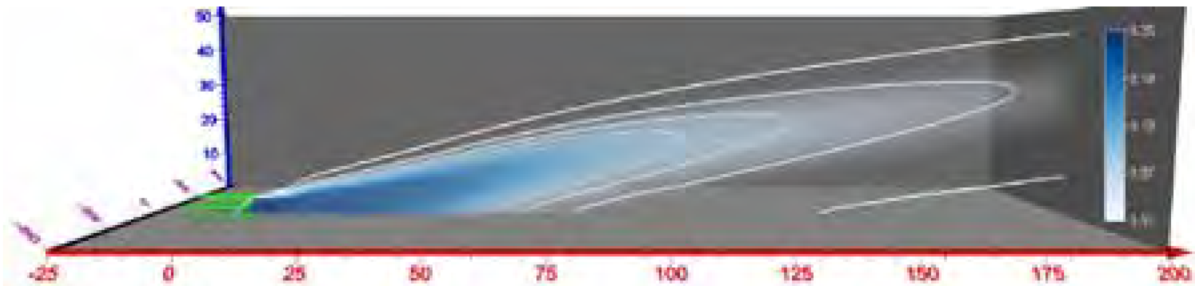
For selected cases



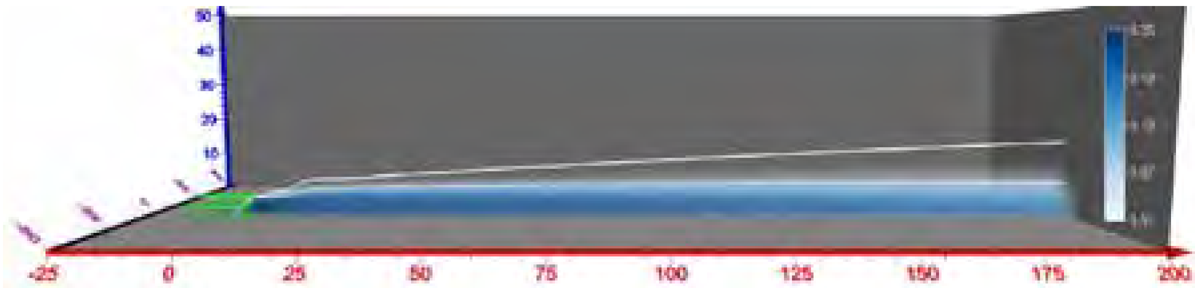
Appendix 2 Figure 1: **Case 1 (6 °C Delta T, 2 m/s wind speed, 0° Co-flow wind direction, 50% ventilation)**



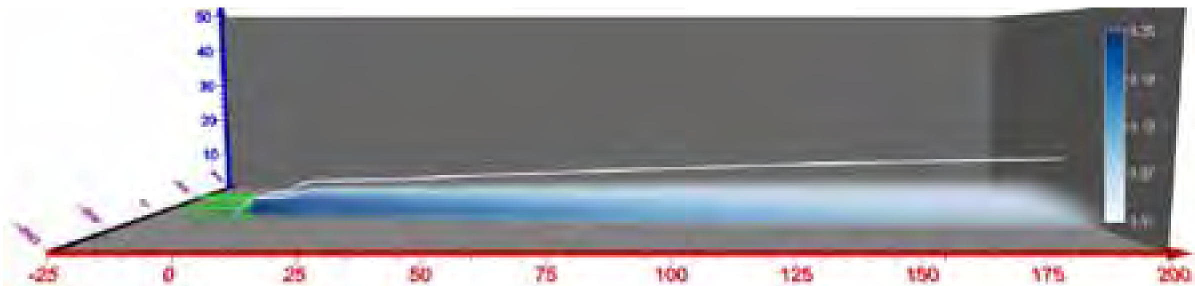
Appendix 2 Figure 2: **Case 3 (6 °C Delta T, 2 m/s wind speed, 0° Co-flow wind direction, 100% ventilation)**



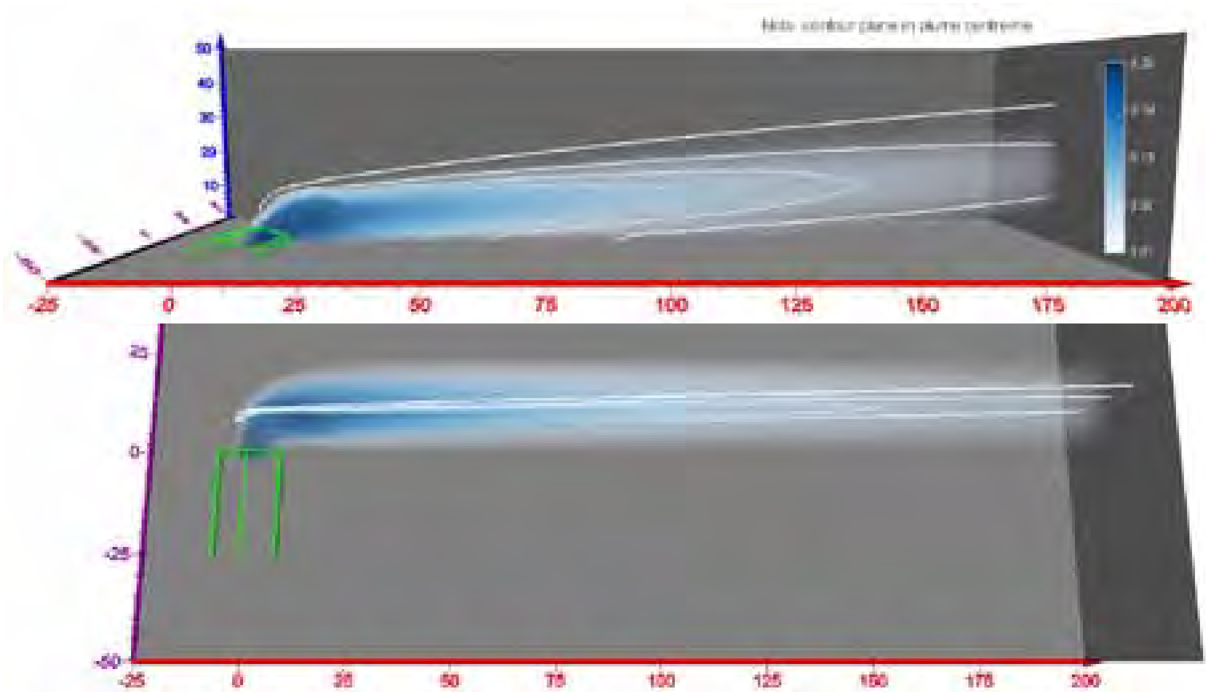
Appendix 2 Figure 3: **Case 4 (10 °C Delta T, 2 m/s wind speed, 0° Co-flow wind direction, 50% ventilation)**



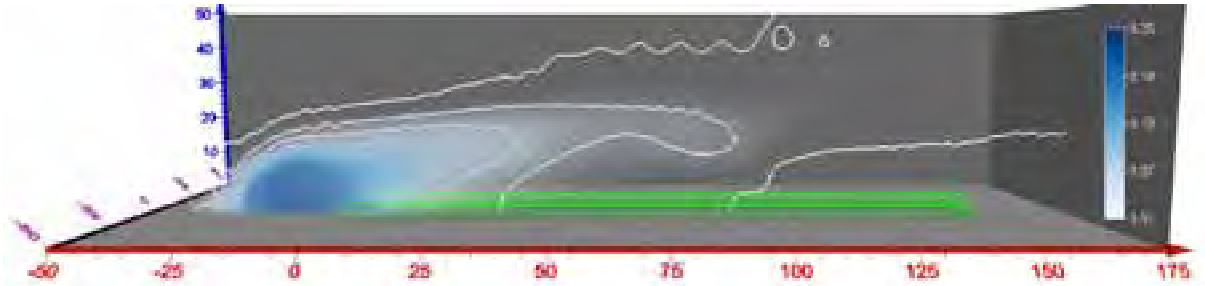
Appendix 2 Figure 4: **Case 6 (0 °C Delta T, 2 m/s wind speed, 0° Co-flow wind direction, 50% ventilation)**



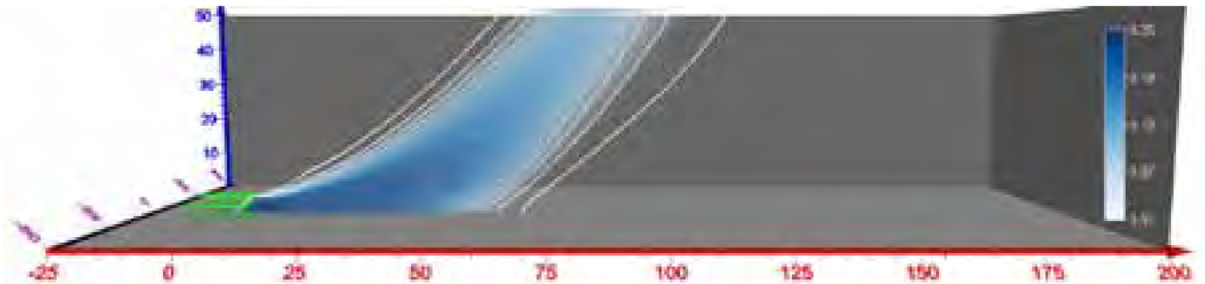
Appendix 2 Figure 5: **Case 7 (-6 °C Delta T, 2 m/s wind speed, 0° Co-flow wind direction, 50% ventilation)**



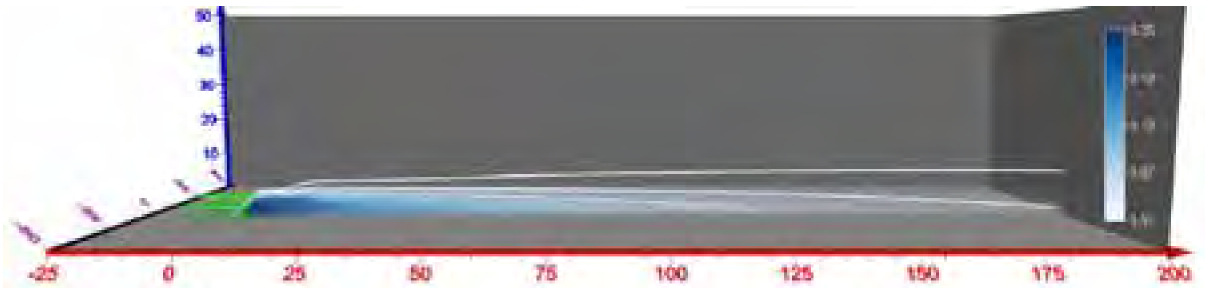
Appendix 2 Figure 6: **Case 11 (6 °C Delta T, 2 m/s wind speed, 90° wind direction, 50% ventilation): Front view (*top*) and Top view (*bottom*)**



Appendix 2 Figure 7: **Case 13 (6 °C Delta T, 2 m/s wind speed, 180° Counter-flow wind direction, 50% ventilation)**



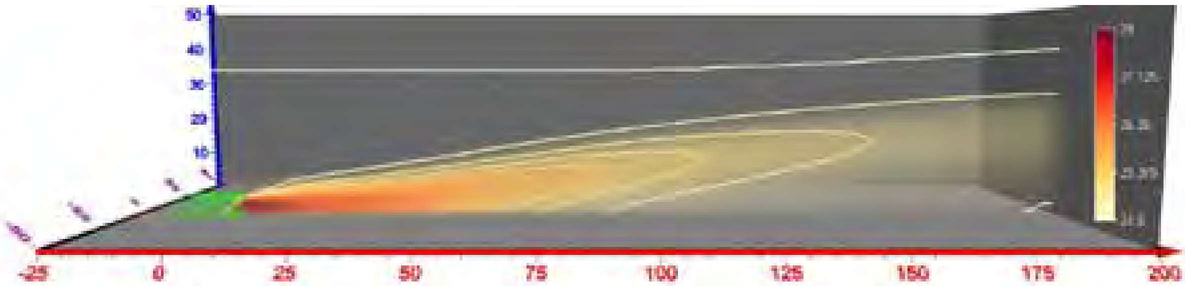
Appendix 2 Figure 8: **Case 14 (6 °C Delta T, 0.5 m/s wind speed, 0° Co-flow wind direction, 50% ventilation)**



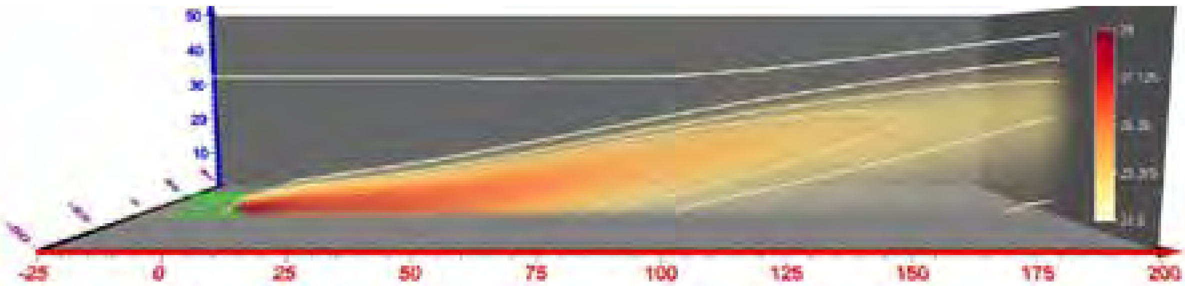
Appendix 2 Figure 9: **Case 15 (6 °C Delta T, 10 m/s wind speed, 0° Co-flow wind direction, 50% ventilation)**

Appendix 3: CFD outputs: plume temperatures

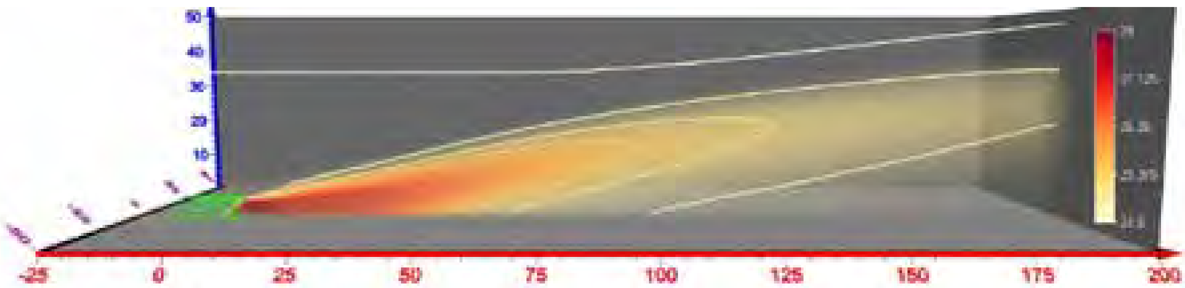
For selected scenarios



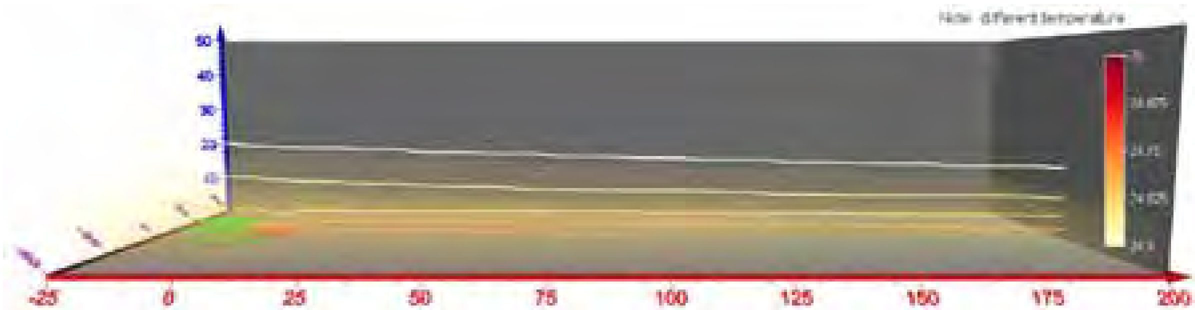
Appendix 3 Figure 1: **Case 1 (6 °C Delta T, 2 m/s wind speed, 0° Co-flow wind direction, 50% ventilation)**



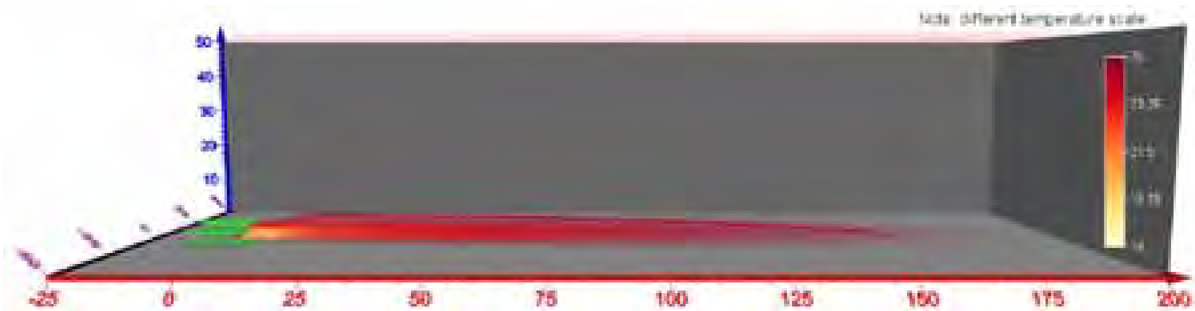
Appendix 3 Figure 2: **Case 3 (6 °C Delta T, 2 m/s wind speed, 0° Co-flow wind direction, 100% ventilation)**



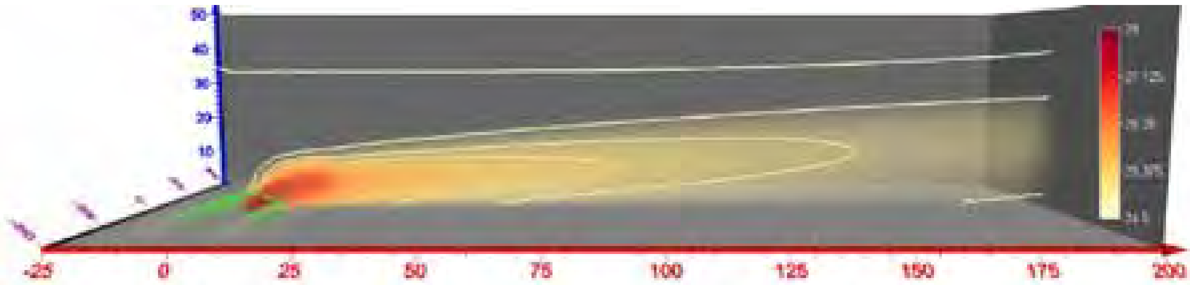
Appendix 3 Figure 3: **Case 4 (10 °C Delta T, 2 m/s wind speed, 0° Co-flow wind direction, 50% ventilation)**



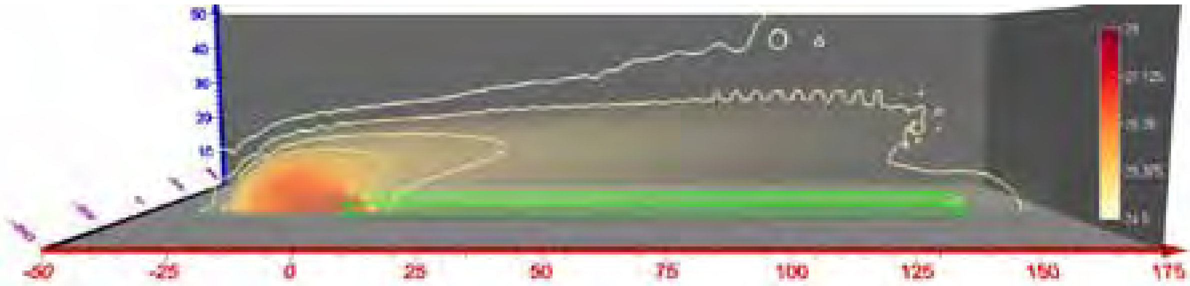
Appendix 3 Figure 4: **Case 6 (0 °C Delta T, 2 m/s wind speed, 0° Co-flow wind direction, 50% ventilation)**



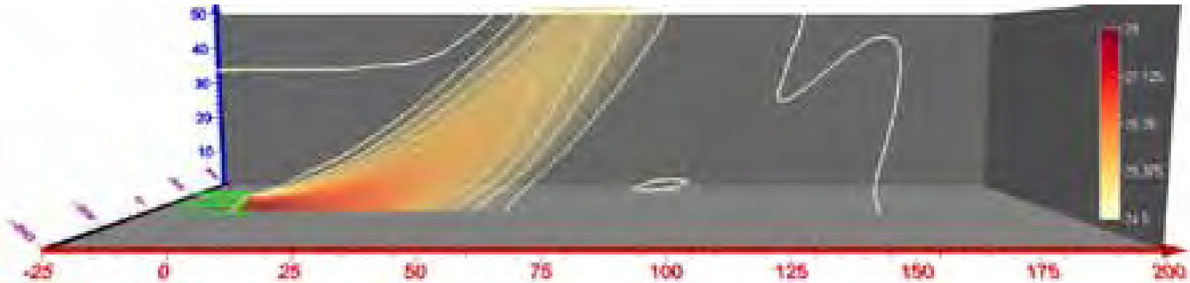
Appendix 3 Figure 5: **Case 7 (-6 °C Delta T, 2 m/s wind speed, 0° Co-flow wind direction, 50% ventilation)**



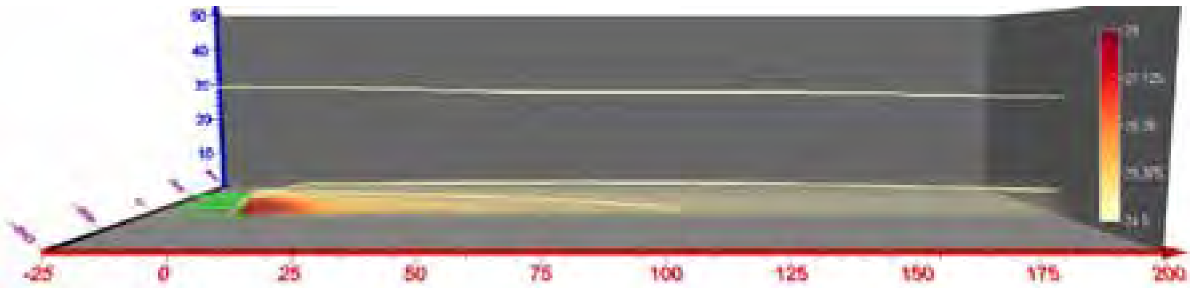
Appendix 3 Figure 6: **Case 11 (6 °C Delta T, 2 m/s wind speed, 90° perpendicular wind direction, 50% ventilation)**



Appendix 3 Figure 7: **Case 13 (6 °C Delta T, 2 m/s wind speed, 180° Counter-flow wind direction, 50% ventilation)**



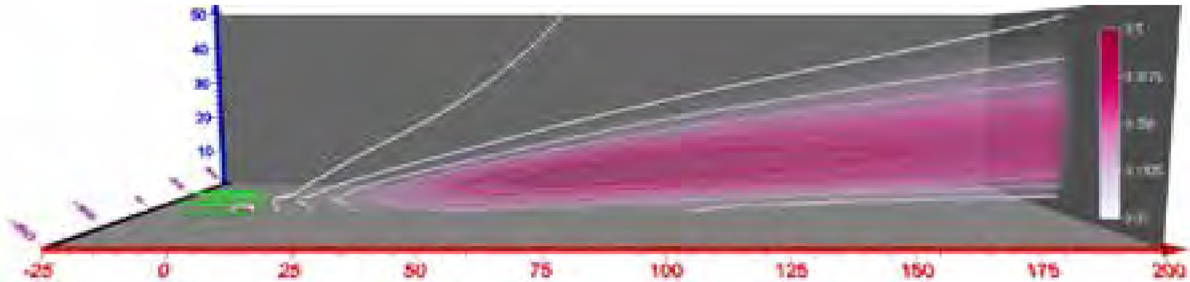
Appendix 3 Figure 8: **Case 14 (6 °C Delta T, 0.5 m/s wind speed, 0° Co-flow wind direction, 50% ventilation)**



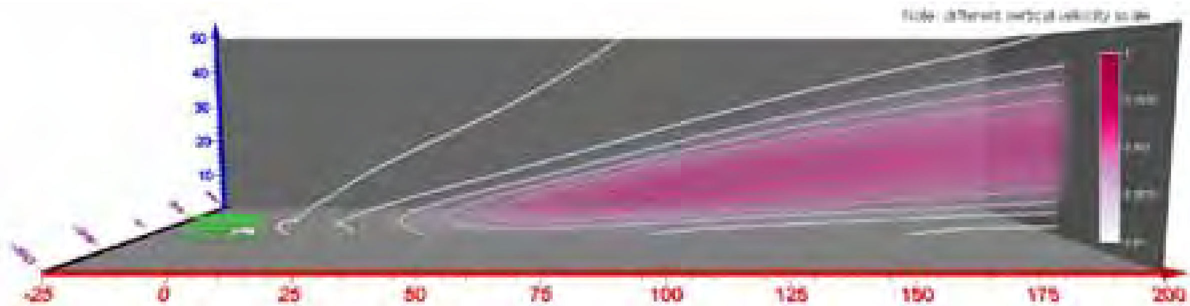
Appendix 3 Figure 9: **Case 15 (6 °C Delta T, 10 m/s wind speed, 0° Co-flow wind direction, 50% ventilation)**

Appendix 4: CFD outputs: plume vertical velocity

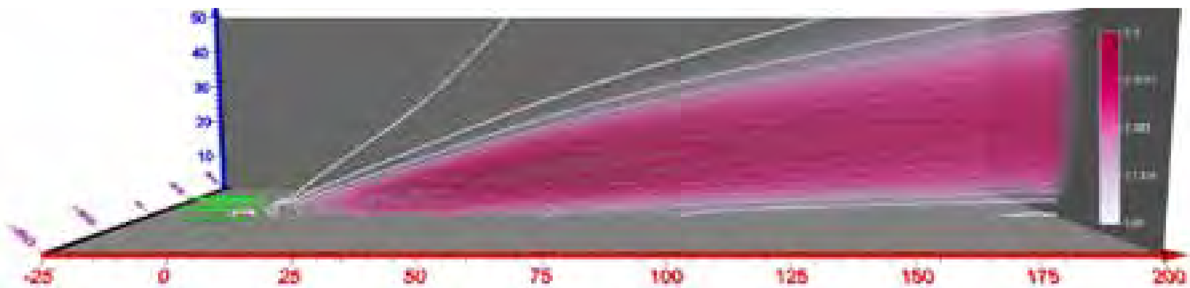
For selected scenarios



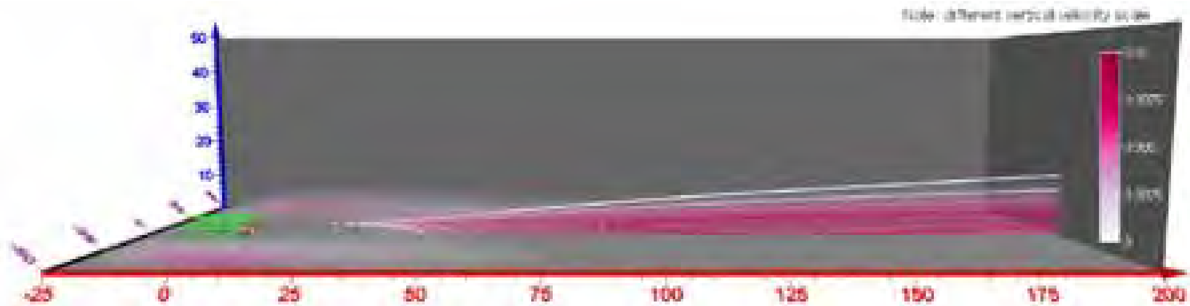
Appendix 4 Figure 1: **Case 1 (6 °C Delta T, 2 m/s wind speed, 0° Co-flow wind direction, 50% ventilation)**



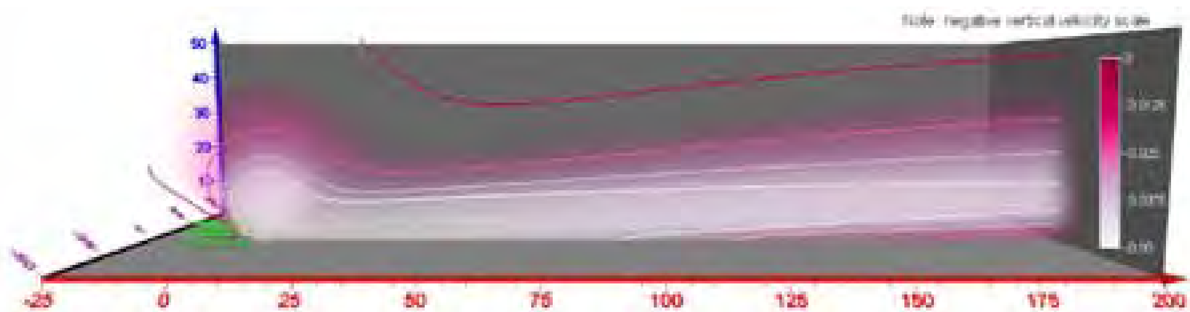
Appendix 4 Figure 2: **Case 3 (6 °C Delta T, 2 m/s wind speed, 0° Co-flow wind direction, 100% ventilation)**



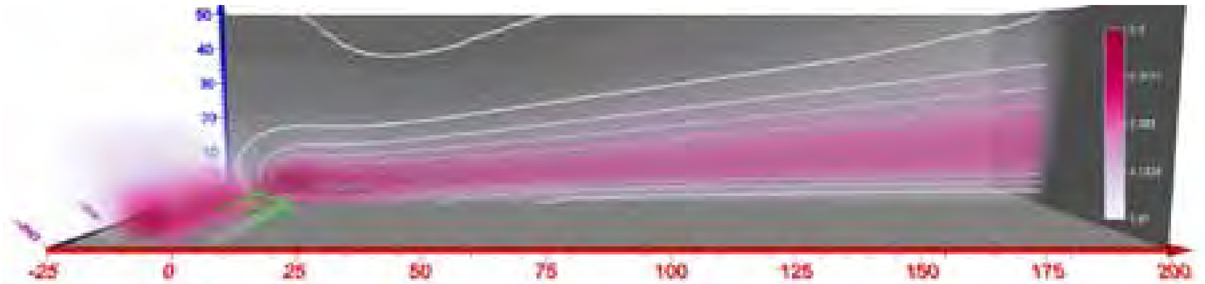
Appendix 4 Figure 3: **Case 4 (10 °C Delta T, 2 m/s wind speed, 0° Co-flow wind direction, 50% ventilation)**



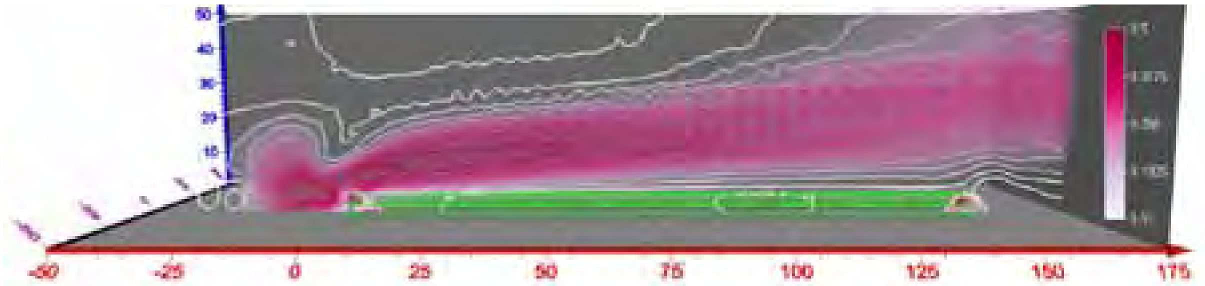
Appendix 4 Figure 4: **Case 6 (0 °C Delta T, 2 m/s wind speed, 0° Co-flow wind direction, 50% ventilation)**



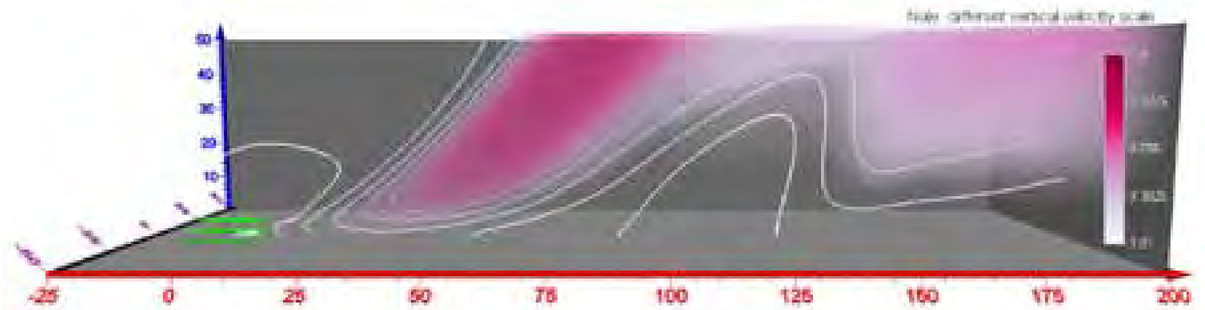
Appendix 4 Figure 5: **Case 7 (-6 °C Delta T, 2 m/s wind speed, 0° Co-flow wind direction, 50% ventilation)**



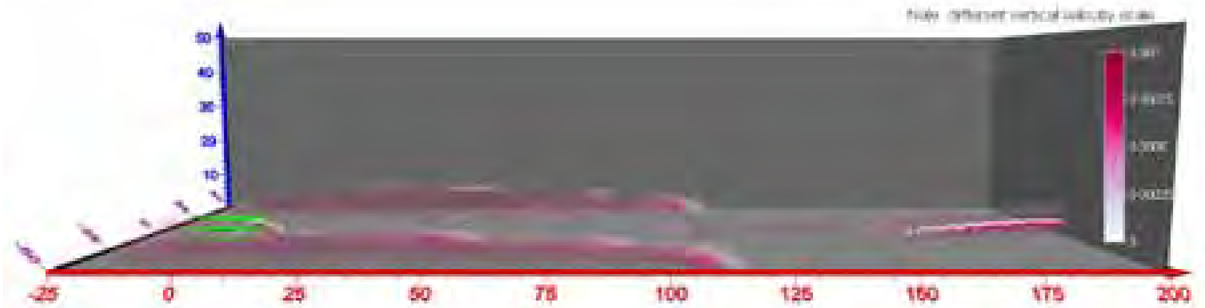
Appendix 4 Figure 6: Case 11 (6 °C Delta T, 2 m/s wind speed, 90° wind direction, 50% ventilation)



Appendix 4 Figure 7: Case 13 (6 °C Delta T, 2 m/s wind speed, 180° wind direction, 50% ventilation)



Appendix 4 Figure 8: Case 14 (6 °C Delta T, 0.5 m/s wind speed, 0° wind direction, 50% ventilation)



Appendix 4 Figure 9: Case 15 (6 °C Delta T, 10 m/s wind speed, 0° Co-flow wind direction, 50% ventilation)

Appendix 5: Plume temperature profiles

Appendix 5 Case 1

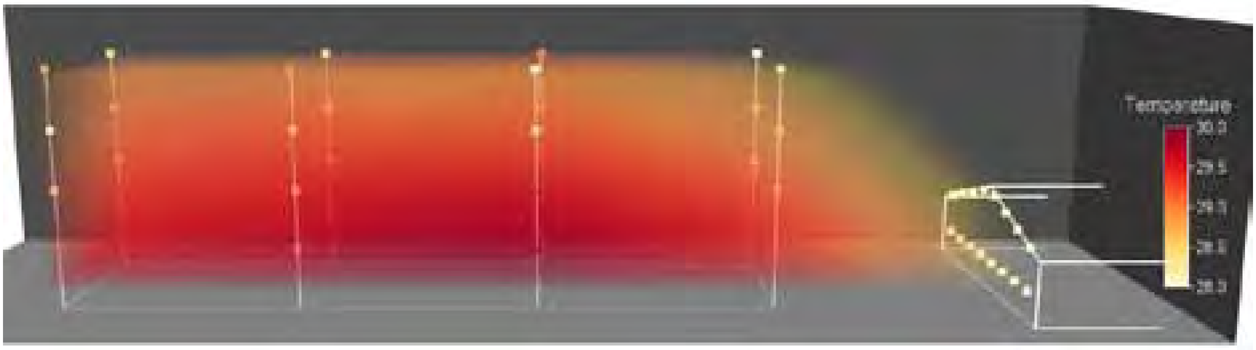


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) (m.s^{-1})	Wind direction (2m) (deg)	Number of active fans
27/11/2008	14:34	2m: 28.6 10m: 27.3	28.5	2m: 1.2 10m: 1.9	2m: 117 10m: 104	8

Appendix 5 Case 2

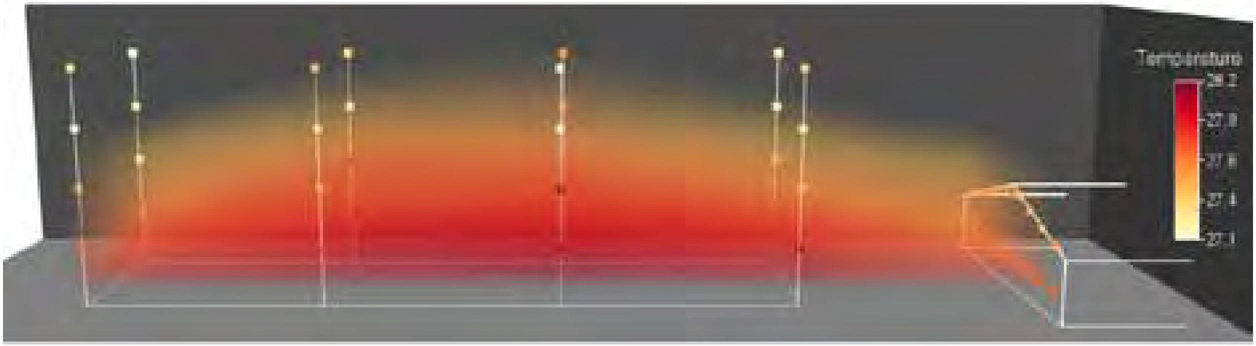


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) (m.s^{-1})	Wind direction (2m) (deg)	Number of active fans
27/11/2008	16:46	2m: 27.6 10m: 27.1	27.7	2m: 0.36 10m: 1.4	2m: 110 10m: 99	8

Appendix 5 Case 3

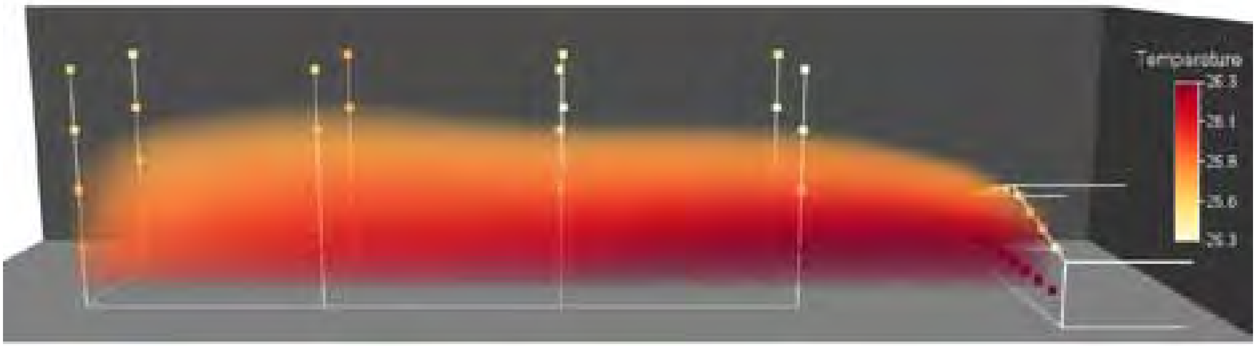


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) (m.s^{-1})	Wind direction (2m) (deg)	Number of active fans
27/11/2008	17:17	2m: 25.6 10m: 25.2	27.1	2m: 1.2 10m: 1.9	2m: 117 10m: 104	8

Appendix 5 Case 4

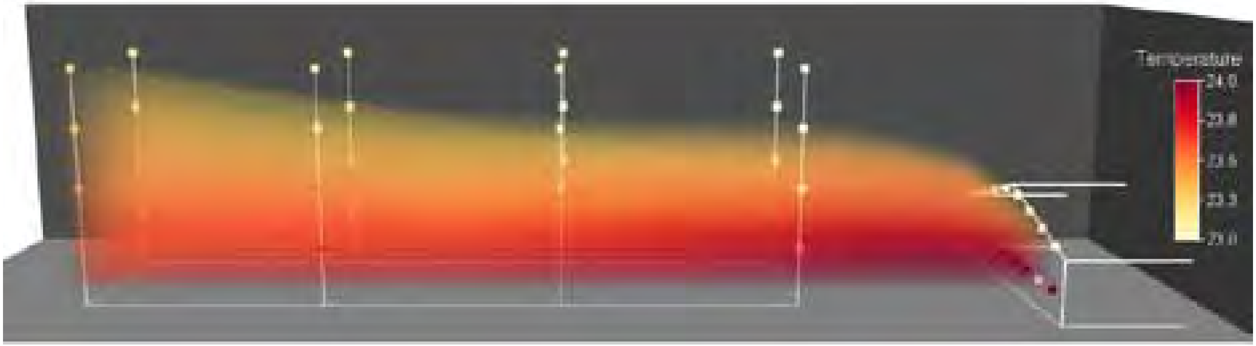


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) ($m.s^{-1}$)	Wind direction (2m) (deg)	Number of active fans
27/11/2008	19:28	2m: 23.0 10m: 23.0	25.2	2m: 0.78 10m: 1.4	2m: 117 10m: 98	7

Appendix 5 Case 5

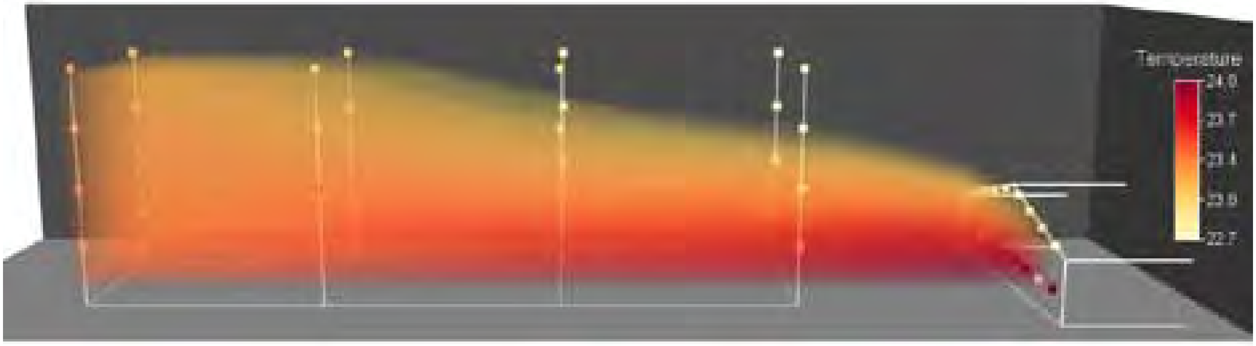


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) ($m.s^{-1}$)	Wind direction (2m) (deg)	Number of active fans
27/11/2008	19:57	2m: 22.8 10m: 22.8	25.0	2m: 0.33 10m: 0.86	2m: 115 10m: 106	6

Appendix 5 Case 6

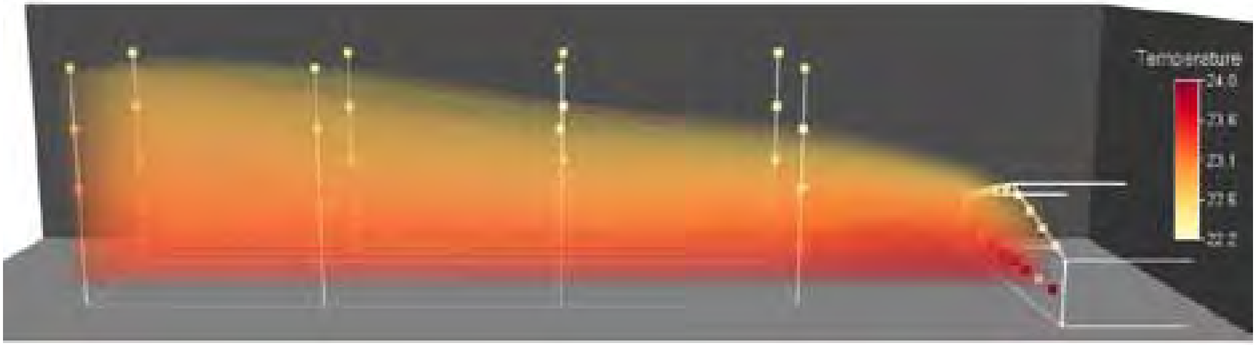


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) ($m.s^{-1}$)	Wind direction (2m) (deg)	Number of active fans
27/11/2008	20:32	2m: 22.4 10m: 22.4	24.8	2m: 0.27 10m: 0.85	2m: 92 10m: 96	6

Appendix 5 Case 7

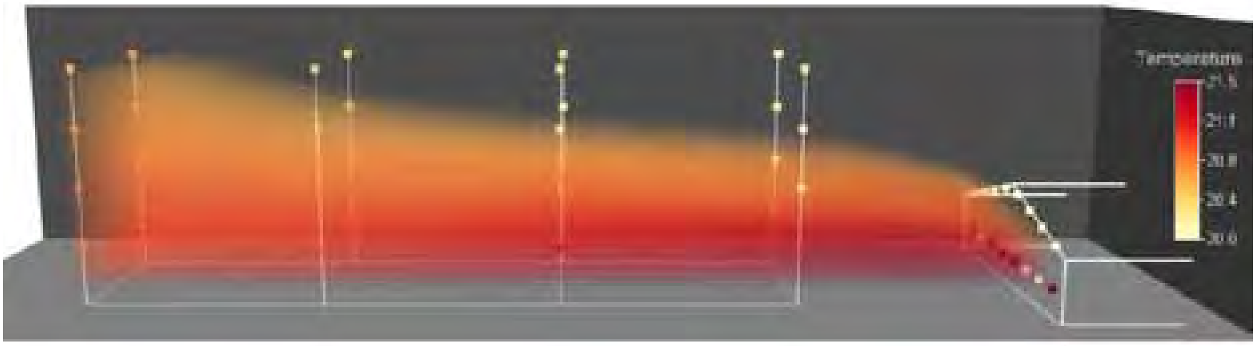


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) ($m.s^{-1}$)	Wind direction (2m) (deg)	Number of active fans
28/11/2008	04:45	2m: 20.1 10m: 20.3	23.5	2m: 0.12 10m: 0.12	2m: 243 10m: 111	5

Appendix 5 Case 8

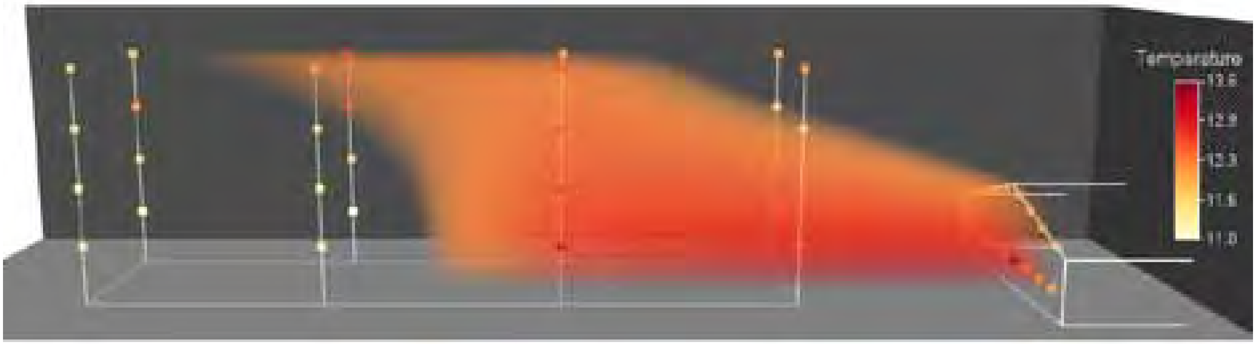


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) ($m.s^{-1}$)	Wind direction (2m) (deg)	Number of active fans
01/12/2008	04:03	2m: 12 10m: 12.4	20.1	2m: 0.25 10m: 0.23	2m: 273 10m: 253	1

Appendix 5 Case 9

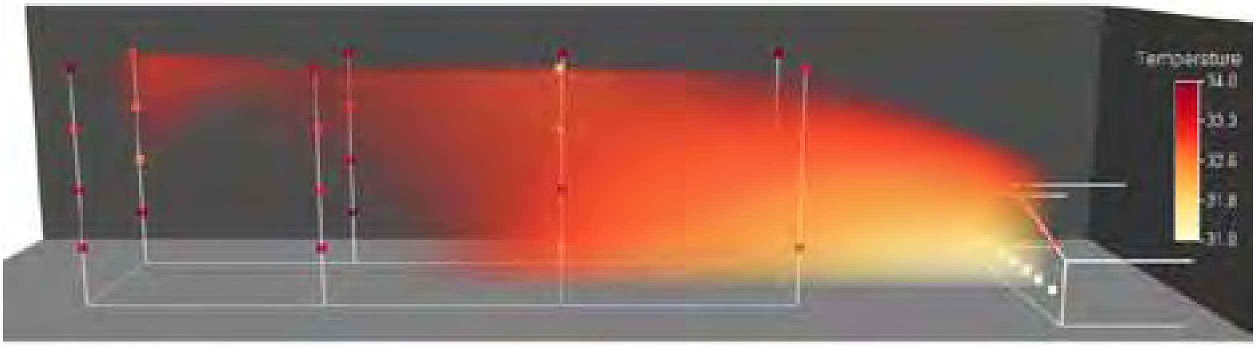


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) ($m.s^{-1}$)	Wind direction (2m) (deg)	Number of active fans
01/12/2008	15:12	2m: 32.8 10m: 32.0	30.4	2m: 0.55 10m: 0.75	2m: 92 10m: 97	8

Appendix 5 Case 10

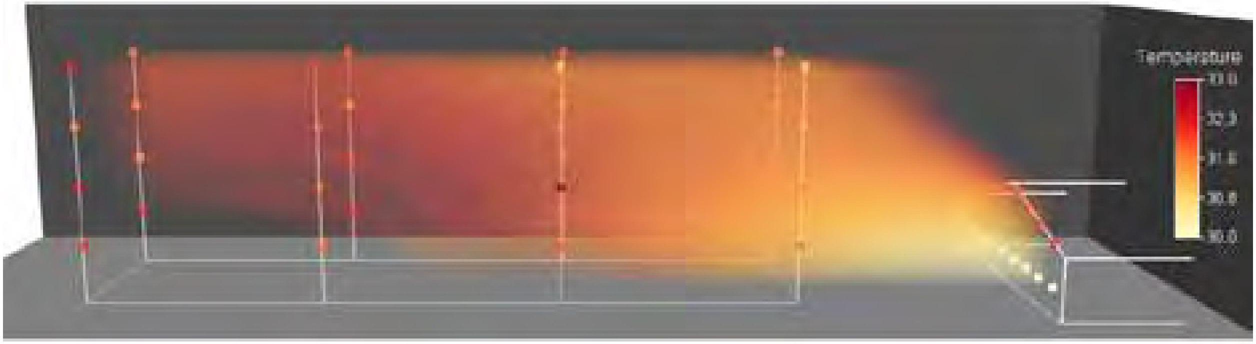


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) ($m.s^{-1}$)	Wind direction (2m) (deg)	Number of active fans
01/12/2008	15:46	2m: 32.1 10m: 31.1	29.1	2m: 1.0 10m: 1.9	2m: 106 10m: 94	8

Appendix 5 Case 11

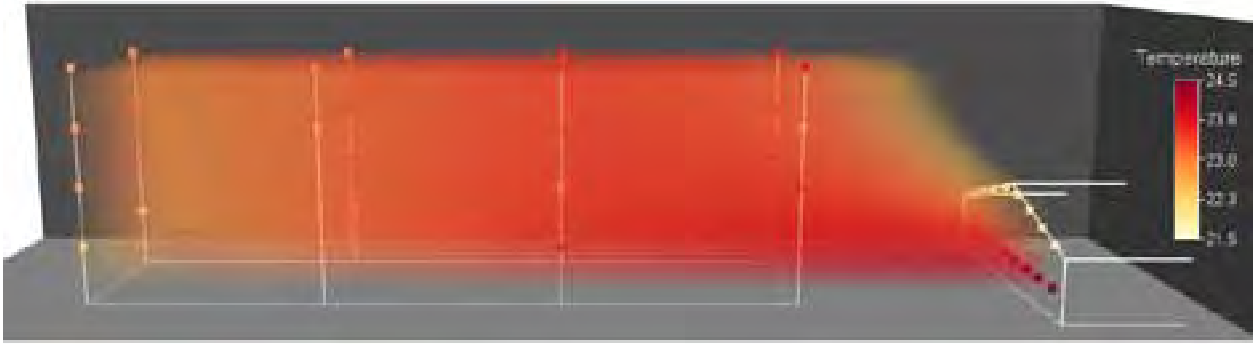


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) ($m.s^{-1}$)	Wind direction (2m) (deg)	Number of active fans
01/12/2008	19:47	2m: 22.0 10m: 23.9	24.7	2m: 0.31 10m: 0.19	2m: 223 10m: 281	8

Appendix 5 Case 12

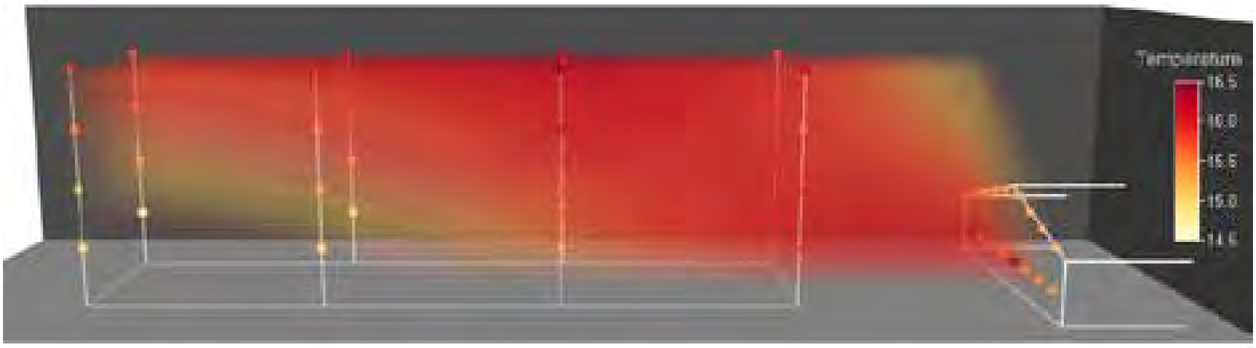


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) ($m.s^{-1}$)	Wind direction (2m) (deg)	Number of active fans
02/12/2008	02:11	2m: 15.4 10m: 16.1	20.2	2m: 0.33 10m: 0.11	2m: 245 10m: 286	2

Appendix 5 Case 13

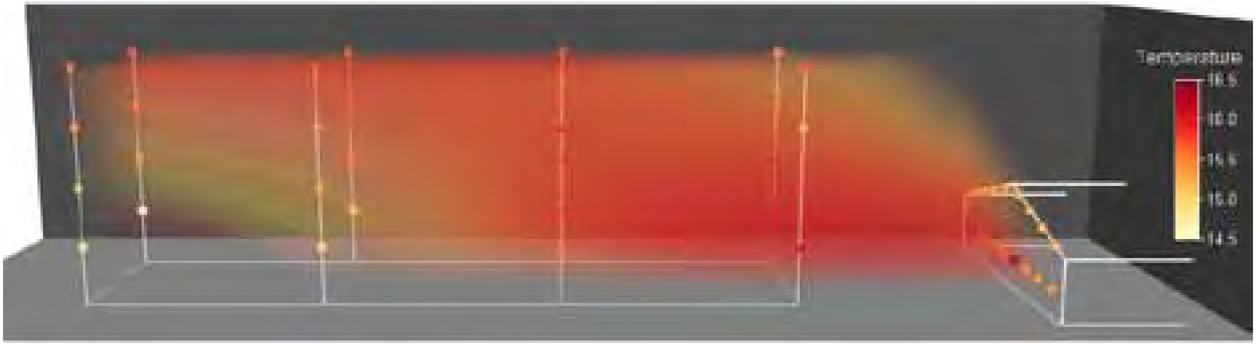


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) ($m.s^{-1}$)	Wind direction (2m) (deg)	Number of active fans
02/12/2008	02:23	2m: 15.3 10m: 15.8	19.9	2m: 0.13 10m: 0.06	2m: 293 10m: 106	2

Appendix 5 Case 14

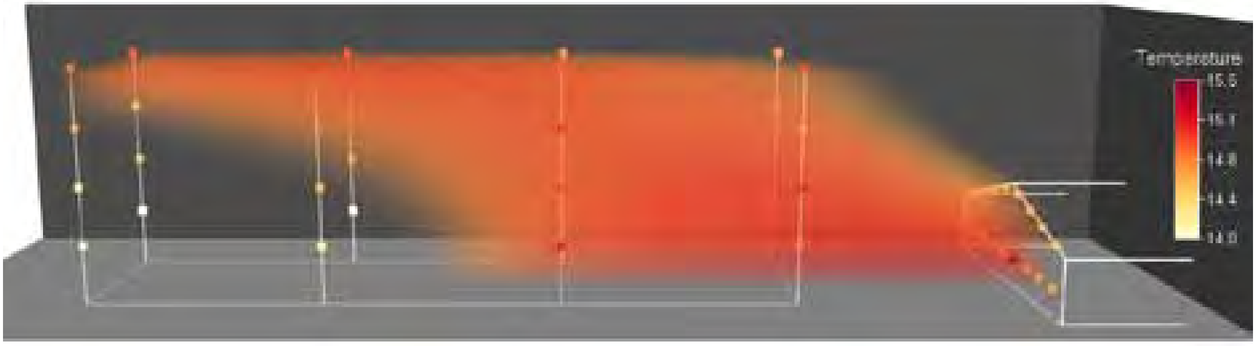


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) ($m.s^{-1}$)	Wind direction (2m) (deg)	Number of active fans
02/12/08	03:38	2m: 14.6 10m: 15.1	19.5	2m: 0.14 10m: 0.22	2m: 317 10m: 354	1

Appendix 5 Case 15

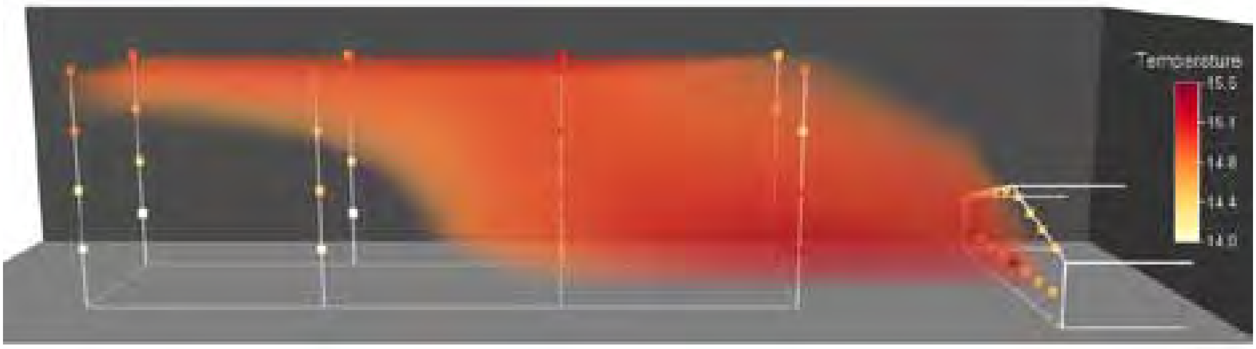


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) ($m.s^{-1}$)	Wind direction (2m) (deg)	Number of active fans
02/12/2008	03:51	2m: 14.5 10m: 14.9	20.4	2m: 0.14 10m: 0.35	2m: 309 10m: 106	2

Appendix 5 Case 16

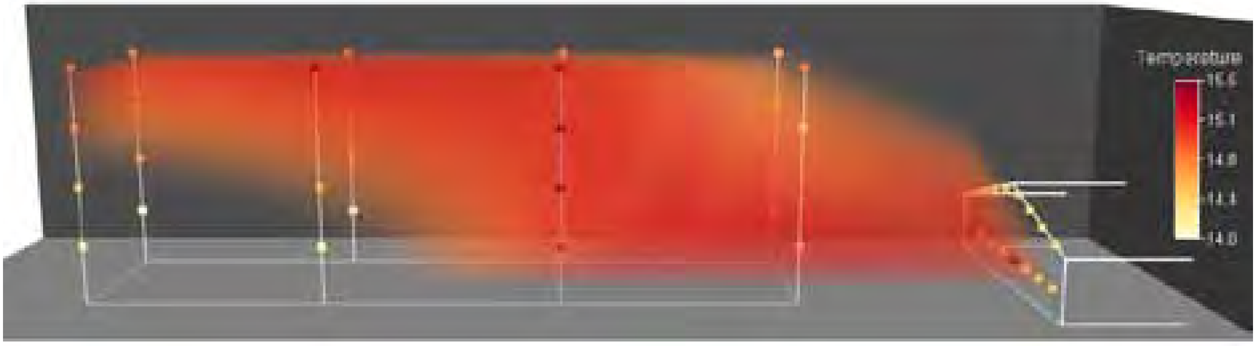


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) ($m.s^{-1}$)	Wind direction (2m) (deg)	Number of active fans
02/12/2008	04:07	2m: 14.4 10m: 14.9	20.3	2m: 0.37 10m: 0.44	2m: 309 10m: 91	2

Appendix 5 Case 17

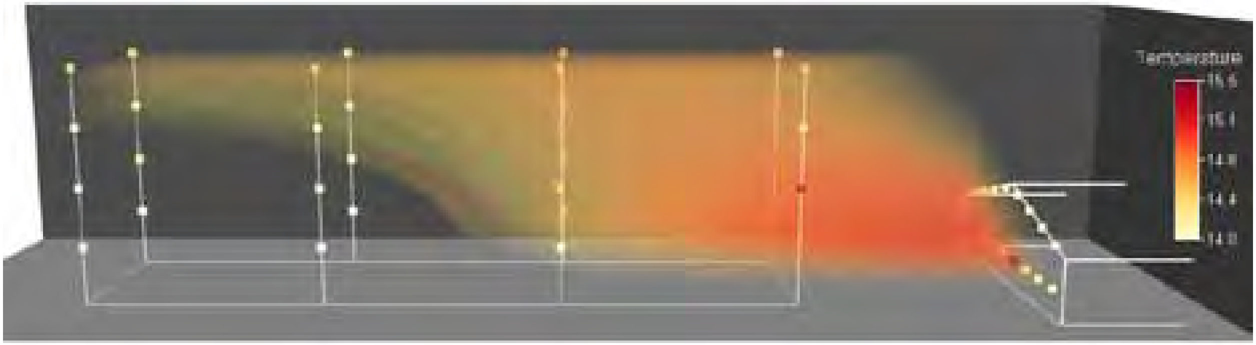


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) ($m.s^{-1}$)	Wind direction (2m) (deg)	Number of active fans
02/12/2008	04:47	2m: 14.1 10m: 14.7	19.9	2m: 0.18 10m: 0.09	2m: 265 10m: 256	2

Appendix 5 Case 18

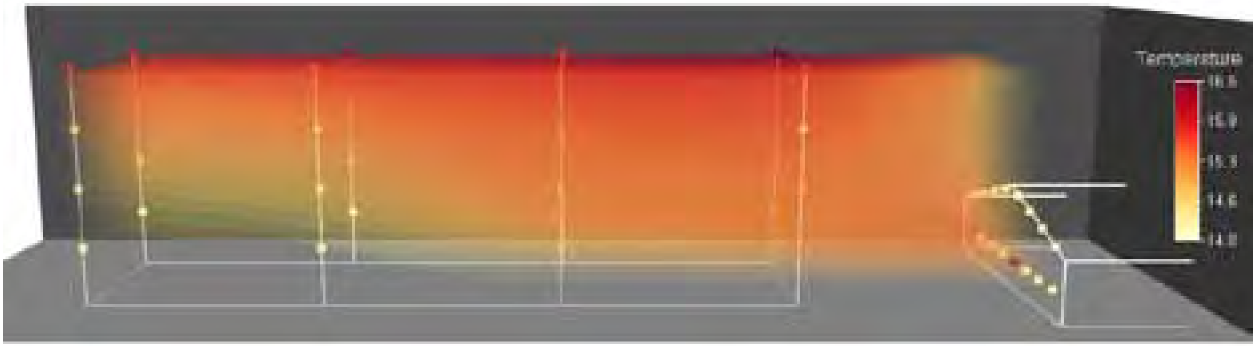


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) ($m.s^{-1}$)	Wind direction (2m) (deg)	Number of active fans
02/12/2008	05:20	2m: 14.4 10m: 15.7	20.1	2m: 0.14 10m: 0.20	2m: 117 10m: 327	2

Appendix 5 Case 19

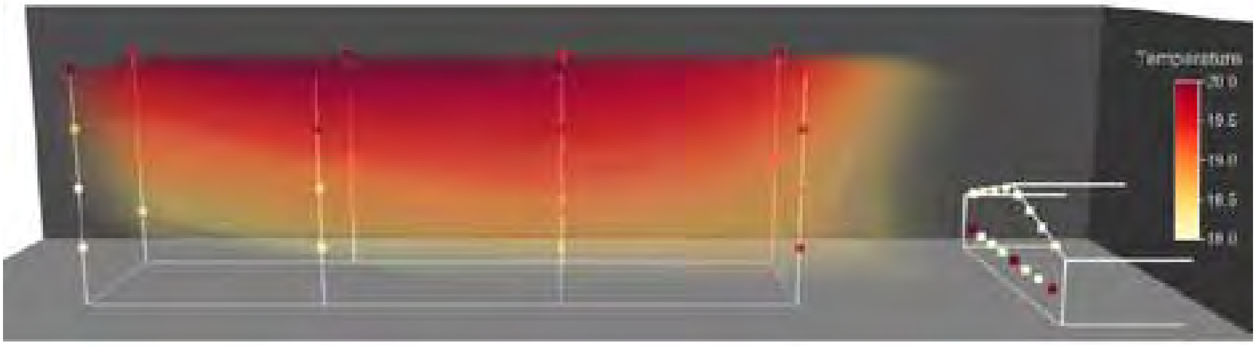


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) ($m.s^{-1}$)	Wind direction (2m) (deg)	Number of active fans
02/12/2008	06:00	2m: 16.4 10m: 19.2	21	2m: 0.08 10m: 0.27	2m: 29 10m: 98	3

Appendix 5 Case 20

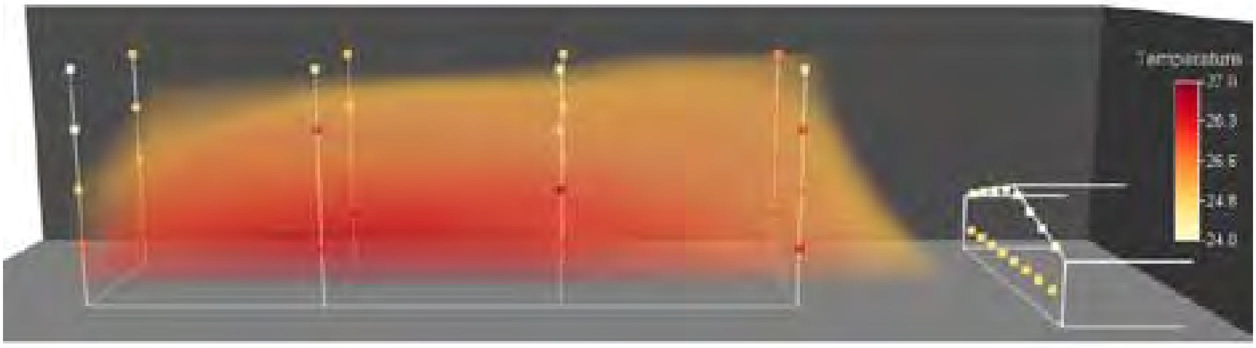


Table of conditions

Date	Time	Ambient temp (°C)	Shed emission temp (°C)	Wind speed (2m) ($m.s^{-1}$)	Wind direction (2m) (deg)	Number of active fans
02/12/2008	07:28	2m: 23.7 10m: 22.8	24.7	2m: 0.71 10m: 1.31	2m: 98 10m: 109	8

Appendix 6: Report for Calpuff modelling hypothetical broiler farms

(Consultant PAEHolmes)

PAEHolmes, 2009. Odour modelling and assessment - Meat chicken farms. Job No. 2655a, 7 July 2009. Brisbane.

REPORT

ODOUR MODELLING AND ASSESSMENT – MEAT CHICKEN FARMS

Department Of Employment, Economic Development And Innovation (DEEDI)

Job No: 2655a

7 July 2009

A PEL Company

PROJECT TITLE:	Odour Modeling And Assessment – Meat Chicken Farms
JOB NUMBER:	2655A
PREPARED FOR:	Mark Dunlop Department Of Employment, Economic Development And Innovation (DEEDI)
PREPARED BY:	Geordie Galvin
QA PROCEDURES CHECKED BY:	Graeme Starke
APPROVED FOR RELEASE BY:	Robin Ormerod
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

DEEDI engaged PAEHolmes (PAEH) to perform dispersion modelling and to provide a summary of modelling performed by PAEH to date, for the meat chicken industry.

Specifically, the objectives of project are:

- to model a series of scenarios using the CALPUFF dispersion model for two hypothetical domains in South East Queensland; and
- provide odour contour plots and relevant information for a number of generic meat chicken farms previously modelled in South East Queensland.

1.1 Scope of Work

The scope of work for this project included:

- Selecting two representative CALMET domains.
- Running CALMET for the two domains.
- Modelling a 175,000 bird and 350,00 bird meat chicken farm:
- at two locations in each of the domains;
- with exhaust air at production and ambient temperatures;
- using the PAEHolmes Point Source Method;
- also modelling the sheds as a Volume Source;
- at a K factor of two.
- Providing odour contour plots of generic meat chicken farms in South East Queensland with sufficient data to enable DEEDI to calculate equivalent buffer distances using the S factor method prepared for the Queensland Environment Protection Agency (EPA) by FSA Consulting.
- Present a comprehensive report.

2 ODOUR ASSESSMENT CRITERIA

This study has complied with the EPA guideline *Odour Impact Assessment from Developments (2004)*[1]. The Guideline sets out the following advice in relation to odour concentration guidelines:

"Proponents of new facilities may undertake an impact assessment with relevant inputs of emissions and local meteorology to an air dispersion model to provide estimates of the likely odour impacts in the surrounding environment. The inputs should be as detailed as possible, reflecting any variation of emissions with time and including at least a full year of representative hourly meteorological data. The modelled odour concentrations at the "most exposed existing or likely future off-site sensitive receptors" should be compared with the following guideline values.

- 0.5 ou, 1-hour average, 99.5th percentile for tall stacks;
- 2.5 ou, 1-hour average, 99.5th percentile for ground-level sources and down-washed plumes from short stacks, and
- for facilities that do not operate continuously, the 99.5th percentile must be applied to the actual hours of operation."

For this study, the default odour criterion of $C_{99.5,1hr}$ = 2.5 ou has been applied to the farms.

3 METHODOLOGY

3.1 Dispersion Modelling Methodology

The air dispersion modelling conducted for this assessment has been based on an advanced modelling system using the models TAPM and CALMET/CALPUFF (see Figure 3.1). This system substantially overcomes the basic limitations of the steady-state Gaussian plume models such as AUSPLUME. These limitations are most severe in very light winds, in coastal environments, and where terrain affects atmospheric flow.

The model system works as follows:

- TAPM is a prognostic meteorological model that generates gridded three-dimensional meteorological data for each hour of the model run period.
- CALMET, the meteorological pre-processor for the dispersion model CALPUFF, calculates three-dimensional meteorological data based upon observed ground and upper level meteorological data, as well as modelled data generated by TAPM.
- CALPUFF then calculates the dispersion of plumes within this three-dimensional meteorological field.

For this study, measured surface data in each of the two domains was used in the modelled scenarios to provide more realistic estimates of surface winds.

3.1.1 TAPM

The Air Pollution Model, or TAPM, is a three dimensional meteorological and air pollution model developed by the CSIRO Division of Atmospheric Research. Detailed description of the TAPM model and its performance is provided elsewhere. The Technical Paper by Hurley (2008) describes technical details of the model equations, parameterisations, and numerical methods. A summary of some verification studies using TAPM is also given in Hurley *et al.* (2008).

TAPM solves the fundamental fluid dynamics and scalar transport equations to predict meteorology and (optionally) pollutant concentrations. It consists of coupled prognostic meteorological and air pollution concentration components. The model predicts airflow important to local scale air pollution, such as sea breezes and terrain induced flows, against a background of larger scale meteorology provided by synoptic analyses.

Upper air data were generated over the study region using TAPM. The TAPM-generated data and observed meteorological data were entered into the CALMET diagnostic meteorological model, which is discussed below.

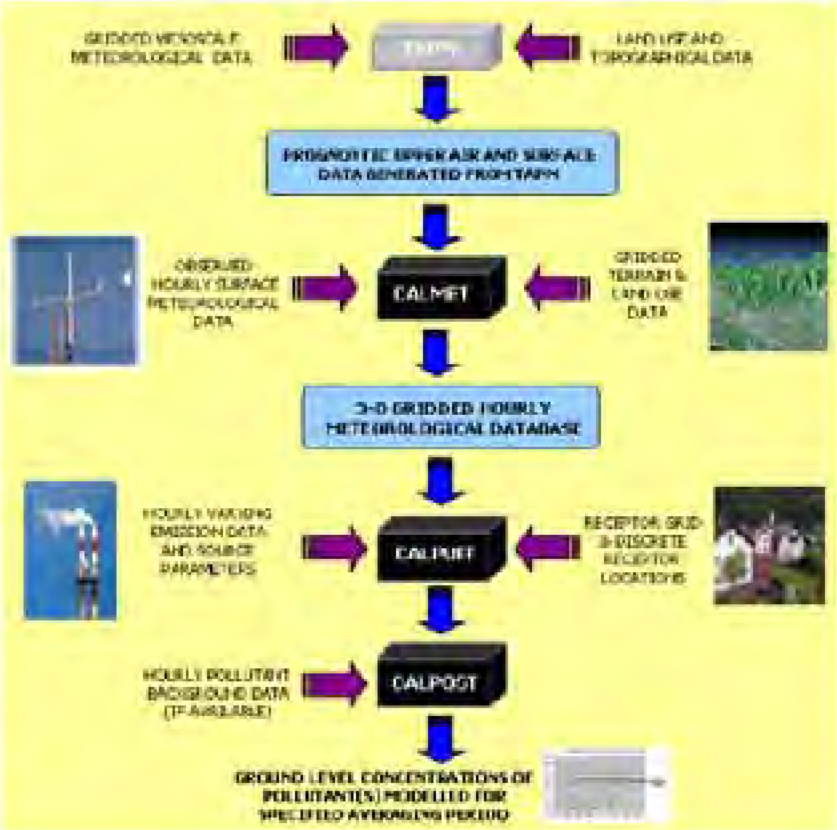

Figure 3.1: Modelling Methodology Used in this Study

3.1.2 CALMET

CALMET is a meteorological pre-processor that 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 the CALPUFF dispersion model.

The hourly TAPM-generated data and observed data for the period of analysis were used as input to the CALMET pre-processor to create a fine resolution, three-dimensional meteorological field for input into the dispersion model. CALMET uses the meteorological inputs in combination with land use and geophysical information for the modelling domain to predict gridded meteorological fields for the region.

Terrain data has been sourced from the Shuttle Terrain Mission dataset and land-use data was sourced from the Department of Mineral Resources and Mines land cover dataset.

Hourly surface meteorological data for each of the two domains were used for the modelling year. The data were supplemented with upper air data derived from TAPM simulations.

3.1.3 CALPUFF

CALPUFF (Scire *et al.*, 2000a) 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. The model contains algorithms for near-source effects such as building downwash, partial plume penetration, sub-grid scale interactions as well as longer-range effects such as pollutant removal, chemical transformation, vertical wind shear and coastal interaction effects. The model employs dispersion equations based on a Gaussian distribution of pollutants across the puff and takes into account the complex arrangement of emissions from point, area, volume, and line sources.

As with any air dispersion model, CALPUFF requires inputs in three major areas:

- Emission rates and source details.
- Meteorology.
- Terrain and surface details, as well as specification of specific receptor locations.

CALPUFF is endorsed by the US EPA, and has been used in many studies throughout Australia.

3.2 Scenarios

A number of scenarios have been modelled. These are summarised below in Table 3.1: Modelled Scenarios

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Table 3.1: Modelled Scenarios

Case Number	Farm Size (birds)	Farm Location	Emission Temperature	Source Type
1	175,000	Domain 1 - A	Ambient	Quasi Point (PAEHolmes Method)
2	350,000	Domain 1 - A	Production	Quasi Point
3	175,000	Domain 1 - B	Ambient	Quasi Point
4	350,000	Domain 1 - B	Production	Quasi Point
5	175,000	Domain 2 - A	Ambient	Quasi Point
6	350,000	Domain 2 - A	Production	Quasi Point
7	175,000	Domain 2 - B	Ambient	Quasi Point
8	350,000	Domain 2 - B	Production	Quasi Point
9	175,000	Domain 1 - A	Ambient	Volume
10	350,000	Domain 1 - A	Ambient	Volume
11	175,000	Domain 1 - B	Ambient	Volume
12	350,000	Domain 1 - B	Ambient	Volume
13	175,000	Domain 2 - A	Ambient	Volume
14	350,000	Domain 2 - A	Ambient	Volume
15	175,000	Domain 2 - B	Ambient	Volume
16	350,000	Domain 2 - B	Ambient	Volume

The farm sizes shown in Table 3.1: Modelled Scenarios

represented 4 sheds each with 43,750 birds (175,000 birds total) or 8 sheds, each with 43,750 birds in each shed (350,000 birds total).

Each modelled shed was 153 metres long, 15 metres wide (15.3 m external width), had a wall height of 2.7 m, with baffles at 2.4 metres above the chicken litter surface. It was assumed that each shed had a maximum ventilation rate of 112 m^3/s. This represented airflow of approximately 9.2 $m^3/hr/bird$ at maximum flow rate. This is in line with industry standard ventilation rates.

Batch lengths were assumed to be 56 days, with a further 10 days of cleaning after harvest. In line with commercial chicken operations, two thin-outs per batch were included in the modelling. The first was at day 35, where 40% of the birds were removed and the second, at day 42, when a further 20% (of the starting total) of the birds were removed, with all birds gone by day 56.

The farm locations within each modelling domain are shown in Figure 3.2 and Figure 3.3.

Figure 3.2: Farm Locations - Domain A

Domain A represents an area west of Brisbane in an area in which the poultry industry may develop in the future. The two farm sites were selected to be representative of possible farm locations within the modelling domain. The first farm's location was selected in a relatively flat area, free from significant localised terrain elements. Farm 2 was selected in an area with more complex terrain and thus more complex airflows. Both sites were influenced by large scale terrain features in the area.

Figure 5.3: Farm Locations - Domain B

Domain B represents an existing poultry production area south of Brisbane. Although a number of farms already exist within the area, two sites were selected to represent potential farm locations. The modelling was based on generic cases where farms may not be present. As with Domain A, the first farm's location was selected in a relatively flat area, free from significant localised terrain elements. Farm 2 was selected in an area with more complex local terrain and associated airflows. Both sites were expected to be influenced by larger scale terrain features.

4 METEOROLOGICAL DATA USED IN ASSESSMENT

Meteorological data is a critical input for any dispersion modelling study. The meteorology at each of the four modelled sites is summarised below. Overall, there are subtle differences between the two sites in each of the domains. This this was expected as a result of both large scale and local terrain influences.

4.1 Domain A – Farm 1

4.1.1 Wind

Wind roses show the frequency of occurrence of winds by direction and strength. The bars correspond to the 16 compass points – N, NNE, NE, etc. The bar at the top of each wind rose diagram represents winds blowing from the north (i.e. northerly winds), and so on. The length of the bar represents the frequency of occurrence of winds from that direction, and the widths of the bar sections correspond to wind speed categories, the narrowest representing the lightest winds. Thus it is possible to visualize how often winds of a certain direction and strength occur over a long period, either for all hours of the day, or for particular periods during the day.

The wind roses for 2000 at Farm 1 are shown in Figure 4.1. They are characterised by weak northerly and south easterly winds in the early morning hours, changing to stronger easterly winds through the day. There is a dominant easterly component for the 24-hour period (Figure 4.2).

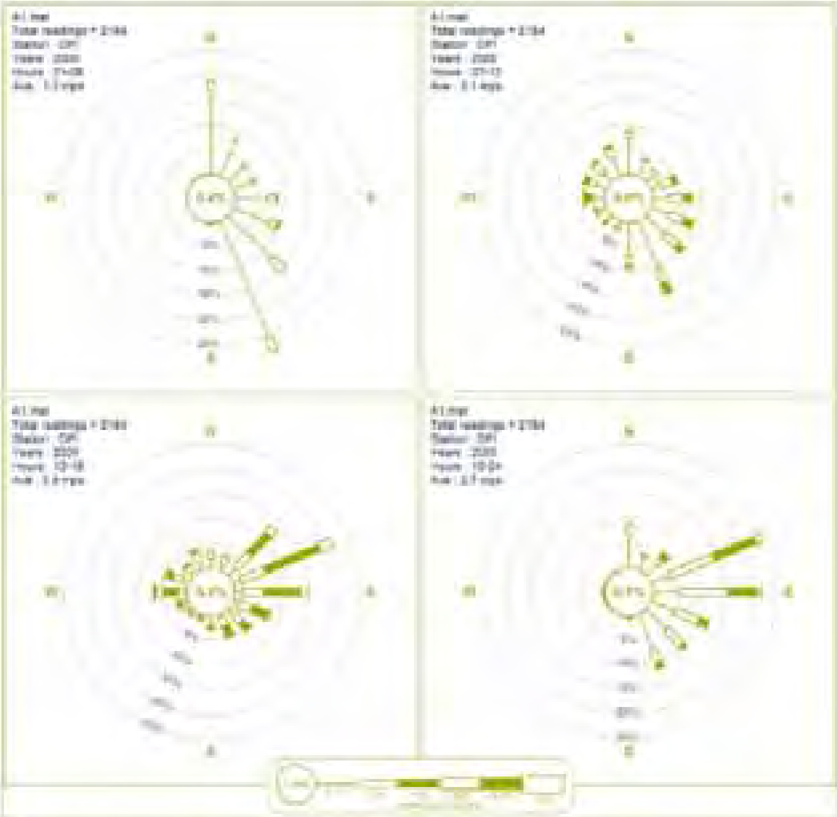


Figure 4.1: Domain A Farm 1 – Wind Roses for January to December 2000

Figure 4.2: Domain A Farm 1 – Wind Roses for All Hours January to December 2000

The frequency distribution of hourly averaged wind speed values is shown in Figure 4.3. Light winds (up to 2 m/s) occur relatively frequently (approximately 48% of the time). Moderate to strong winds (greater than 6 m/s) occur less than 5% of the time.

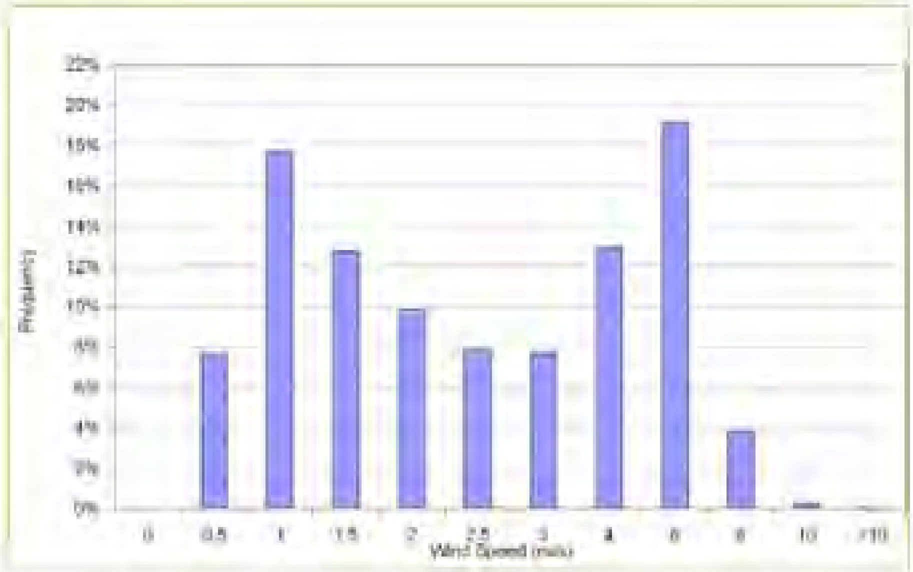


Figure 4.3: Domain A Farm 1 - Wind Speed Distribution for 2000

Overall, the wind roses show that the site has a high proportion of easterly winds, reflecting influences from the local terrain.

4.1.2 Stability

Atmospheric turbulence is an important factor in plume dispersion. Turbulence acts to increase the cross-sectional area of the plume due to random motions, thus diluting or diffusing a plume. As turbulence increases, the rate of plume dilution or diffusion increases. Weak turbulence limits plume diffusion and is a critical factor in causing high plume concentrations downwind of a source, particularly when combined with very low wind speeds.

Turbulence is related to the vertical temperature gradient, the condition of which determines what is known as stability, or thermal stability. For traditional dispersion modelling using Gaussian plume models, categories of atmospheric stability are used in conjunction with other meteorological data to describe atmospheric conditions and thus dispersion.

The most well-known stability classification is the Pasquill-Gifford scheme, which denotes stability classes from A to F. Class A is described as highly unstable and occurs in association with strong surface heating and light winds, leading to intense convective turbulence and much enhanced plume dilution.

At the other extreme, class F denotes very stable conditions associated with strong temperature inversions and light winds, which commonly occur under clear skies at night and in the early morning. Under these conditions plumes can remain relatively undiluted for considerable distances downwind.

Intermediate stability classes grade from moderately unstable (B), through neutral (D) to slightly stable (E). Whilst classes A and F are strongly associated with clear skies, class D is linked to windy and/or cloudy weather, and short periods around sunset and sunrise when surface heating or cooling is small.

As a general rule, unstable (or convective) conditions dominate during the daytime and stable flows are dominant at night. This diurnal pattern is most pronounced when there is relatively little cloud cover and light to moderate winds.

The frequency distribution of estimated stability classes in the meteorological file is presented in Figure 4.4. The data show a total of 48% of hours with either E or F stability class, which is typical of inland locations in southeast Queensland.

Figure 4.4: Domain A Farm 1 Frequency Distribution of Estimated Stability Classes for 2000

4.1.3 Mixing Height

The diurnal variation of mixing height is summarised in Figure 4.5. The diurnal cycle is clear in this figure. At night, mixing height is normally relatively low. After sunrise, it typically increases to between 500 m and 3,000 m in response to convective mixing that results from solar heating of the earth's surface during the day. The mixing height in the model was limited to 2,000 m. Because there is a relatively localised zone of impact around the farm and the sources are near the ground, ground level concentrations are quite insensitive to daytime mixing heights. Hence, the mixing height limit has no significant effect on predicted odour impacts.

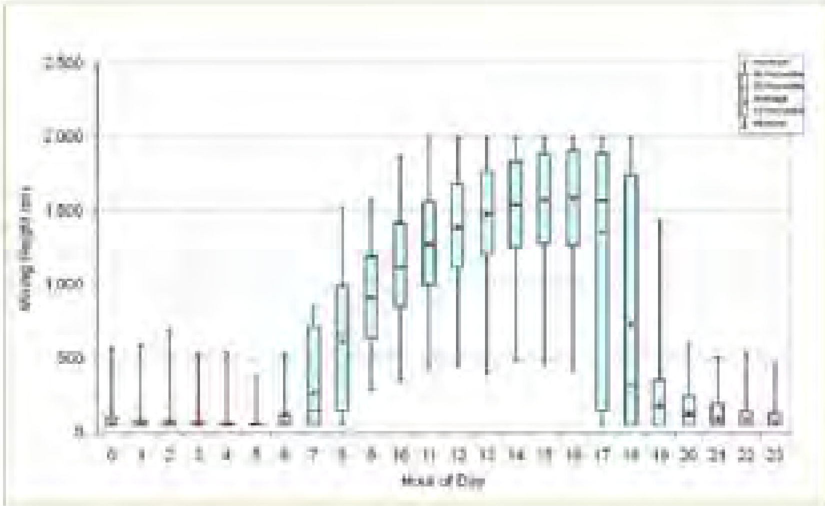


Figure 4.5: Domain A Farm 1 Estimated Mixing Height for Site

4.1.4 Site Temperature Profile

Ambient temperature plays a role in both the dispersion of odour, but also in the generation of odour due to the ventilation of the sheds.

The yearly temperature profile for the site is shown in Figure 4.6. The average temperature was 20°C, with a maximum of 36°C and a minimum of 4°C.

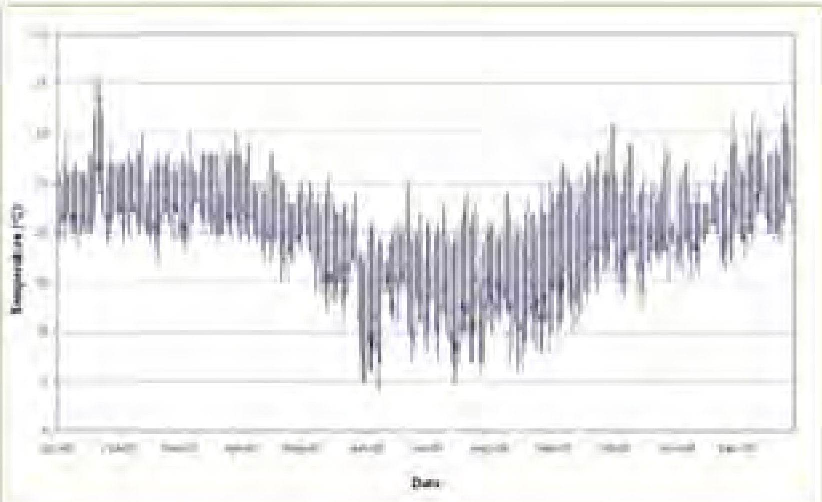


Figure 4.6: Domain A Farm 1 Yearly Temperature – January to December 2000

4.2 Domain A – Farm 2

4.2.1 Wind

The wind roses for 2000 for Site 2 are shown in Figure 4.7. These are characterised by weak south westerly, or north easterly winds (depending on the time of year) in the early morning hours, changing to stronger easterly or north easterly winds through the day, resulting in a dominant easterly component with a noticeable light south westerly component for the 24-hour period (Figure 4.8).

Figure 4.7: Domain A Farm 2 – Wind Roses for January to December 2000

Figure 4.8: Domain A Farm 2 - Wind Roses for All Hours January to December 2000

The frequency distribution of hourly averaged wind speed values is shown in Figure 4.9. Light winds (up to 2 m/s) occur relatively frequently, approximately 47% of the time. Moderate to strong winds (greater than 6 m/s) occur less than 4% of the time.

Overall, the wind roses show that the site has a high proportion of easterly winds with a significant early morning south westerly component.

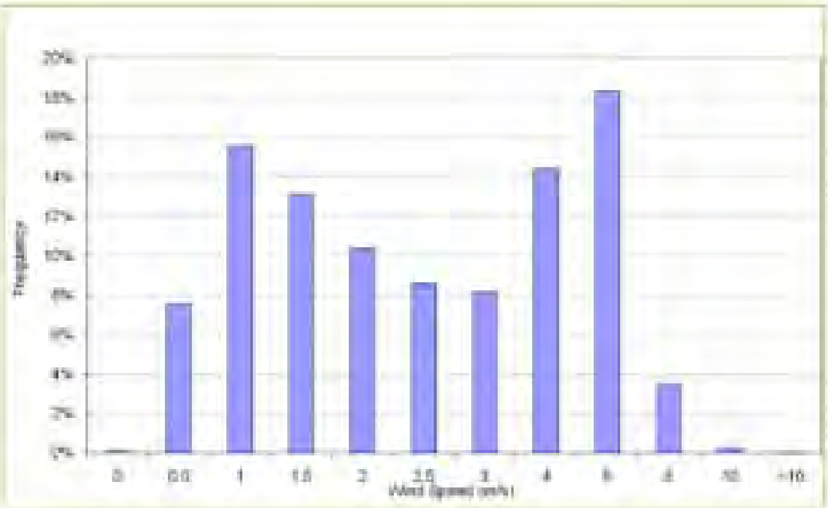


Figure 4.9: Domain A Farm 2 - Wind Speed Distribution for 2000

4.2.2 Stability

The frequency distribution of estimated stability classes in the meteorological file is presented in Figure 4.10. The data show a total of 49% of hours with either E or F stability class.

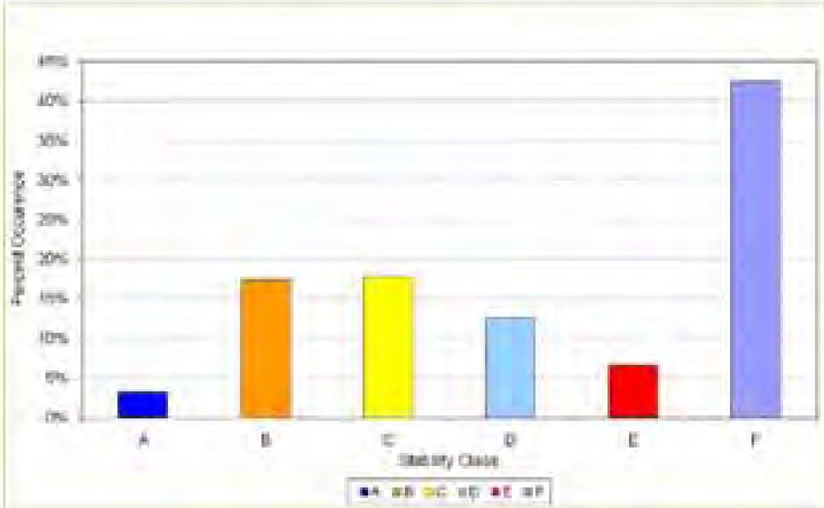


Figure 4.10: Domain A Farm 2 Frequency Distribution of Estimated Stability Classes

4.2.3 Mixing Height

The diurnal variation of mixing height is summarised in Figure 4.11.

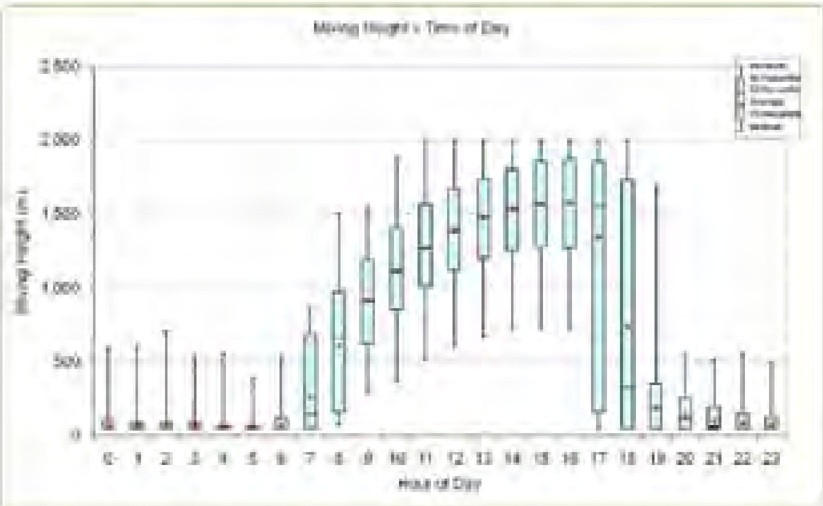


Figure 4.11: Domain A Farm 2 Estimated Mixing Height for Site

4.2.4 Site Temperature Profile

The yearly temperature time series for the site is shown in Figure 4.12. The average temperature was 20°C, with a maximum of 36°C and a minimum of 4°C.

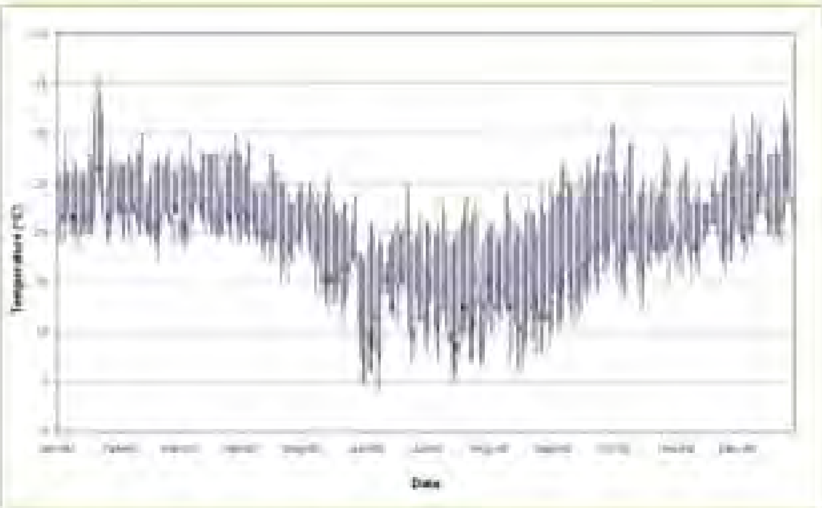


Figure 4.12: Domain A Farm 1 Yearly Temperature – January to December 2000

4.3 Domain B – Farm 1

4.3.1 Wind

The wind roses for 2002 for Farm 1 are shown in Figure 4.13. They are characterised by weak southerly winds in the early morning hours, changing to stronger easterly winds in the afternoon, resulting in dominant southerly winds, and a secondary south easterly component for the 24-hour period (Figure 4.14).

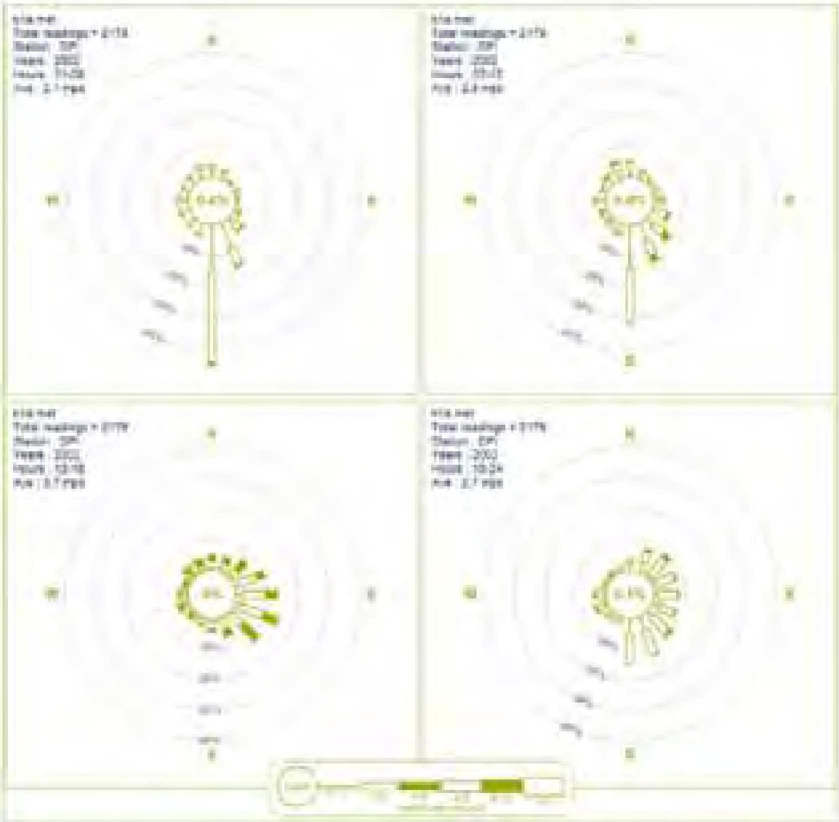


Figure 4.13: Domain B Farm 1 - Wind Roses for January to December 2002

Figure 4.14: Domain B Farm 1 - Wind Roses for All Hours January to December 2002

The frequency distribution of hourly averaged wind speed values is shown in Figure 4.15. Light winds (up to 2 m/s) occur relatively frequently, approximately 30% of the time. Moderate to strong winds (greater than 6 m/s) occur less than 2% of the time.

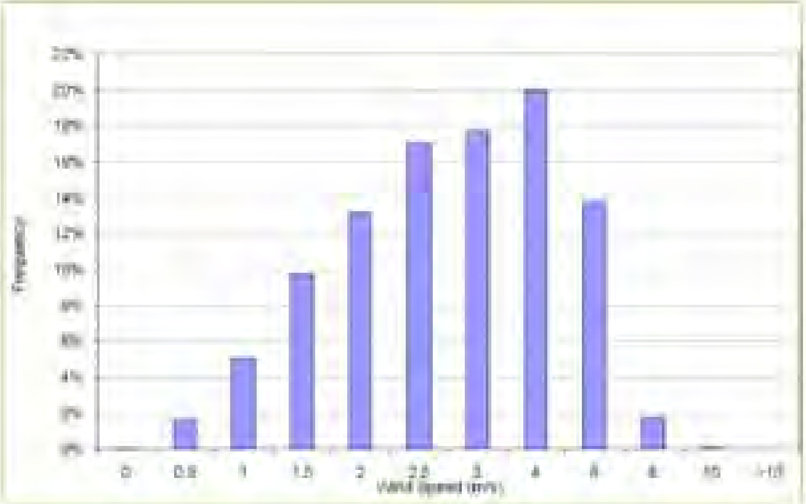


Figure 4.15: Domain B Farm 1 - Wind Speed Distribution for 2002

Overall, the wind roses show that winds blow from most directions at some stage of the year, but there is a dominant southerly component. This is due to the location of the site, which is within a large northward draining valley. Accordingly, large scale katabatic flow to the north appears to be a critical factor for the dispersion of odour from site.

4.3.2 Stability

The frequency distribution of estimated stability classes in the meteorological file is presented in Figure 4.16. The data show a total of 49% of hours with either E or F stability class, typical of inland locations in southeast Queensland.

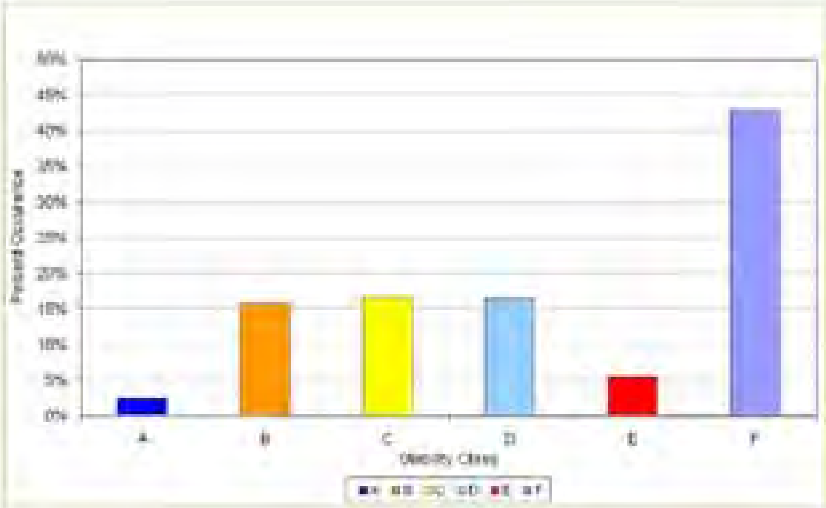


Figure 4.16: Domain B Farm 1 - Frequency Distribution of Estimated Stability Classes

4.3.3 Mixing Height

The diurnal variation of mixing height is summarised in Figure 4.17. The diurnal cycle is clear in this figure, showing the expected increase of mixing height during the day until a late afternoon peak.

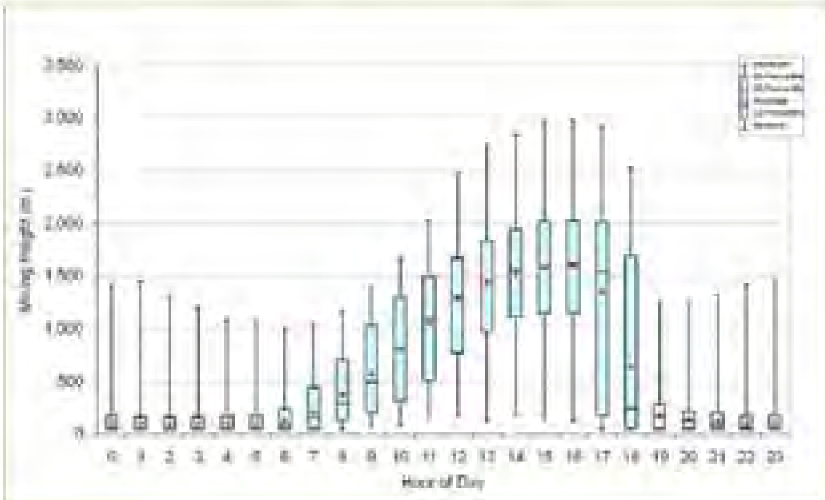


Figure 4.17: Domain B Farm 1 - Estimated Mixing Height for Site

4.3.4 Site Temperature Profile

The temperature time series for 2002 at the site is shown in Figure 4.18. The average temperature was 20°C, with a maximum of 41°C and a minimum of 2°C.

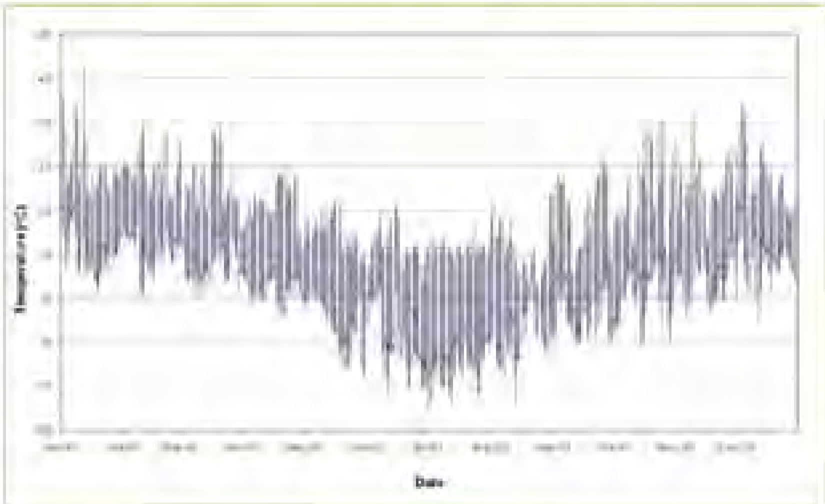


Figure 4.18: Domain B Farm 1 Yearly Temperature – January to December 2002

4.4 Domain B – Farm 2

4.4.1 Wind

The wind roses for 2002 format Farm 2 are shown in Figure 4.19. These are characterised by south westerly winds in the early morning hours, changing to predominantly north easterly in the afternoon. The result is a distinct bimodal (south westerly and north easterly) distribution in the 24-hour period data (Figure 4.20). The south westerly winds during the early morning are likely influenced by terrain features immediately to the south west of the farm site.

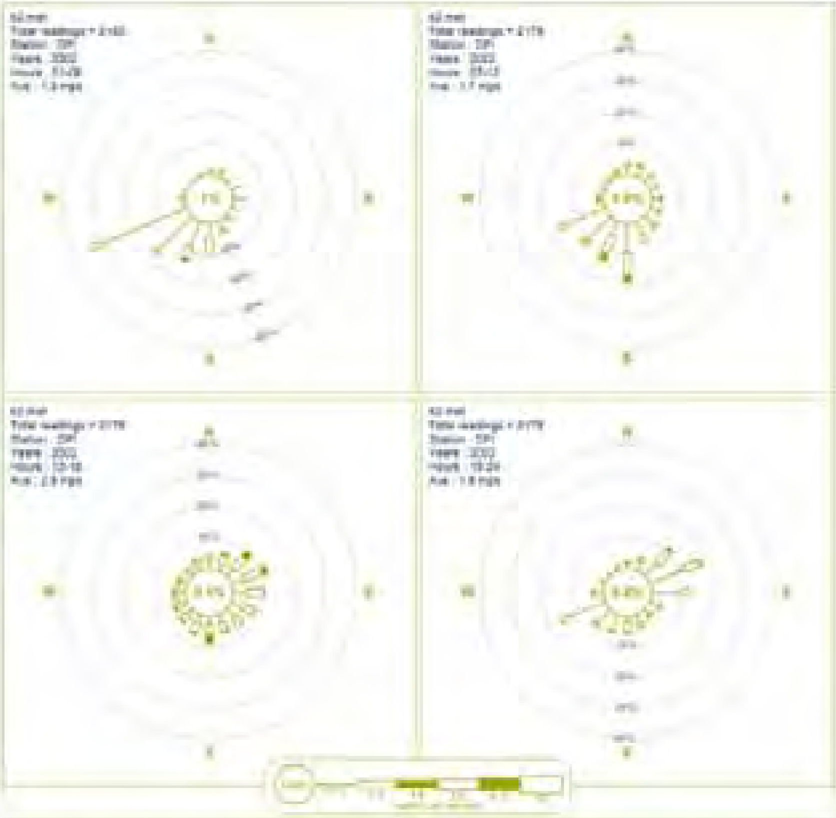


Figure 4.19: Domain B Farm 2 - Wind Roses for January to December 2002

Figure 4.20: Domain B Farm 2 - Wind Roses for All Hours January to December 2002

The frequency distribution of hourly averaged wind speed values is shown in Figure 4.21. Light winds (up to 2 m/s) occur very frequently, approximately 62% of the time. Moderate to strong winds (greater than 6 m/s) occur less than 1% of the time, indicating a low wind environment.

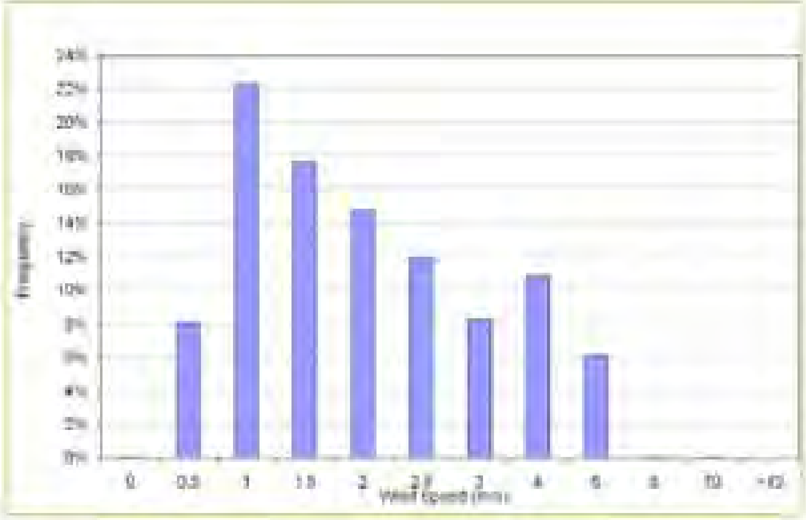


Figure 4.21: Domain B Farm 2 - Wind Speed Distribution for 2002

Overall, the wind roses show that the site has a high proportion of south westerly and north easterly winds, shaped by local terrain influences acting to modify the predominant regional flows. Further, the site has a higher proportion of low wind speed events compared to the Farm 1 site. This is most likely due to the close proximity of the farm to local hills.

4.4.2 Stability

The frequency distribution of estimated stability classes in the meteorological file is presented in Figure 4.22. The data show a total of 50% of hours with either E or F stability class, consistent with the inland and relatively sheltered location of the site.

Figure 4.22: Domain B Farm 2 - Frequency Distribution of Estimated Stability Classes for 2002

4.4.3 Mixing Height

The diurnal variation of mixing height is summarised in Figure 4.23. The diurnal cycle is clear in this figure.

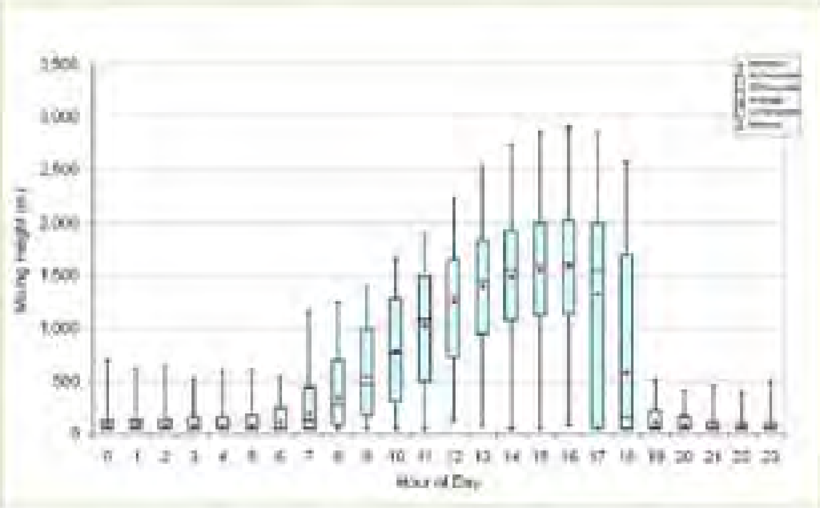


Figure 4.23: Domain B Farm 2 –Estimated Mixing Height for Site

4.4.4 Temperature

The yearly temperature time series for 2002 is shown in Figure 4.24. The average temperature was 20°C, with a maximum of 41°C and a minimum of 2°C.

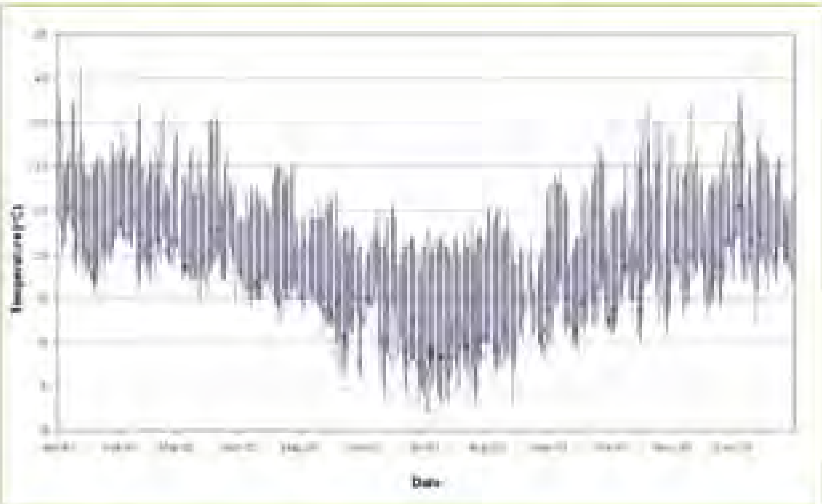


Figure 4.24: : Domain B Farm 2 Yearly Temperature – January to December 2002

5 ODOUR EMISSIONS ESTIMATION

5.1 Basis of Odour Emissions Data

Odour emission rates (OERs) for this assessment have been estimated using a modelling approach based on data from a variety of meat chicken farms in south eastern Queensland and New South Wales, as well as theoretical considerations.

The approach generates hourly varying emission rates from each shed based on the following factors:

- The number of birds, which varies later in the batch as harvesting takes place.
- The stocking density of birds, which is a function of bird numbers, bird age and shed size.
- Ventilation rate, which depends on bird age and ambient temperature.
- Design and management practices, particularly those aimed at controlling litter moisture.

Data from existing farms were gathered from tunnel-ventilated sheds (many with nipple drinkers) and chicken batches at approximately five weeks of age or more. For the dataset, the minimum bird age when sampling was performed was four weeks and five days. These samples are considered to represent the maximum odour generating potential.

5.1.1 Analysis of Odour Data

Odour data collected were standardised to relate the OER per unit bird density and shed area to the ventilation rate at the time of sampling. The resulting relationship is shown in Figure 5.1. The data can be segregated into two groups:

- Farms operating under typical conditions.
- Farms that were experiencing elevated odour emissions due to shed design or management issues at the time of sampling.

Management issues include such factors as addressing heatwave conditions, using foggers (which lead to high litter moisture) and maintaining internal shed temperatures so that it is not significantly above target temperatures for the batch age.

Design factors such as relatively low ventilation speeds and retrofitted shed construction were also relevant to most of these measurements, which are from farms that were built prior to recent improvements in design standards.

As illustrated by the "scattering" of the management issues data in Figure 5.1, the degree to which these issues affect odour levels is highly variable. The curves represent a conservative estimate of the relationship between ambient temperature and odour emissions for tunnel ventilated sheds operating under varying degrees of management. The "best" curve (green) represents a well designed and managed shed with a high level of control over (for example) litter moisture levels. The "worst" curve (red) represents a shed experiencing difficulties due to factors such as adverse weather conditions, equipment failure, poor design or management or a combination of these factors. Most of the farms for which data are presented in Figure 5.1 differ significantly from the best practice design and management criteria for modern farms which include:

- Mechanical ventilation;
- Nipple and cup drinkers;

- Fully insulated sheds;
- Impervious floors;
- Single batch litter use;
- Daily litter inspection and replacement (if litter becomes wet).

The most recent data collected shows best practice farms operating with K factors typically between 1.5 and 3.

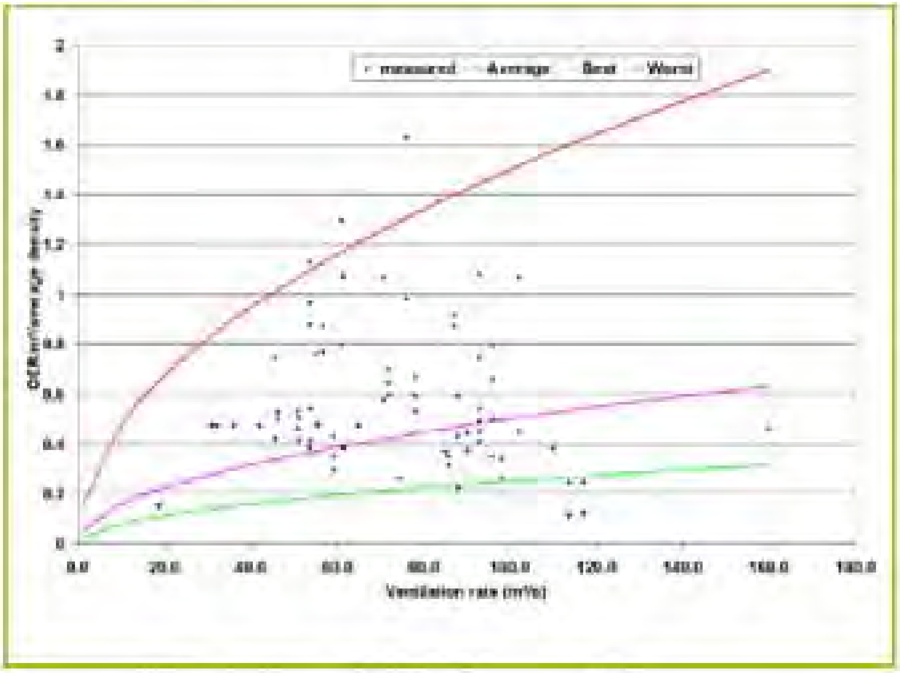


Figure 5.1: Data Used in Odour Emissions Modelling

5.2 Odour Emissions Estimation

From Figure 5.1, the relationship between the "standardised" OER and shed ventilation is expressed as:

$$OER_s = 0.025\,K\,V^{0.5} \qquad (1)$$

where:

OER$_s$ = standardised odour emission rate (ou.m³/s) per unit shed area (m²) per unit of bird density (in kg/m²)

V = ventilation rate (m³/s) and

K = scaling factor between 1 and 5 where a value of 1 represents a well designed and managed shed (see below for more information). A value of 1 equates to minimum possible emission rates associated with a very well designed and managed shed (see below for more information) but on recent evidence from odour measurements, a value of K=1 should not be used for new farms. For a best practice operation, recent evidence suggests that a suitable minimum value of K to apply to new operations lies in the range 1.5 to 2.

Equation 1 can be expanded to provide a prediction of the OER from a shed at any given stage of the growth cycle as follows:

$$OER = 0.025\, K\, A\, D\, V^{0.5} \qquad (2)$$

where:

OER = odour emission rate (ou.m³/s);

A = total shed floor area (m²);

D = average bird density (in kg/m²);

V = ventilation rate (m³/s); and

K = scaling factor between 1 and 5 where 1 represents an extremely well designed and managed shed, i.e., state of the art (see below for more information)

Bird density (D) is related to the age of the birds and the stocking density (i.e. the number of birds placed per unit area). It is common practice within the meat chicken industry to vary the stocking density with the time of year and market demands. Lower ambient temperatures during the winter months allow for higher bird densities. With a known stocking density, a value of the mass per unit area can be estimated based on the relationship shown in Figure 5.2.

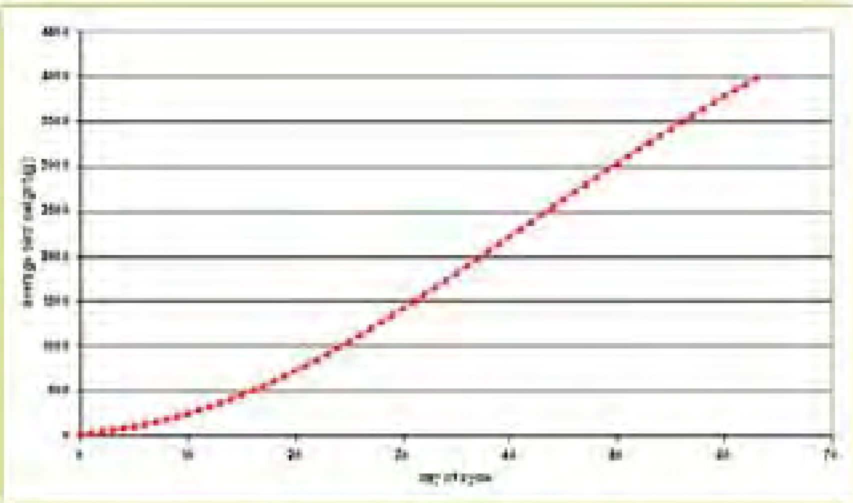


Figure 5.2: Average Bird Weight by Age*

The ventilation rate (V) used at any given time is a function of the age of the birds and the ambient temperature and humidity. Figure 5.3 provides an estimate of the ventilation required for a given tunnel ventilated shed as a percentage of the maximum for summertime conditions.

Figure 5.3: Shed Ventilation as a Percentage of Maximum Ventilation

Bird Age (weeks)	1	2	3	4	5	6	7	8
Temperature (°C) above Target	Ventilation Rate (as a Percentage of the Maximum)							
<1	1.28	2.55	5.11	7.66	9.79	11.49	17.02	17.02
1	1.28	12.50	12.50	25.00	25.00	25.00	25.00	25.00
2	1.28	25.00	25.00	37.50	37.50	37.50	37.50	37.50
3	1.28	37.50	37.50	50.00	50.00	50.00	50.00	50.00
4	1.28	37.50	37.50	50.00	50.00	50.00	50.00	50.00
5	1.28	37.50	37.50	62.50	75.00	75.00	75.00	75.00
7	1.28	37.50	37.50	62.50	75.00	75.00	87.50	100.00
8	1.28	62.50	62.50	62.50	75.00	75.00	100.00	100.00
9	1.28	62.50	62.50	87.50	100.00	100.00	100.00	100.00

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

The scaling factor (K) referred to in equations 1 and 2 is essentially a rating for the design and management of the sheds. The calculation of K for any given farm is based on several components of farm management.

* Source: Ross Broiler Manual www.ross-intl.aviagen.com

For the purposes of this project, a K factor of 2 was adopted. Our experience suggests that a K factor of two represents the typical emissions from a modern, well managed meat chicken farm. In exceptional cases the K value based on measured data may around or even less than 1.

Figure 5.4 shows the variability of OER for the two shed groups during a grow-out cycle as the emissions vary based on equation 2. The decline in emissions after day 56 represents the clean out of the sheds[4].

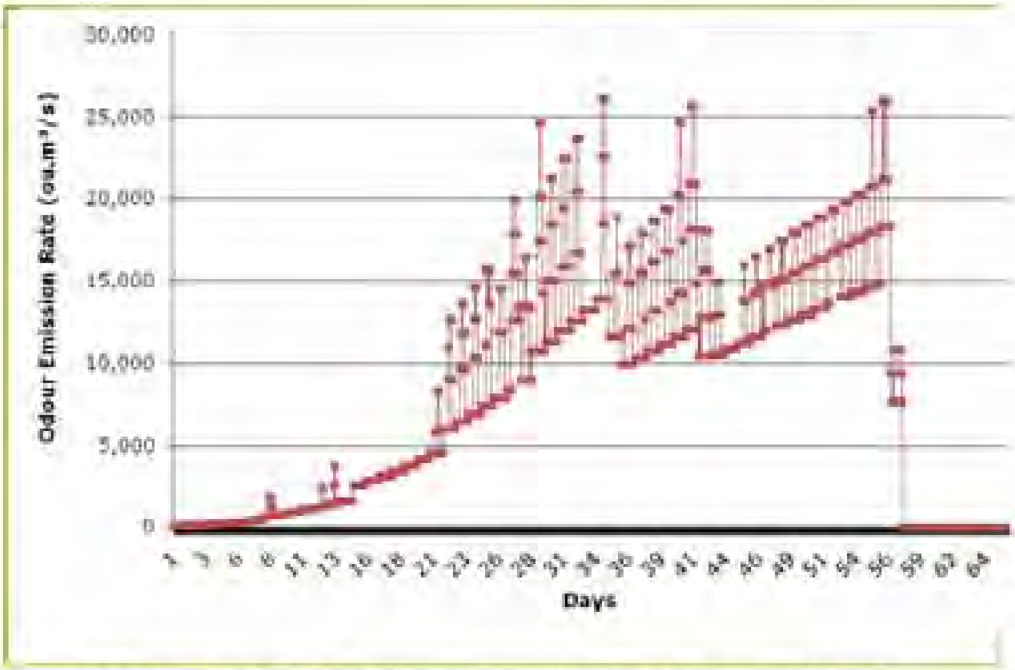


Figure 5.4: Example of Modelled Shed OER Variations Over a Batch (Domain 2, K factor of 2)

5.3 Source Details

Traditionally, emissions from animal husbandry buildings have been modelled as volume sources (e.g. Jiang & Sands, 2000). In dispersion models such as CALPUFF, volume sources are not capable of incorporating thermal plume buoyancy. However, there are times when air vented from poultry sheds is warmer than the ambient temperature, and at these times some buoyancy effect leading to plume rise might be expected. Even temperature differentials as small as 1-2°C may have a significant effect on near-field ground level concentrations (Ormerod *et al.* 2003). The effects of plume buoyancy on ground level concentrations of odour are generally confined to distances of less than 400 m or so from the sheds, under stable conditions with light winds. However, if there is significant vertical wind shear (change of wind direction with height) even a slightly elevated plume may end up being transported in a different

[4] While the shed clean-out may result in elevated odour release during disturbance of the litter, actual odour emissions from the sheds can be easily managed by minimising the amount of air exchange through the shed during clean-out.

direction than would occur without plume buoyancy included in the calculations (if a three-dimensional dispersion model is used).

Emissions from standard tunnel-ventilated poultry sheds are directed horizontally, with no significant vertical component. Therefore, any plume rise occurs as a result of thermal buoyancy of the emissions only, with no plume rise component due to vertical momentum. To deal with the effects of thermal buoyancy for this study, each standard shed has been modelled as four point sources with no mechanically-generated plume rise whilst maintaining the thermal mass of the plume (i.e. vertical momentum (rainhat option) is switched off within CALPUFF). The four sources are centred and the ends of the sheds and are displaced by 15m from the fans to the centre of each source. This incorporates the effect of plume displacement due to the initial horizontal momentum, and is separated slightly in the vertical, between 0.5 and 2 m in height. Building wake effects are included via the US EPA's Building Profile Input Program (BPIP). Shed exhaust temperatures were based on the average target temperatures detailed by the University of Georgia in their Poultry Housing Tips series.

For the scenario where the shed emissions were assumed to be at ambient temperature, the temperature from the meteorological dataset was used as the emission temperature in the model. For the volume source approach detailed in Table 3.1: Modelled Scenarios

the source was modelled as a volume source in CALPUFF.

6 MODELLING RESULTS

Odour concentrations resulting from the farm scenarios have been predicted using a K factor of 2. For all farms, the ground level 99.5th percentile 1-hour concentrations ($C_{99.5,1hr}$) are presented in the figures below as a red line.

6.1 Domain A

A comparison of the ambient and batch target temperatures (exhaust temperatures) is shown in Figure 6.1. There were slight differences between the sites modelled, however these were less than one degree Celsius. The figure shows that the greatest difference between the target and ambient temperatures occurred during winter each year.

It is important to note that the information shown in Figure 6.1 represents a comparison between the ambient temperature and the target temperature (i.e., the temperature required to maintain birds at their thermo-neutral comfort range for a given stage of growth). It is important to note that the target temperature is the effective temperature, which is not the directly measured temperature but rather a measure that takes into account the cooling effect of wind. For example, if the target temperature is 21°C and fans are at full speed, the actual temperature (sensible temperature) may be approximately 25°C.

On this basis, the use of the target temperatures (as published in various poultry guides) in the modelling is likely to result in the under prediction of exhaust temperatures. Hence, there is a conservative tendency towards reducing the effect of plume rise. In the absence of more accurate data from production facilities, target temperature is the most straightforward indicator of exit temperature.

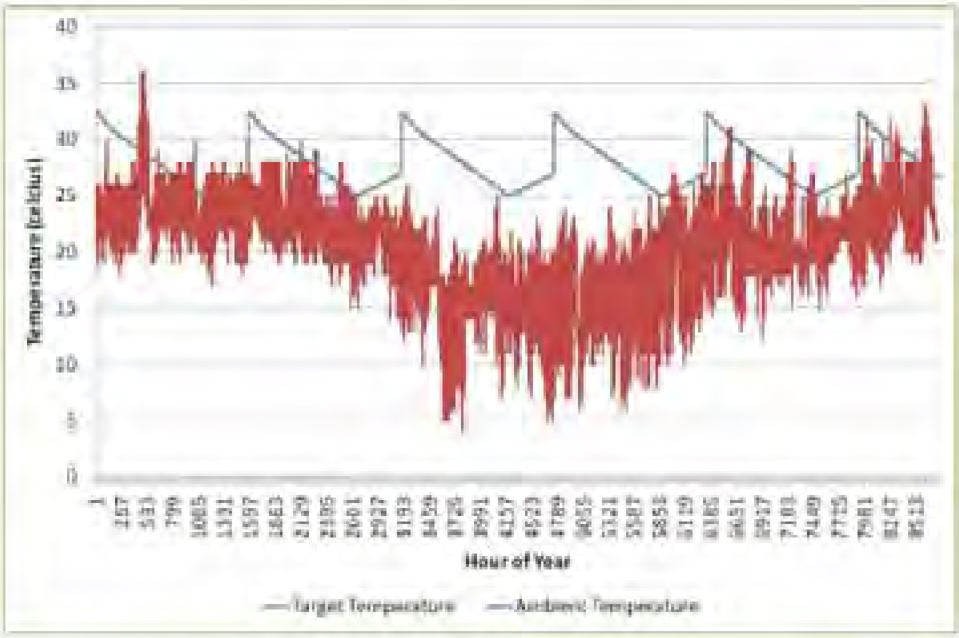


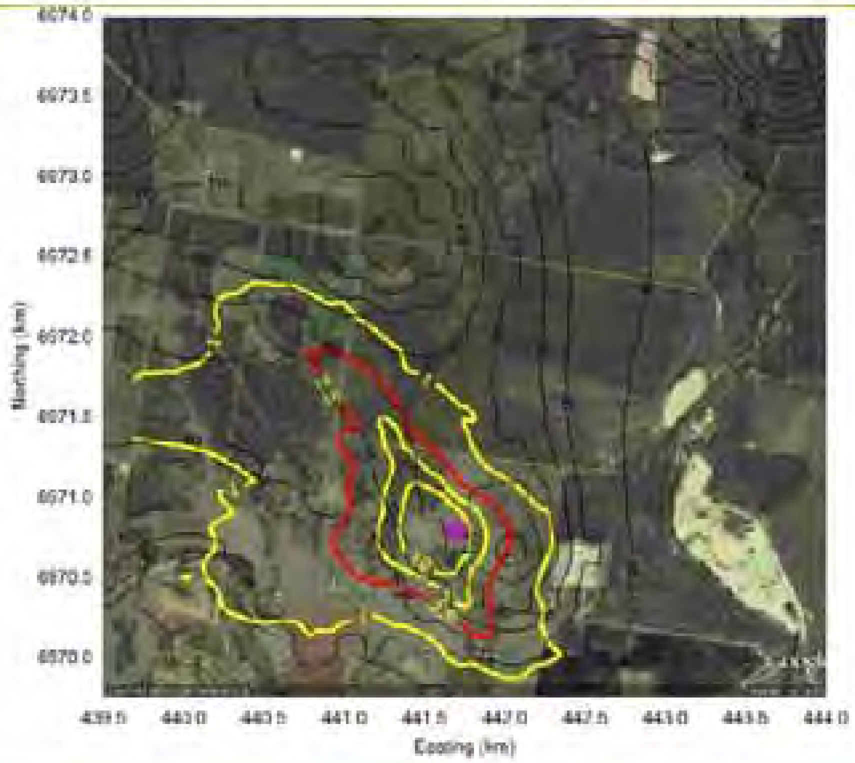
Figure 6.1: Domain A – Comparison of Target and Ambient Temperatures for Domain A Modelling Scenarios

6.1.1 Domain A – Farm 1

Predicted $C_{99.5,\ 1hr}$ odour concentrations for the 175,000 bird farm at production exhaust temperature, ambient exhaust temperature and the volume source scenario are shown in Figure 6.2, Figure 6.3 and Figure 6.4 respectively. The predicted odour concentrations for the 350,000 bird scenario for the production exhaust temperature, ambient exhaust temperature and the volume source runs are shown in Figure 6.5, Figure 6.6 and Figure 6.7 respectively.

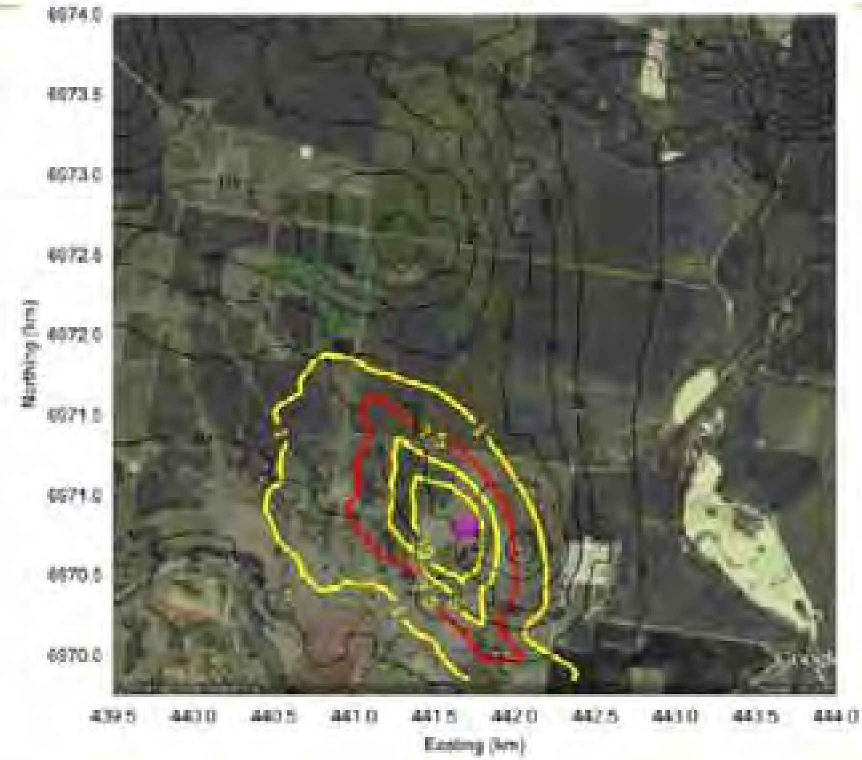
Species: Odour	Location: Domain A	Scenario: K = 2 175,000 birds Production temperature	Percentile: 99.5th	Averaging Time: 1-Hour
Model Used: CALPUFF v6.0	**Units:** ou	**Guideline:** 2.5 ou (red line)	**Met Data:** 2000 CALMET Generated	**Plot:** G. Galvin C. Starke

Figure 6.2: Domain A Farm 1 – 175,000 birds, Production Temperature



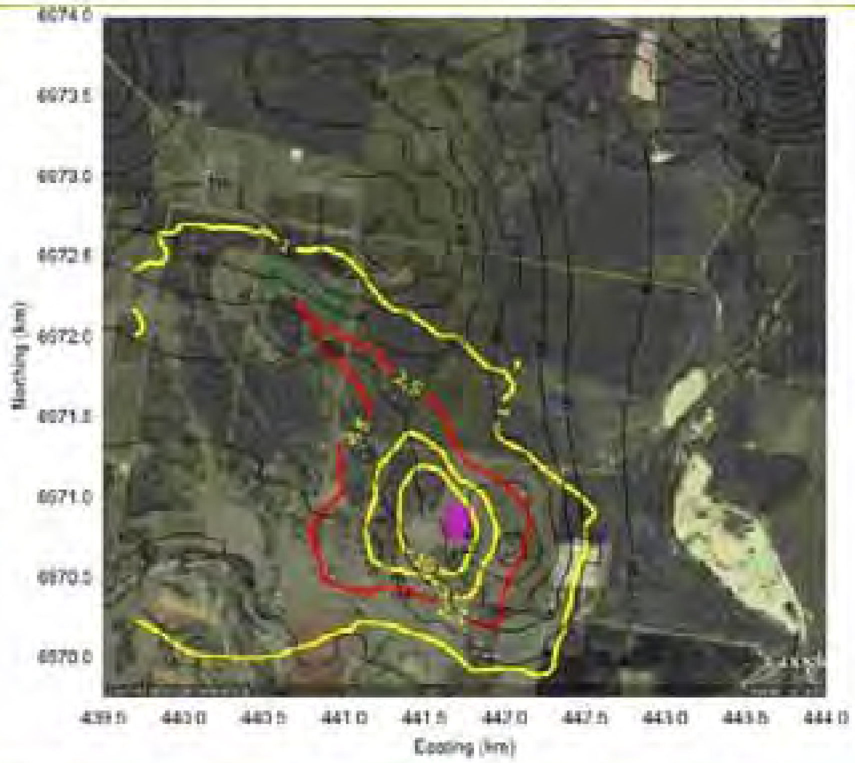
Species: Odour	**Location:** Domain A	**Scenario:** K = 2 175,000 birds Ambient Temperature	**Percentile:** 99.5[th]	**Averaging Time:** 1-Hour
Model Used: CALPUFF v6.0	**Units:** ou	**Guideline:** 2.5 ou (red line)	**Met Data:** 2000 CALMET Generated	**Plot:** G. Galvin G. Starke

Figure 6.3: Domain A Farm 1 – 175,000 birds, Ambient Temperature



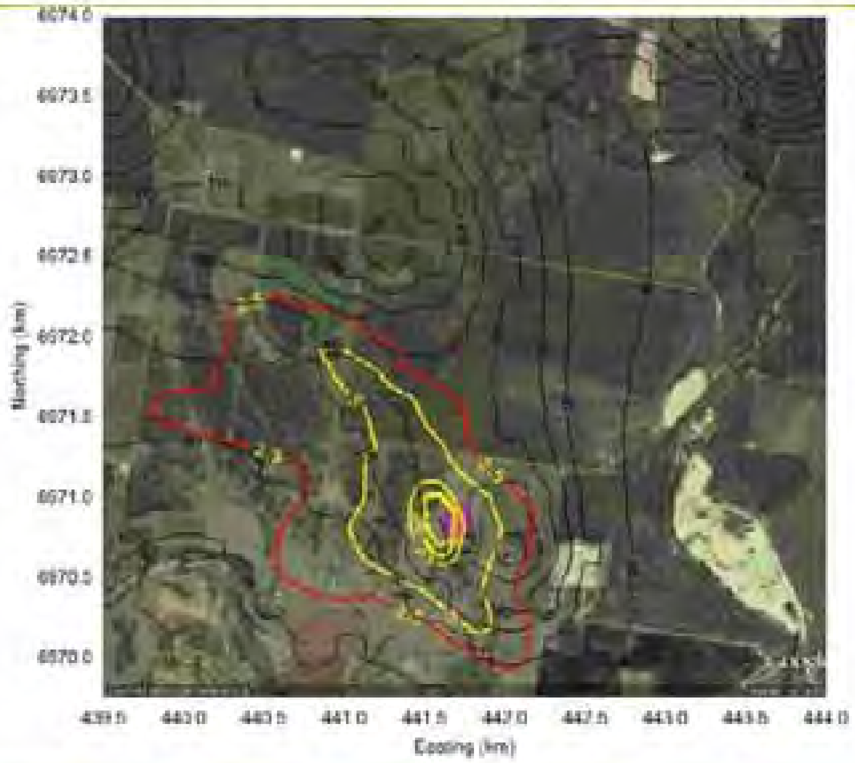
Species: Odour	Location: Domain A	Scenario: K = 2 175,000 birds Volume Source	Percentile: 99.5th	Averaging Time: 1-Hour
Model Used: CALPUFF v6.0	Units: ou	Guideline: 2.5 ou (red line)	Met Data: 2000 CALMET Generated	Plot: G. Galvin C. Starke

Figure 6.4: Domain A Farm 1 – 175,000 birds, Volume Source



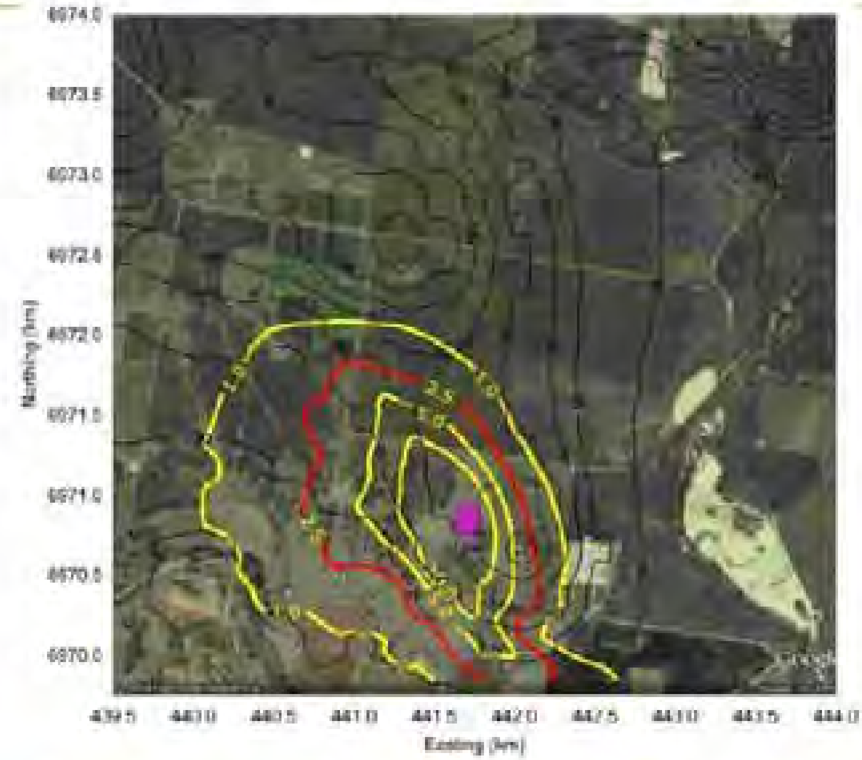
Species:	Location:	Scenario:	Percentile:	Averaging Time:
Odour	Domain A	K = 2 350,000 birds Production Temperature	99.5th	1-Hour
Model Used:	**Units:**	**Guideline:**	**Met Data:**	**Plot:**
CALPUFF v6.0	ou	2.5 ou (red line)	2000 CALMET Generated	G. Galvin G. Starke

Figure 6.5: Domain A Farm 1 – 350,000 birds, Production Temperature



Species: Odour	**Location:** Domain A	**Scenario:** K = 2 350,000 birds Ambient temperature	**Percentile:** 99.5th	**Averaging Time:** 1-Hour
Model Used: CALPUFF v6.0	**Units:** ou	**Guideline:** 2.5 ou (red line)	**Met Data:** 2000 CALMET Generated	**Plot:** C. Galvin G. Starke

Figure 6.6: Domain A Farm 1 – 350,000 birds, Ambient Temperature

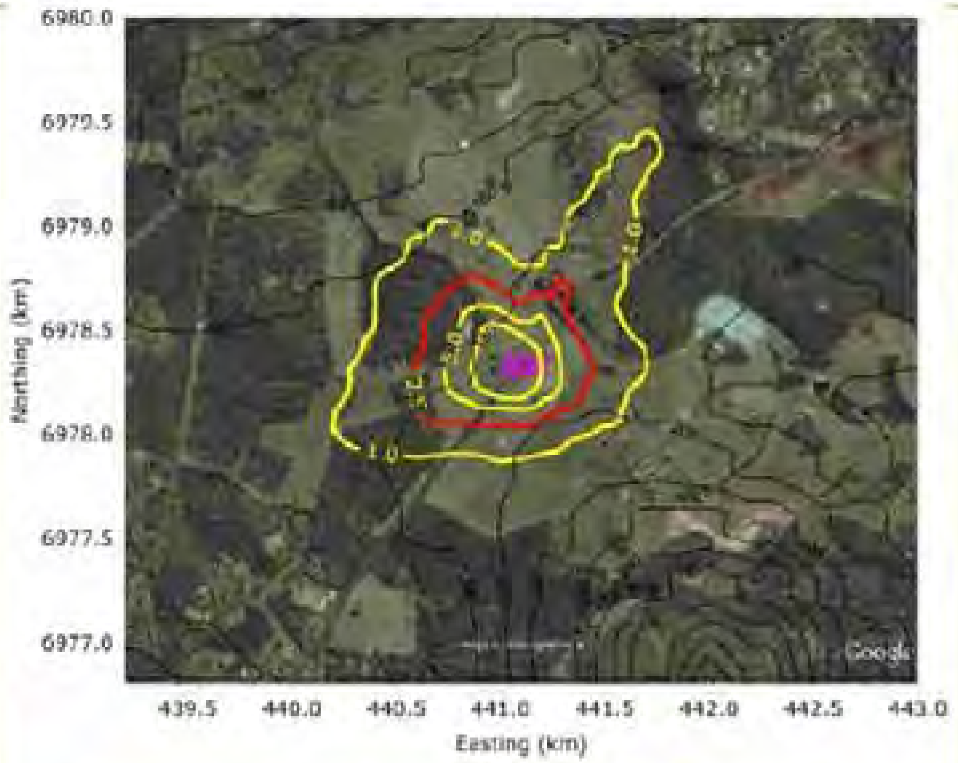


Species:	Location:	Scenario:	Percentile:	Averaging Time:
Odour	Domain A	K = 2 350,000 birds Volume Source	99.5th	1-Hour
Model Used:	**Units:**	**Guideline:**	**Met Data:**	**Plot:**
CALPUFF v6.0	Ou	2.5 ou (red line)	2000 CALMET Generated	G. Galvin G. Starke

Figure 6.7: Domain A Farm 1 - 350,000 birds, Volume Source

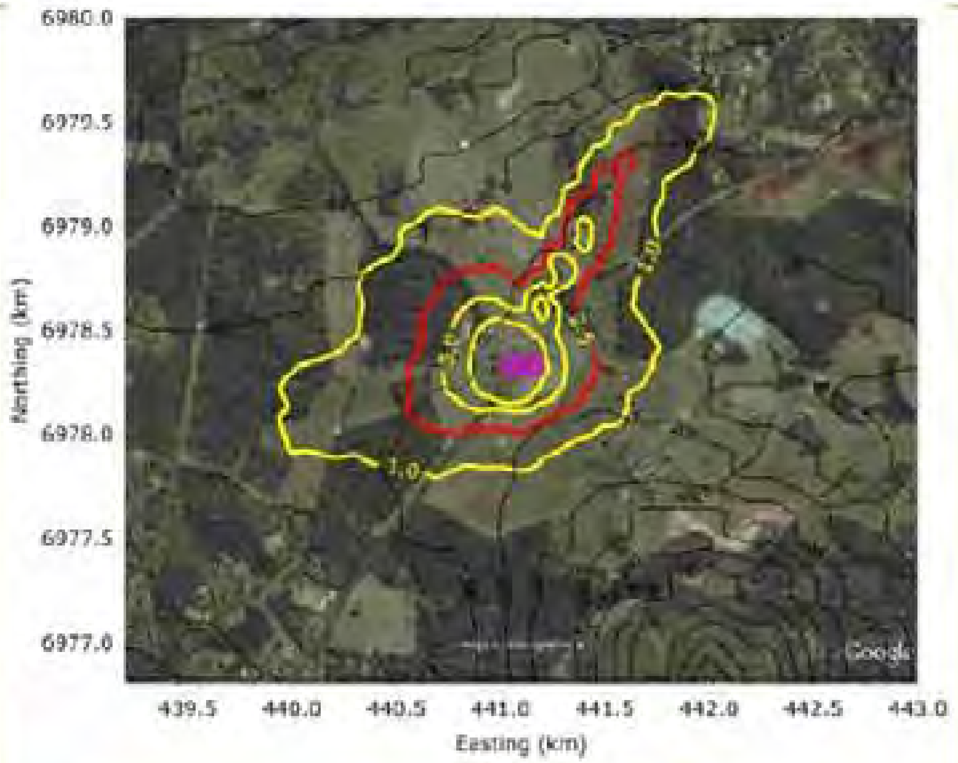
6.1.2 Domain A – Farm 2

Predicted $C_{99.5\ 1hr}$ odour concentrations for the 175,000 bird farm at production exhaust temperature, ambient exhaust temperature and the volume source scenario are shown in Figure 6.8, Figure 6.9 and Figure 6.10 respectively. The predicted odour concentrations for the 350,000 bird scenario for the production exhaust temperature, ambient exhaust temperature and the volume source runs are shown in Figure 6.11, Figure 6.12 and Figure 6.13 respectively.



Species: Odour	**Location:** Domain A	**Scenario:** K = 2 175,000 birds Production temperature	**Percentile:** 99.5th	**Averaging Time:** 1-Hour
Model Used: CALPUFF v6.0	**Units:** ou	**Guideline:** 2.5 ou (red line)	**Met Data:** 2000 CALMET Generated	**Plot:** G. Galvin C. Starke

Figure 6.8: Domain A Farm 2 – 175,000 birds, Production Temperature

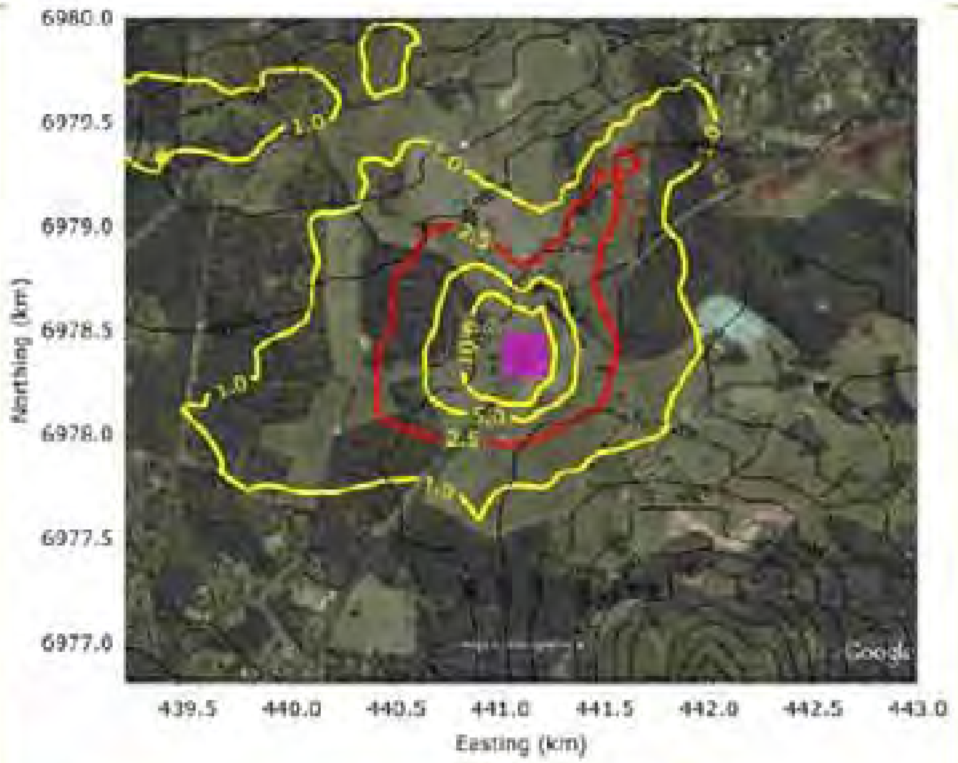


Species: Odour	Location: Domain A	Scenario: K = 2 175,000 birds Ambient Temperature	Percentile: 99.5th	Averaging Time: 1-Hour
Model Used: CALPUFF v6.0	Units: ou	Guideline: 2.5 ou (red line)	Met Data: 2000 CALMET Generated	Plot: G. Galvin G. Starke

Figure 6.9: Domain A Farm 2 – 175,000 birds, Ambient Temperature

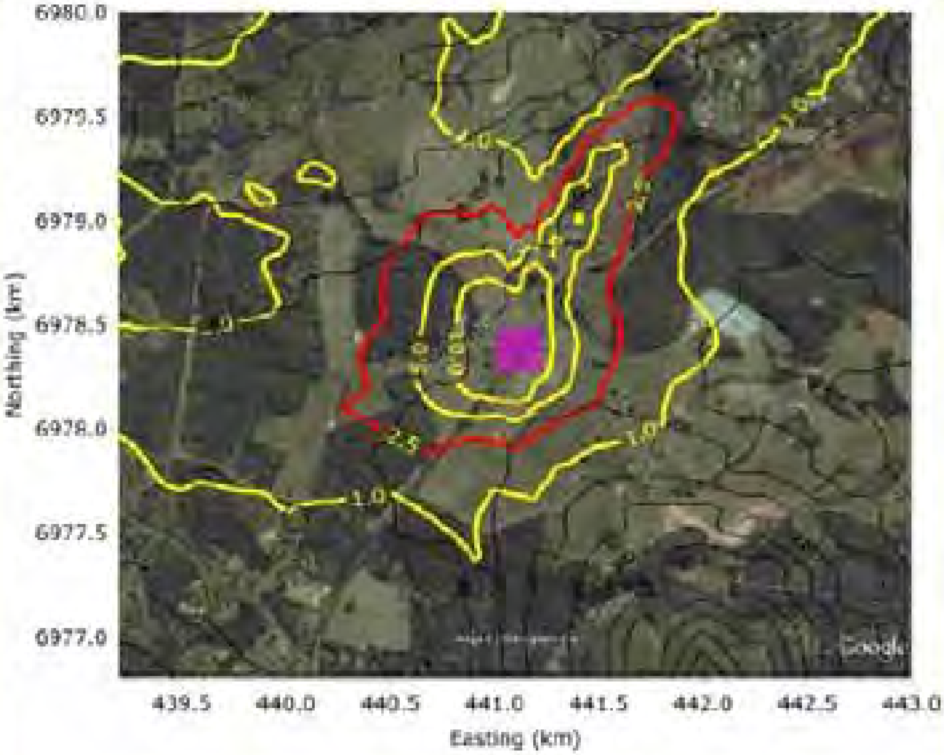
Species: Odour	Location: Domain A	Scenario: K = 2 175,000 birds Volume Source	Percentile: 99.5th	Averaging Time: 1-Hour
Model Used: CALPUFF v6.0	Units: ou	Guideline: 2.5 ou (red line)	Met Data: 2000 CALMET Generated	Plot: G. Galvin C. Starke

Figure 6.10: Domain A Farm 2 – 175,000 birds, Volume Source



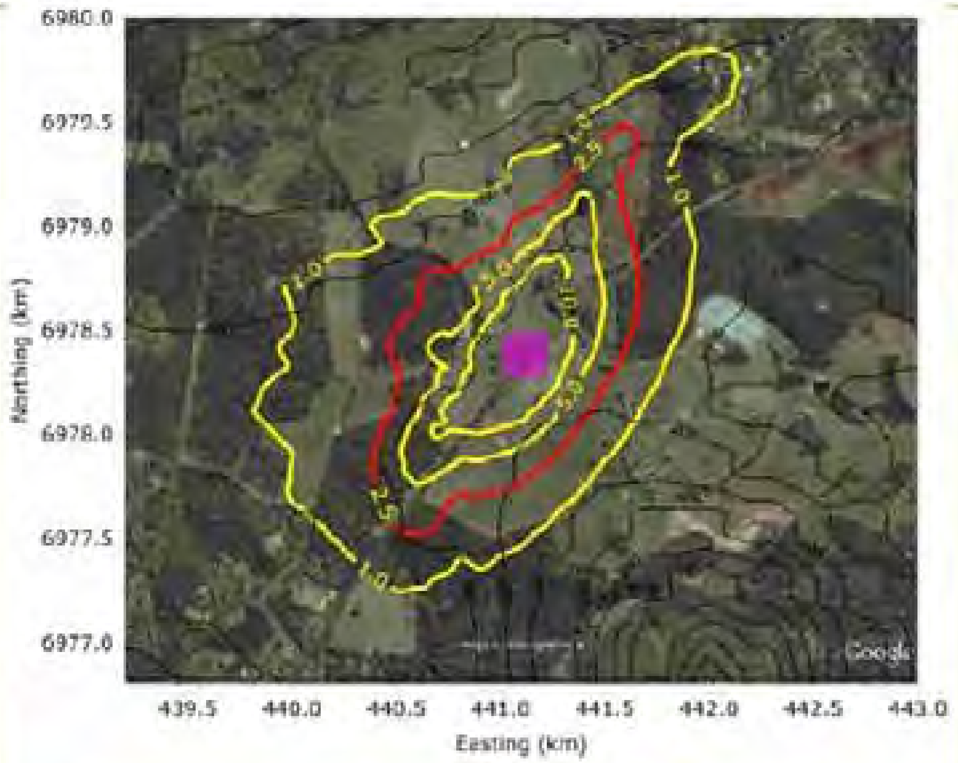
Species: Odour	Location: Domain A	Scenario: K = 2 350,000 birds Production Temperature	Percentile: 99.5th	Averaging Time: 1-Hour
Model Used: CALPUFF v6.0	Units: ou	Guideline: 2.5 ou (red line)	Met Data: 2000 CALMET Generated	Plot: G. Galvin C. Starke

Figure 6.11: Domain A Farm 2 - 350,000 birds, Production Temperature



Species: Odour	**Location:** Domain A	**Scenario:** K = 2 350,000 birds Ambient temperature	**Percentile:** 99.5th	**Averaging Time:** 1-Hour
Model Used: CALPUFF v6.0	**Units:** ou	**Guideline:** 2.5 ou (red line)	**Met Data:** 2000 CALMET Generated	**Plot:** G. Galvin G. Starke

Figure 6.12: Domain A Farm 2 – 350,000 birds, Ambient Temperature



Species: Odour	Location: Domain A	Scenario: K = 2 350,000 birds Volume Source	Percentile: 99.5th	Averaging Time: 1-Hour
Model Used: CALPUFF v6.0	Units: ou	Guideline: 2.5 ou (red line)	Met Data: 2000 CALMET Generated	Plot: G. Galvin C. Starke

Figure 6.13: Domain A Farm 2 - 350,000 birds, Volume Source

6.2 Domain B

A comparison of the ambient and batch target temperatures (exhaust temperatures) are shown in **Error! Reference source not found.**. The figure shows that the greatest difference between the target and ambient temperatures occurred during winter each year. As described in Section 6.1, the target temperature is the effective temperature, and not the sensible temperature.

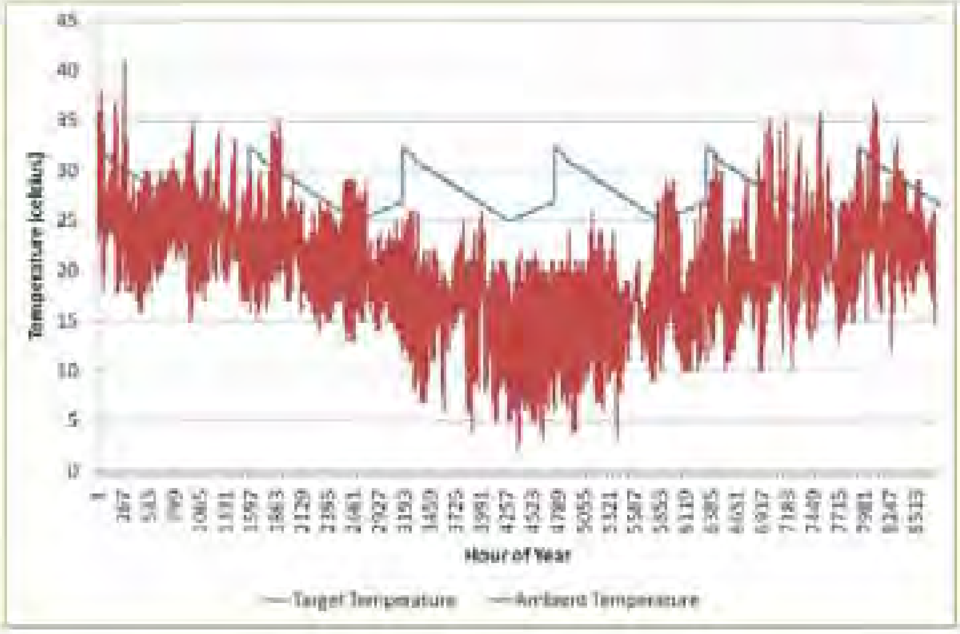


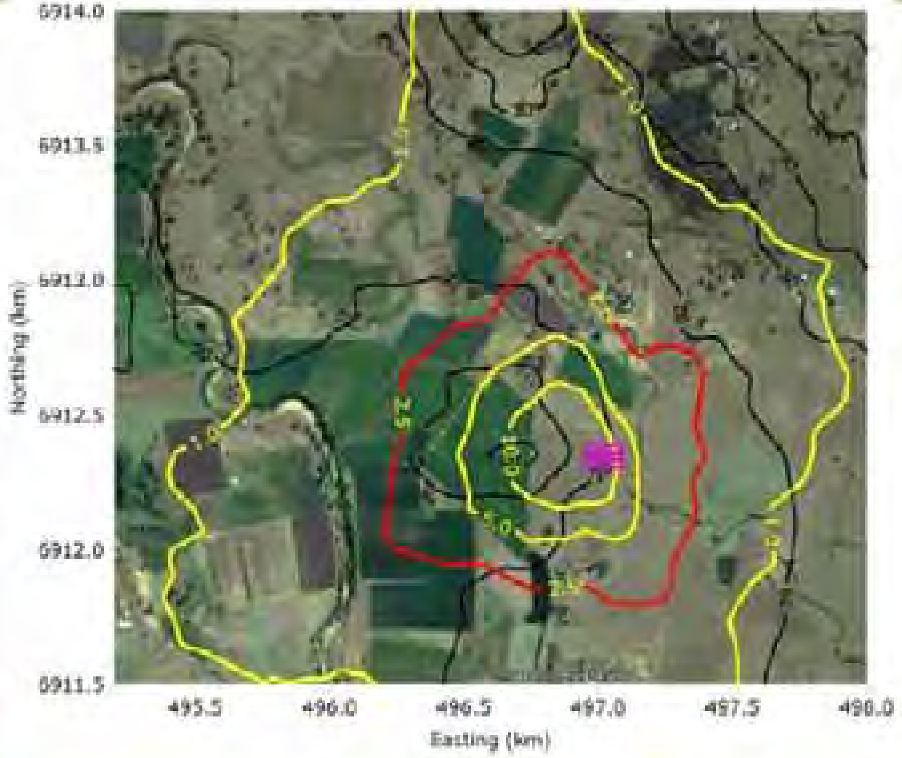
Figure 6.14: Domain B – Comparison of Target and Ambient Temperatures for Domain B Modelling Scenarios

6.2.1 Domain B – Farm 1

Predicted $C_{99.5\ 1hr}$ odour concentrations for the 175,000 bird farm at production exhaust temperature, ambient exhaust temperature and the volume source scenario are shown in Figure 6.15, Figure 6.16 and Figure 6.17 respectively. The predicted odour concentrations for the 350,000 bird scenario for the production exhaust temperature, ambient exhaust temperature and the volume source runs are shown in Figure 6.18, Figure 6.19 and Figure 6.20 respectively.

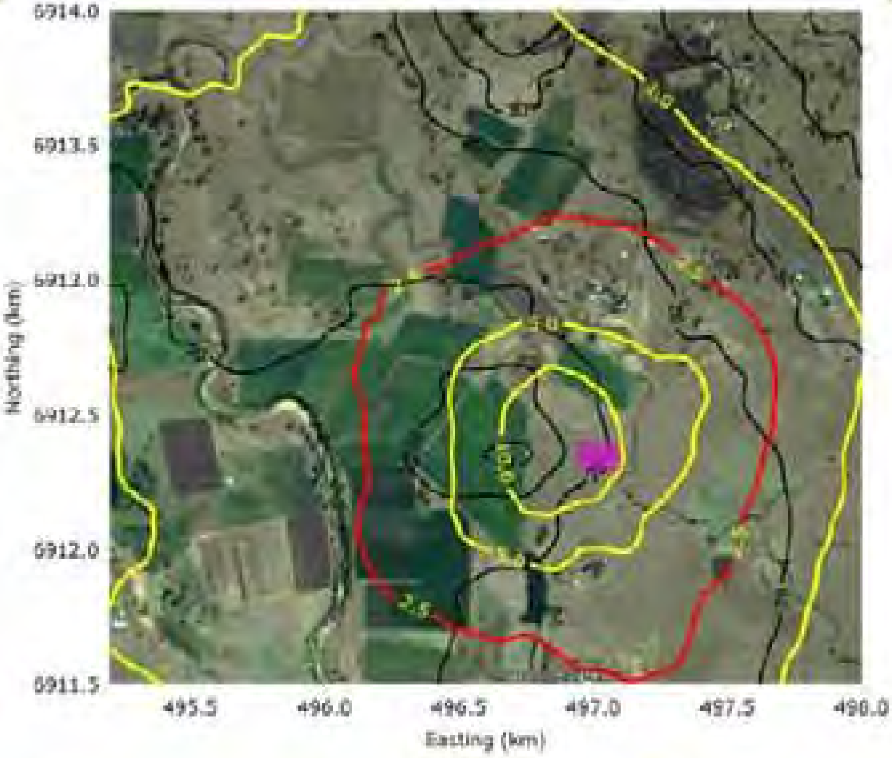
Species:	Location:	Scenario:	Percentile:	Averaging Time:
Odour	Domain B	K = 2 175,000 birds Production temperature	99.5th	1-Hour
Model Used:	**Units:**	**Guideline:**	**Met Data:**	**Plot:**
CALPUFF v6.0	ou	2.5 ou (red line)	2000 CALMET Generated	G. Galvin C. Starke

Figure 6.15: Domain B Farm 1 – 175,000 birds, Production Temperature



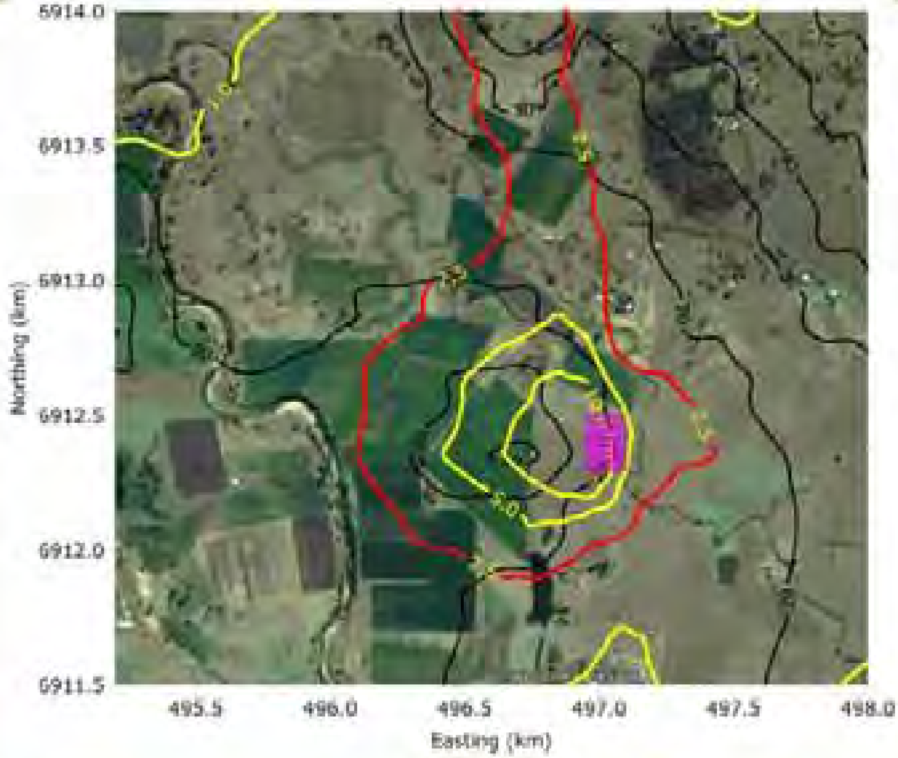
Species: Odour	Location: Domain B	Scenario: K = 2 175,000 birds Ambient Temperature	Percentile: 99.5th	Averaging Time: 1-Hour
Model Used: CALPUFF v6.0	Units: ou	Guideline: 2.5 ou (red line)	Met Data: 2000 CALMET Generated	Plot: G. Galvin C. Starke

Figure 6.16: Domain B Farm 1 – 175,000 birds, Ambient Temperature



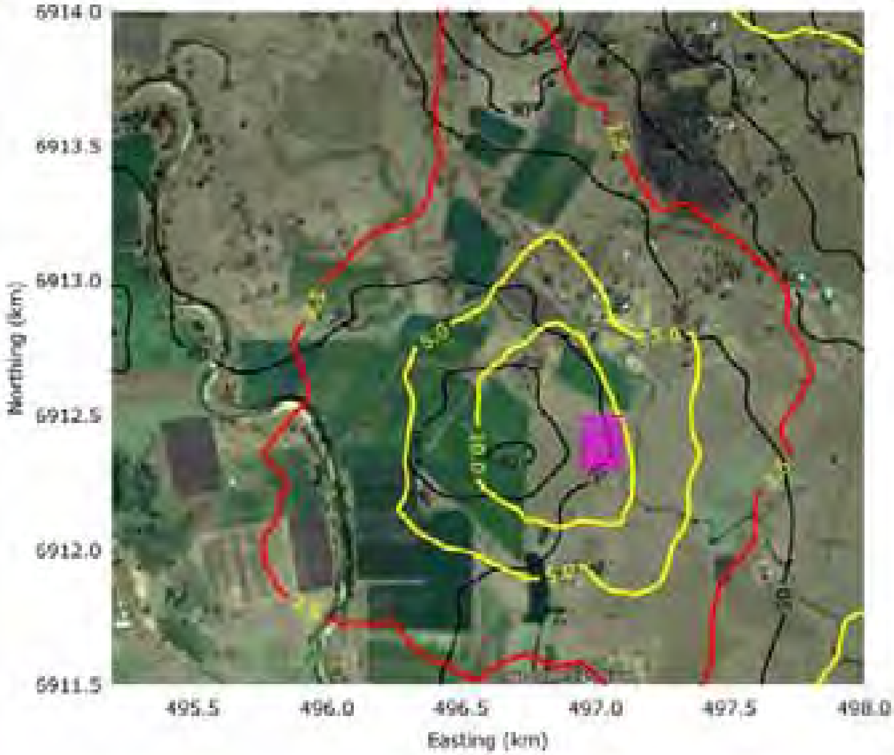
Species: Odour	Location: Domain B	Scenario: K = 2 175,000 birds Volume Source	Percentile: 99.5th	Averaging Time: 1-Hour
Model Used: CALPUFF v6.0	Units: ou	Guideline: 2.5 ou (red line)	Met Data: 2000 CALMET Generated	Plot: G. Galvin G. Starke

Figure 6.17: Domain B Farm 1 – 175,000 birds, Volume Source



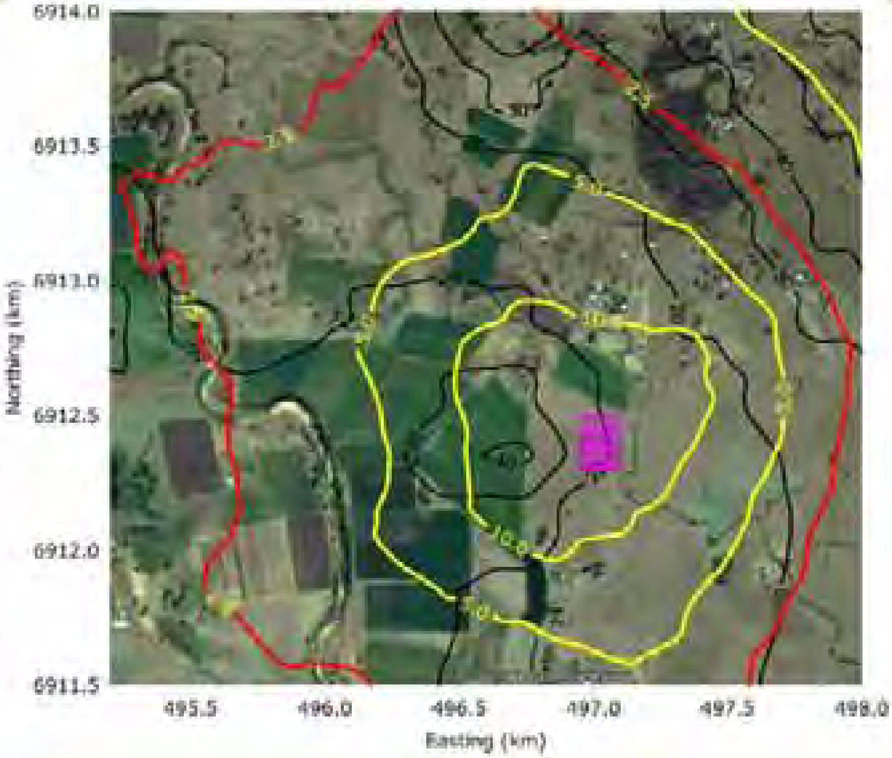
Species: Odour	Location: Domain B	Scenario: K = 2 350,000 birds Production Temperature	Percentile: 99.5th	Averaging Time: 1-Hour
Model Used: CALPUFF v6.0	Units: ou	Guideline: 2.5 ou (red line)	Met Data: 2000 CALMET Generated	Plot: G. Galvin C. Starke

Figure 6.18: Domain B Farm 1 – 350,000 birds, Production Temperature



Species: Odour	**Location:** Domain B	**Scenario:** K = 2 350,000 birds Ambient temperature	**Percentile:** 99.5th	**Averaging Time:** 1-Hour
Model Used: CALPUFF v6.0	**Units:** ou	**Guideline:** 2.5 ou (red line)	**Met Data:** 2000 CALMET Generated	**Plot:** G. Galvin G. Starke

Figure 6.19: Domain B Farm 1 – 350,000 birds, Ambient Temperature

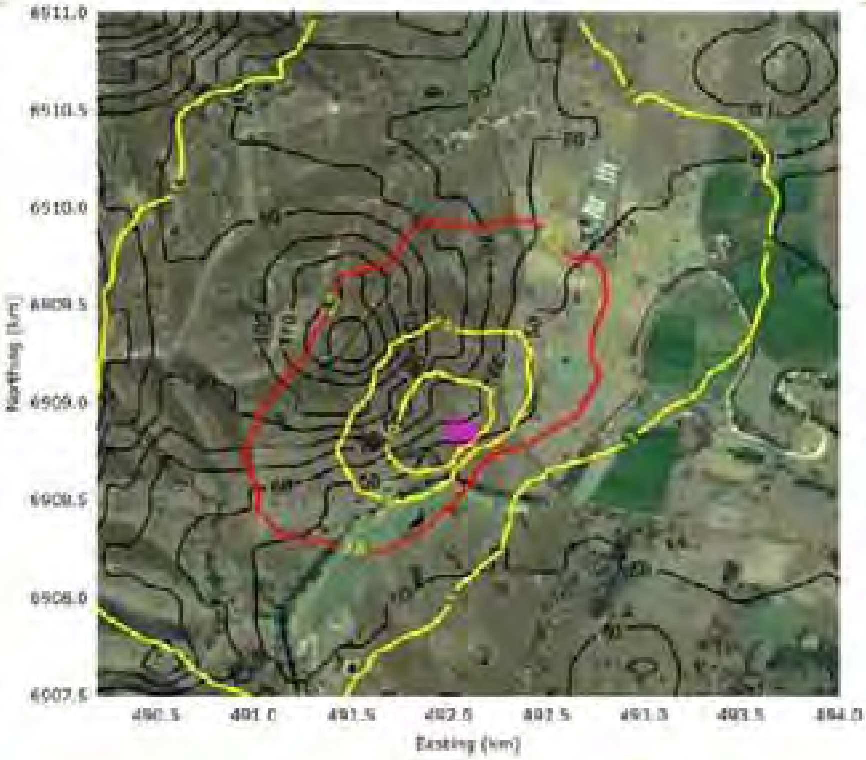


Species: Odour	Location: Domain B	Scenario: K = 2 350,000 birds Volume Source	Percentile: 99.5th	Averaging Time: 1-Hour
Model Used: CALPUFF v6.0	Units: ou	Guideline: 2.5 ou (red line)	Met Data: 2000 CALMET Generated	Plot: G. Galvin C. Starke

Figure 6.20: Domain B Farm 1 - 350,000 birds, Volume Source

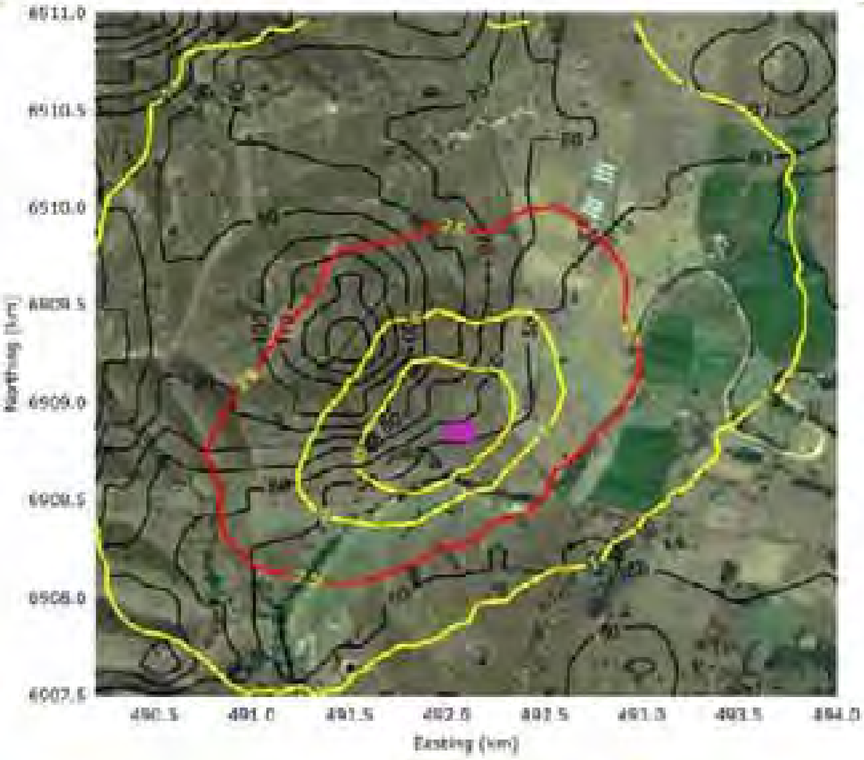
6.2.2 Domain B – Farm 2

Predicted $C_{99.5\ 1hr}$ odour concentrations for the 175,000 bird farm at production exhaust temperature, ambient exhaust temperature and the volume source scenario are shown in Figure 6.21, Figure 6.22 and Figure 6.23 respectively. The predicted odour concentrations for the 350,000 bird scenario for the production exhaust temperature, ambient exhaust temperature and the volume source runs are shown in Figure 6.24, Figure 6.25 and Figure 6.26 respectively.



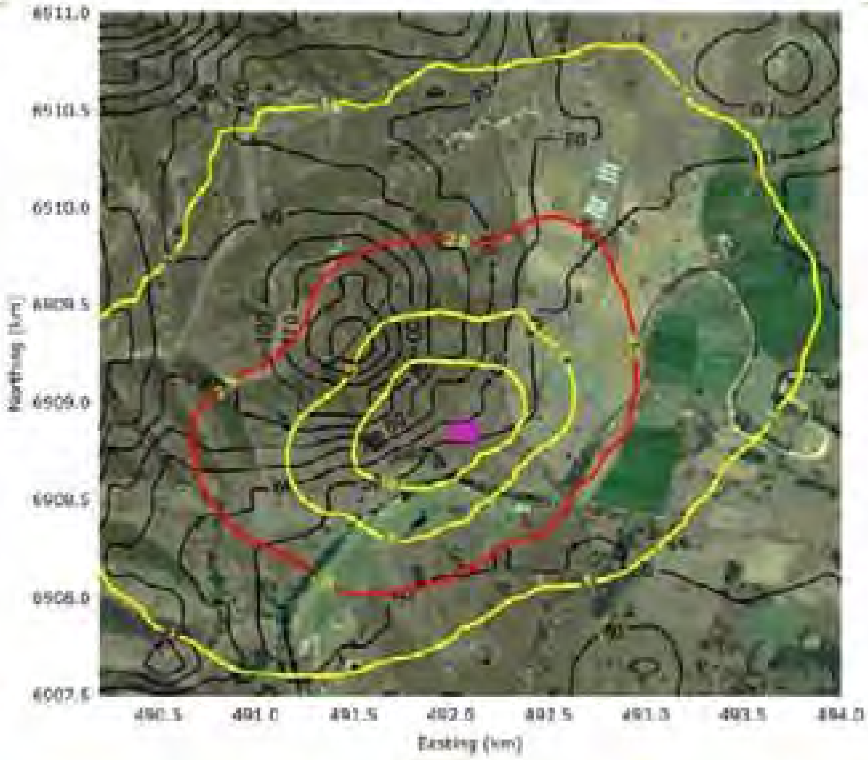
Species: Odour	Location: Domain B	Scenario: K = 2 175,000 birds Production temperature	Percentile: 99.5th	Averaging Time: 1-Hour
Model Used: CALPUFF v6.0	**Units:** ou	**Guideline:** 2.5 ou (red line)	**Met Data:** 2000 CALMET Generated	**Plot:** G. Galvin C. Starke

Figure 6.21: Domain B Farm 2 – 175,000 birds, Production Temperature



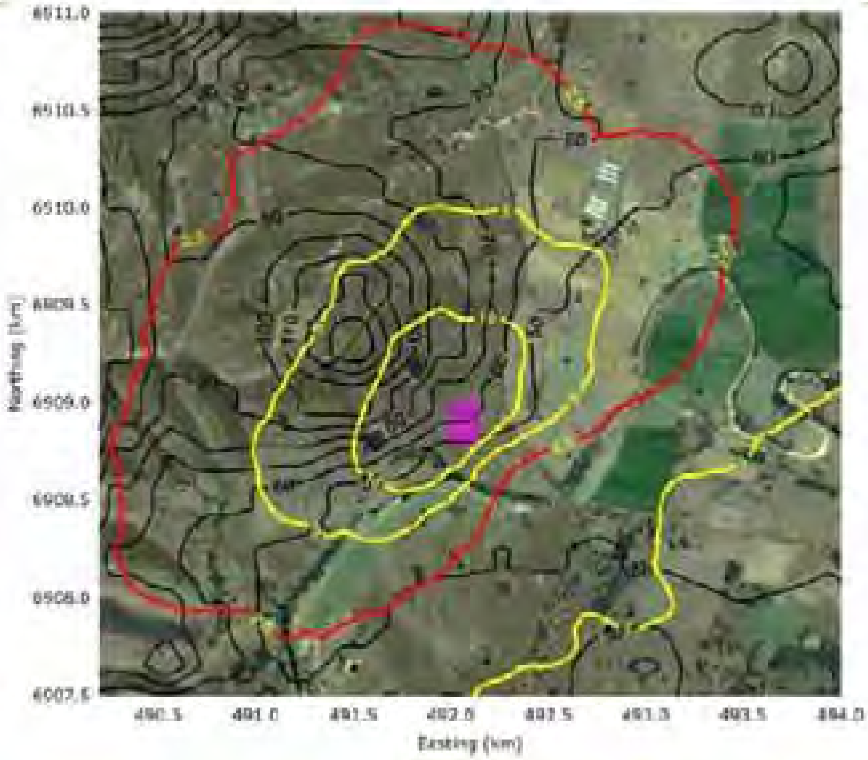
Species:	Location:	Scenario:	Percentile:	Averaging Time:
Odour	Domain B	K = 2 175,000 birds Ambient Temperature	99.5th	1-Hour
Model Used:	**Units:**	**Guideline:**	**Met Data:**	**Plot:**
CALPUFF v6.0	ou	2.5 ou (red line)	2000 CALMET Generated	G. Galvin G. Starke

Figure 6.22: Domain B Farm 2 – 175,000 birds, Ambient Temperature



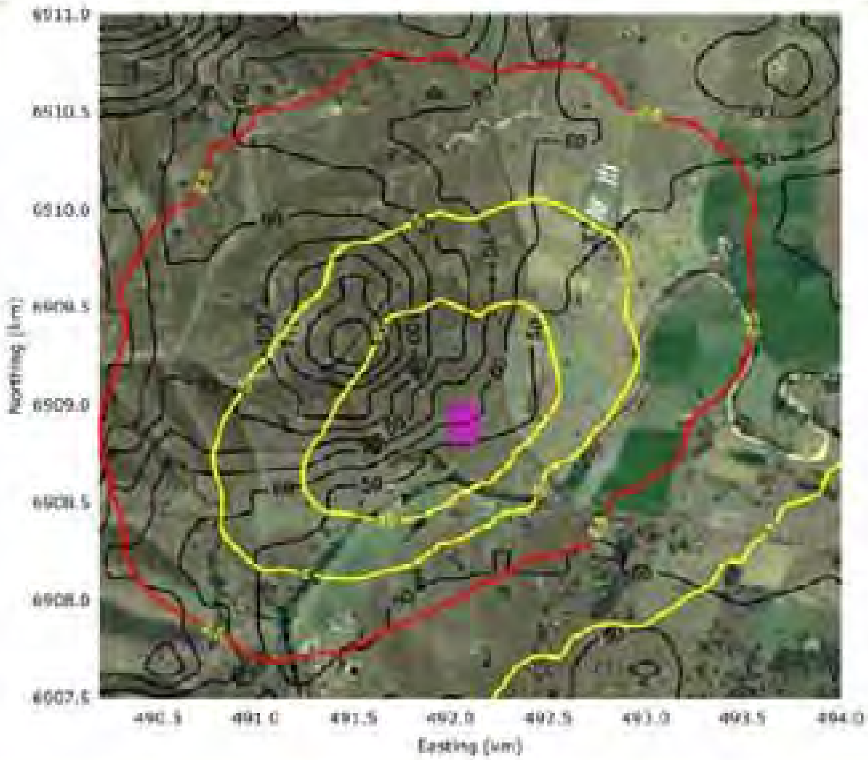
Species: Odour	Location: Domain B	Scenario: K = 2 175,000 birds Volume Source	Percentile: 99.5^{th}	Averaging Time: 1-Hour
Model Used: CALPUFF v6.0	Units: ou	Guideline: 2.5 ou (red line)	Met Data: 2000 CALMET Generated	Plot: G. Galvin G. Starke

Figure 6.23: Domain B Farm 2 – 175,000 birds, Volume Source



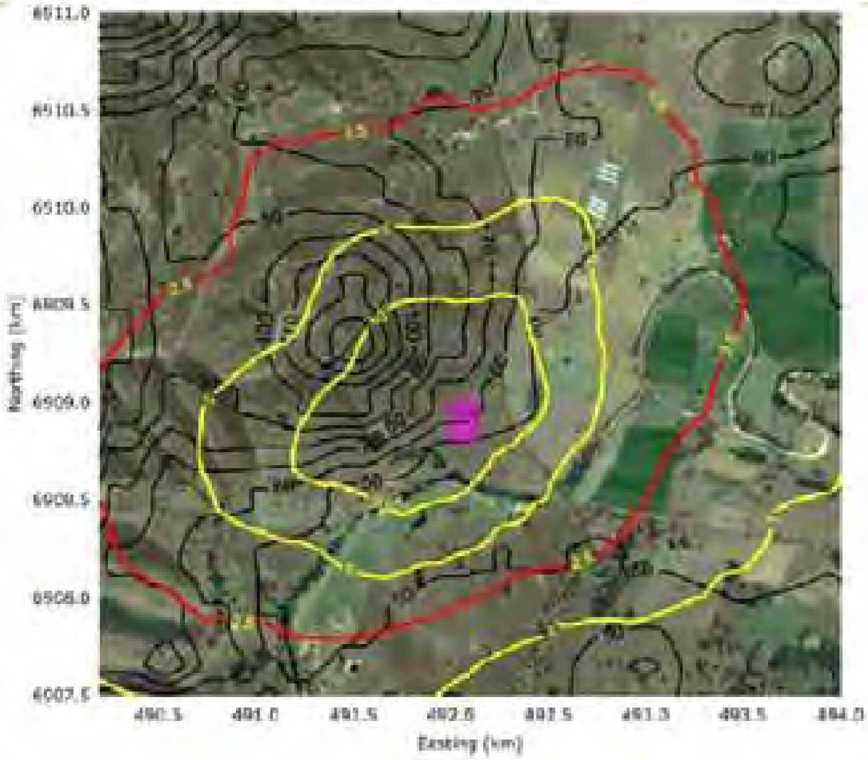
Species: Odour	Location: Domain B	Scenario: K = 2 350,000 birds Production Temperature	Percentile: 99.5th	Averaging Time: 1-Hour
Model Used: CALPUFF v6.0	Units: ou	Guideline: 2.5 ou (red line)	Met Data: 2000 CALMET Generated	Plot: G. Galvin C. Starke

Figure 6.24: Domain B Farm 2 - 350,000 birds, Production Temperature



Species: Odour	**Location:** Domain B	**Scenario:** K = 2 350,000 birds Ambient temperature	**Percentile:** 99.5th	**Averaging Time:** 1-Hour
Model Used: CALPUFF v6.0	**Units:** ou	**Guideline:** 2.5 ou (red line)	**Met Data:** 2000 CALMET Generated	**Plot:** G. Galvin G. Starke

Figure 6.25: Domain B Farm 2 – 350,000 birds, Ambient Temperature



Species: Odour	Location: Domain B	Scenario: K = 2 350,000 birds Volume Source	Percentile: 99.5th	Averaging Time: 1-Hour
Model Used: CALPUFF v6.0	Units: ou	Guideline: 2.5 ou (red line)	Met Data: 2000 CALMET Generated	Plot: G. Galvin C. Starke

Figure 6.26: Domain B Farm 2 - 350,000 birds, Volume Source

7 FARM SUMMARIES

Five farms previously modelled by PAEHolmes are summarised below. They have been included to provide an indication of modelling studies that have been used in applications for approval of new farms. The farms have been listed as Farm A, through to Farm E.

Where model outputs are shown, they have been prepared using the PAEHolmes methodology as shown in Section 5.3.

7.1 FARM A

Farm A is located in South East Queensland. The farm details are summarised in Table 7.1 and the meteorology at the site is summarised in Figure 7.1.

The modelled odour contours for the farm are shown in Figure 7.2 with the red line representing the $C_{99.5,\ 1h}$ Queensland odour guideline, and the red crosses representing the location of selected sensitive receptors. A K factor of 1.7 was used for the modelling.

Table 7.1 : Farm A Summary

Essential information	
Number of birds (essential)	200,000
Is a permanent windbreak wall/berm wall fitted?	No
Is a vegetative windbreak wall established?	Vegetation around the sheds, but not windbreak wall style
Number of sheds	5
Proximity to other farms	No nearby farms

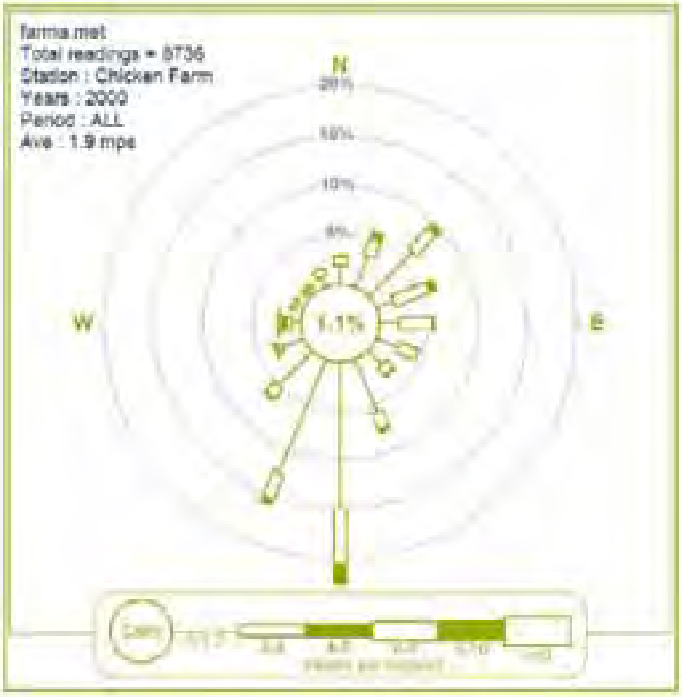


Figure 7.1 : Wind Rose - Farm A

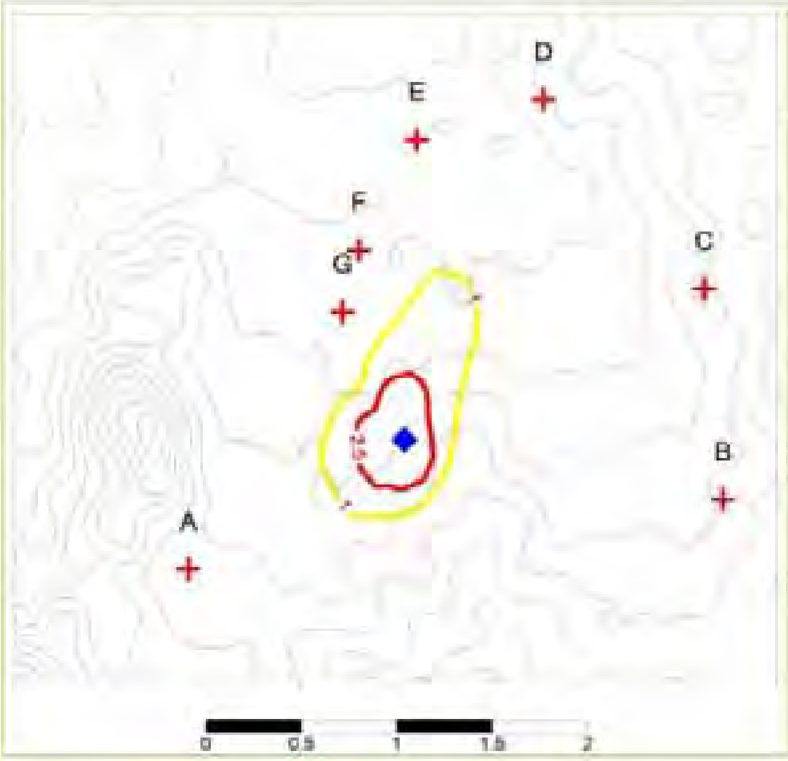


Figure 7.2 : Farm A - Model Output

A summary of the various S factors applicable to the farm, as requested by DEEDI are summarised below in Table 7.2 through Table 7.11.

Table 7.2 : Queensland S Factor Inputs - Farm A

Shed design and management factors (refer to table in 'Guiding information' section)	
Shed design	New tunnel
Drinking system	Nipple/cup
Automated shed environment controller	Yes
Inspect/replace litter daily	Yes
Average litter depth at start of batch	50mm
Maximum shed speed m/s	2.5m/s+

Table 7.3 : Queensland S Factor Inputs for Land Use - Farm A

Receptor	Receptor type/buffer type
Receptor 1	Sensitive land use - house
Receptor 2	Sensitive land use - house
Receptor 3	Sensitive land use - house
Receptor 4	Sensitive land use - house
Receptor 5	Sensitive land use - house
Receptor 6	Sensitive land use - house
Receptor 7	Sensitive land use - house

Table 7.4 : Queensland S Factor Inputs for Surface Roughness - Farm A

Receptor	Surface roughness between farm and receptor
Receptor 1	Long grass few trees
Receptor 2	Long grass few trees
Receptor 3	Long grass few trees
Receptor 4	Long grass few trees
Receptor 5	Long grass few trees
Receptor 6	Long grass few trees
Receptor 7	Long grass few trees

Table 7.5 : Queensland S Factor Inputs for Terrain - Farm A

Receptor	Terrain between farm and receptor
Receptor 1	Upslope flat
Receptor 2	Upslope flat
Receptor 3	Upslope flat
Receptor 4	Downslope broad valley drainage
Receptor 5	Downslope broad valley drainage
Receptor 6	Downslope broad valley drainage
Receptor 7	Downslope broad valley drainage

Table 7.6 : South Australian S Factor Inputs for Receptor Type - Farm A

Receptor	Receptor type
Receptor 1	Rural dwelling
Receptor 2	Rural dwelling
Receptor 3	Rural dwelling
Receptor 4	Rural dwelling
Receptor 5	Rural dwelling
Receptor 6	Rural dwelling
Receptor 7	Rural dwelling

Table 7.7 : South Australian S Factor Inputs for Manure management - Farm A

Receptor	Manure handling
Receptor 1	Taken off site
Receptor 2	Taken off site
Receptor 3	Taken off site
Receptor 4	Taken off site
Receptor 5	Taken off site
Receptor 6	Taken off site
Receptor 7	Taken off site

Table 7.8 : New South Wales S Factor Inputs for Receptor Type - Farm A

Receptor	Receptor Type
Receptor 1	Single rural residence
Receptor 2	Single rural residence
Receptor 3	Single rural residence
Receptor 4	Single rural residence
Receptor 5	Single rural residence
Receptor 6	Single rural residence
Receptor 7	Single rural residence

Table 7.9 : New South Wales S Factor Inputs for Terrain - Farm A

Receptor	Terrain between farm and receptor
Receptor 1	Flat
Receptor 2	Flat
Receptor 3	Flat
Receptor 4	Flat
Receptor 5	Flat
Receptor 6	Flat
Receptor 7	Flat

Table 7.10 : New South Wales S Factor Inputs for Terrain Type - Farm A

Receptor	Vegetation between farm and receptor
Receptor 1	Few trees long grass
Receptor 2	Few trees long grass
Receptor 3	Few trees long grass
Receptor 4	Few trees long grass
Receptor 5	Few trees long grass
Receptor 6	Few trees long grass
Receptor 7	Few trees long grass

Table 7.11 : New South Wales S Factor Inputs for Wind Frequency Factor - Farm A

Wind frequency toward receptor	Percentage
Receptor 1	25.9
Receptor 2	6.8
Receptor 3	21.3
Receptor 4	49.0
Receptor 5	50.5
Receptor 6	49.3
Receptor 7	37.2

7.2 FARM B

Farm B is located in South East Queensland. The farm details are summarised in Table 7.12 and the meteorology at the site is summarised in Figure 7.3.

The modelled odour contours for the farm are shown in Figure 7.4 with the red line representing the $C_{99.5\ 1hr}$ Queensland odour guideline, and the red crosses representing the location of selected sensitive receptors. A K factor of 1.8 was used for the modelling.

Table 7.12 : Farm B Summary

Item	Information
Number of birds (essential)	200,000
Is a permanent windbreak wall/berm wall fitted?	No
Is a vegetative windbreak wall established?	No
Number of sheds	5
Proximity to other farms	No nearby farms

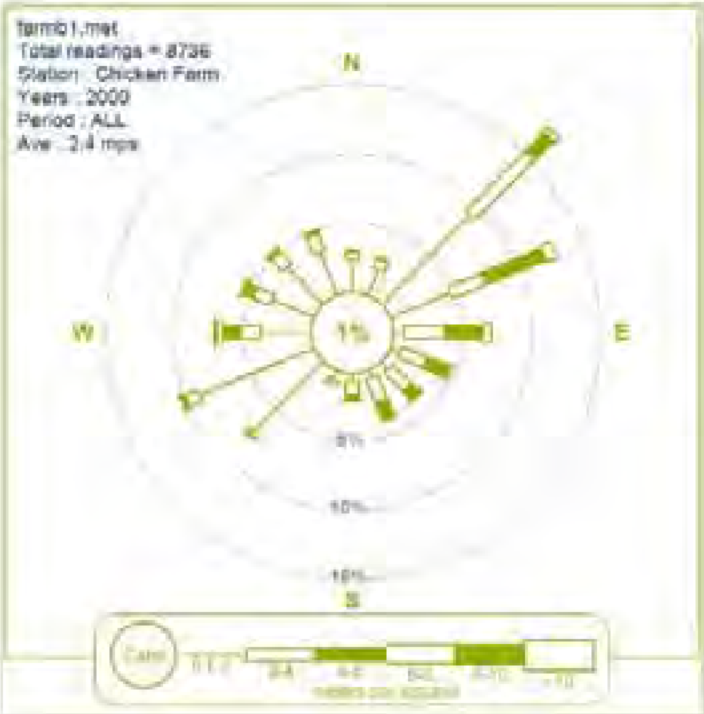


Figure 7.3 : Wind Rose - Farm B

Figure 7.4 : Farm 8 - Model Output

A summary of the various S factors applicable to the farm, as requested by DEEDI are summarised below in Table 7.13 through Table 7.22.

Table 7.13 : Queensland S Factor Inputs - Farm 8

Shed design and management factors	
Shed design	New tunnel
Drinking system	Nipple/cup
Automated shed environment controller	Yes
Inspect/replace litter daily	Yes
Average litter depth at start of batch	50mm
Maximum shed speed m/s	2.5m/s+

Table 7.14 : Queensland S Factor Inputs for Land Use - Farm 8

Receptor	Receptor type/buffer type
Receptor 1	Sensitive land use - house
Receptor 2	Sensitive land use - house
Receptor 3	Sensitive land use - house
Receptor 4	Sensitive land use - house
Receptor 5	Sensitive land use - house
Receptor 6	Sensitive land use - house
Receptor 7	Sensitive land use - house
Receptor 8	Sensitive land use - house

Table 7.15 : Queensland S Factor Inputs for Surface Roughness - Farm B

Receptor	Surface roughness between farm and receptor
Receptor 1	Level Wooded
Receptor 2	Level Wooded
Receptor 3	Level Wooded
Receptor 4	Level Wooded
Receptor 5	Few trees long grass
Receptor 6	Few trees long grass
Receptor 7	Level Wooded
Receptor 8	Level Wooded

Table 7.16 : Queensland S Factor Inputs for Terrain - Farm B

Receptor	Terrain between farm and receptor
Receptor 1	Upslope flat
Receptor 2	Upslope flat
Receptor 3	Upslope flat
Receptor 4	Upslope flat
Receptor 5	Upslope flat
Receptor 6	Upslope flat
Receptor 7	Upslope flat
Receptor 8	Upslope flat

Table 7.17 : South Australian S Factor Inputs for Receptor Type - Farm B

Receptor	Receptor Type
Receptor 1	Rural dwelling
Receptor 2	Rural dwelling
Receptor 3	Rural dwelling
Receptor 4	Rural dwelling
Receptor 5	Rural dwelling
Receptor 6	Rural dwelling
Receptor 7	Rural dwelling
Receptor 8	Rural dwelling

Table 7.18 : South Australian S Factor Inputs for Manure management - Farm B

Receptor	Manure handling
Receptor 1	Taken off site
Receptor 2	Taken off site
Receptor 3	Taken off site
Receptor 4	Taken off site
Receptor 5	Taken off site
Receptor 6	Taken off site
Receptor 7	Taken off site
Receptor 8	Taken off site

Table 7.19 : New South Wales S Factor Inputs for Receptor Type - Farm B

Receptor	Receptor Type
Receptor 1	Single rural residence
Receptor 2	Single rural residence
Receptor 3	Single rural residence
Receptor 4	Single rural residence
Receptor 5	Single rural residence
Receptor 6	Single rural residence
Receptor 7	Single rural residence
Receptor 8	Single rural residence

Table 7.20 : New South Wales S Factor Inputs for Terrain - Farm B

Receptor	Terrain between farm and receptor
Receptor 1	Flat-Undulating country
Receptor 2	Flat
Receptor 3	Flat
Receptor 4	Flat
Receptor 5	Flat
Receptor 6	Flat
Receptor 7	Flat
Receptor 8	Flat

Table 7.21 : New South Wales S Factor Inputs for Terrain Type - Farm B

Receptor	Vegetation between farm and receptor
Receptor 1	Wooded Country
Receptor 2	Wooded Country
Receptor 3	Wooded Country
Receptor 4	Wooded Country
Receptor 5	Few trees long grass
Receptor 6	Few trees long grass
Receptor 7	Wooded Country
Receptor 8	Wooded Country

Table 7.22 : New South Wales S Factor Inputs for Wind Frequency Factor - Farm B

Wind frequency toward receptor	Percentage
Receptor 1	28.2
Receptor 2	18.4
Receptor 3	26.9
Receptor 4	13.4
Receptor 5	9.8
Receptor 6	49.3
Receptor 7	37.2
Receptor 8	27.6

7.3 FARM C

Farm C is located in South East Queensland. The farm details are summarised in Table 7.23 and the meteorology at the site is summarised in Figure 7.5.

The modelled odour contours for the farm are shown in Figure 7.6with the red line representing the $C_{99.5\ 1hr}$ Queensland odour guideline, and the red crosses representing the location of selected sensitive receptors. A K factor of 3 was used for the modelling.

Table 7.23 : Farm C Summary

Item	Information
Number of birds (essential)	200,000
Is a permanent windbreak wall/berm wall fitted?	No
Is a vegetative windbreak wall established?	Yes at a distance from the sheds
Number of sheds	5
Proximity to other farms	No nearby farms

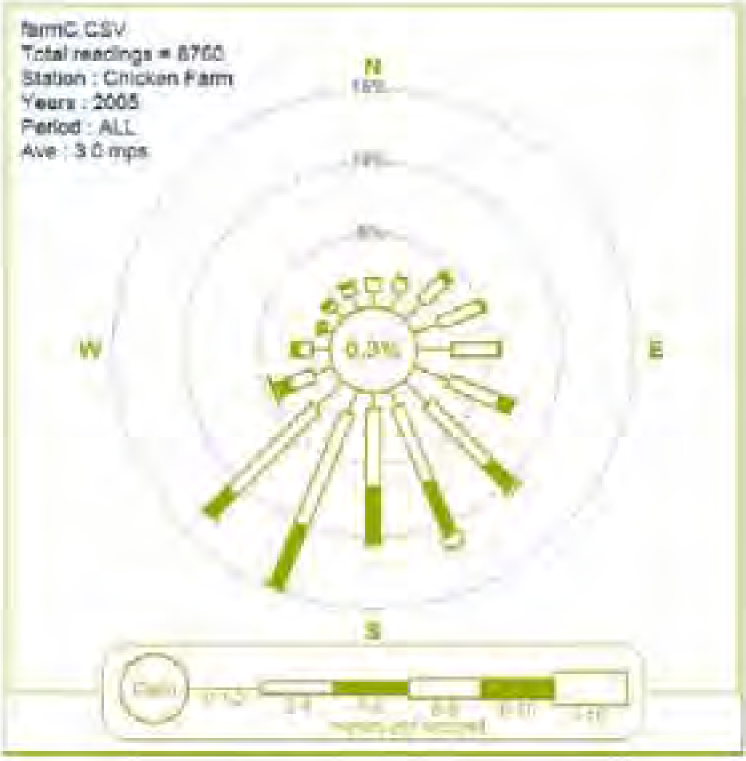


Figure 7.5 : Wind Rose - Farm C

Figure 7.6 : Farm C - Model Output

A summary of the various S factors applicable to the farm, as requested by DEEDI are summarised below in Table 7.24 through Table 7.33.

Table 7.24 : Queensland S Factor Inputs - Farm C

Shed design and management factors	
Shed design	New tunnel
Drinking system	Nipple/cup
Automated shed environment controller	Yes
Inspect/replace litter daily	Yes
Average litter depth at start of batch	50mm
Maximum shed speed m/s	2.5m/s+

Table 7.25 : Queensland S Factor Inputs for Land Use - Farm C

Receptor	Receptor type/buffer type
Receptor 1	Sensitive land use - house
Receptor 2	Sensitive land use - house
Receptor 3	Sensitive land use - house
Receptor 4	Sensitive land use - house
Receptor 5	Sensitive land use - house

Table 7.26 : Queensland S Factor Inputs for Surface Roughness - Farm C

Receptor	Surface roughness between farm and receptor
Receptor 1	Few trees long grass
Receptor 2	Few trees long grass
Receptor 3	Level wooded
Receptor 4	Level wooded
Receptor 5	Few trees long grass

Table 7.27 : Queensland S Factor Inputs for Terrain - Farm C

Receptor	Terrain between farm and receptor
Receptor 1	Sloping terrain
Receptor 2	Sloping terrain
Receptor 3	Sloping terrain
Receptor 4	Sloping terrain
Receptor 5	Sloping terrain

Table 7.28 : South Australian S Factor Inputs for Receptor Type - Farm C

Receptor	Receptor Type
Receptor 1	Rural dwelling
Receptor 2	Rural dwelling
Receptor 3	Rural dwelling
Receptor 4	Rural dwelling
Receptor 5	Rural dwelling

Table 7.29 : South Australian S Factor Inputs for Manure management - Farm C

Receptor	Manure handling
Receptor 1	Taken off site
Receptor 2	Taken off site
Receptor 3	Taken off site
Receptor 4	Taken off site
Receptor 5	Taken off site

Table 7.30 : New South Wales S Factor Inputs for Receptor Type - Farm C

Receptor	Receptor Type
Receptor 1	Single rural residence
Receptor 2	Single rural residence
Receptor 3	Single rural residence
Receptor 4	Single rural residence
Receptor 5	Single rural residence

Table 7.31 : New South Wales S Factor Inputs for Terrain - Farm C

Receptor	Terrain between farm and receptor
Receptor 1	Flat
Receptor 2	Flat
Receptor 3	Flat
Receptor 4	Flat
Receptor 5	Flat

Table 7.32 : New South Wales S Factor Inputs for Terrain Type - Farm C

Receptor	Vegetation between farm and receptor
Receptor 1	Few trees long grass
Receptor 2	Few trees long grass
Receptor 3	Wooded country
Receptor 4	Wooded country
Receptor 5	Few trees long grass

Table 7.33 : New South Wales S Factor Inputs for Wind Frequency Factor - Farm C

Wind frequency toward receptor	Percentage
Receptor 1	40.1
Receptor 2	46.9
Receptor 3	34.4
Receptor 4	24.7
Receptor 5	6.1

7.4 FARM D

Farm D is located in South East Queensland. The farm details are summarised in Table 7.34 and the meteorology at the site is summarised in Figure 7.7.

The modelled odour contours for the farm are shown in Figure 7.8 with the red line representing the $C_{99.5\ 1h}$ Queensland odour guideline, and the red crosses representing the location of selected sensitive receptors. A K factor of 2.4 was used for the modelling.

Table 7.34 : Farm D Summary

Item	Information
Number of birds (essential)	210,000
Is a permanent windbreak wall/berm wall fitted?	No
Is a vegetative windbreak wall established?	Yes, vegetative screen has been planted on the farm
Number of sheds	7
Proximity to other farms	No nearby farms

Figure 7.7 : Wind Rose - Farm D

Figure 7.8 : Farm D - Model Output

A summary of the various S factors applicable to the farm, as requested by DEEDI are summarised below in Table 7.35 through Table 7.44.

Table 7.35 : Queensland S Factor Inputs - Farm D

Shed design and management factors	
Shed design	New tunnel
Drinking system	Nipple/cup
Automated shed environment controller	Yes
Inspect/replace litter daily	Yes
Average litter depth at start of batch	50mm
Maximum shed speed m/s	2.5m/s+

Table 7.36 : Queensland S Factor Inputs for Land Use - Farm D

Receptor	Receptor type/buffer type
Receptor 1	Sensitive land use - house
Receptor 2	Sensitive land use - house
Receptor 3	Sensitive land use - house
Receptor 4	Sensitive land use - house

Table 7.37 : Queensland S Factor Inputs for Surface Roughness - Farm D

Receptor	Surface Roughness Between Farm and Receptor
Receptor 1	Few trees long grass
Receptor 2	Few trees long grass
Receptor 3	Few trees long grass
Receptor 4	Few trees long grass

Table 7.38 : Queensland S Factor Inputs for Terrain - Farm D

Receptor	Terrain between farm and receptor
Receptor 1	Upslope sloping terrain
Receptor 2	Downslope sloping terrain
Receptor 3	Downslope sloping terrain
Receptor 4	Downslope sloping terrain

Table 7.39 : South Australian S Factor Inputs for Receptor Type - Farm D

Receptor	Receptor Type
Receptor 1	Rural dwelling
Receptor 2	Rural dwelling
Receptor 3	Rural dwelling
Receptor 4	Rural dwelling

Table 7.40 : South Australian S Factor Inputs for Manure management - Farm D

Receptor	Manure handling
Receptor 1	Taken off site
Receptor 2	Taken off site
Receptor 3	Taken off site
Receptor 4	Taken off site

Table 7.41 : New South Wales S Factor Inputs for Receptor Type - Farm D

Receptor	Receptor Type
Receptor 1	Single rural residence
Receptor 2	Single rural residence
Receptor 3	Single rural residence
Receptor 4	Single rural residence

Table 7.42 : New South Wales S Factor Inputs for Terrain - Farm D

Receptor	Terrain between farm and receptor
Receptor 1	High relief
Receptor 2	Low relief
Receptor 3	Low relief
Receptor 4	Low relief

Table 7.43 : New South Wales 5 Factor Inputs for Terrain Type - Farm D

Receptor	Vegetation between farm and receptor
Receptor 1	Few trees long grass
Receptor 2	Few trees long grass
Receptor 3	Few trees long grass
Receptor 4	Few trees long grass

Table 7.44 : New South Wales 5 Factor Inputs for Wind Frequency Factor - Farm D

Wind frequency toward receptor	Percentage
Receptor 1	6.3
Receptor 2	41.2
Receptor 3	45.3
Receptor 4	48.4

7.5 FARM E

Farm E is located in South East Queensland. The farm details are summarised in Table 7.45 and the meteorology at the site is summarised in Figure 7.9.

The modelled odour contours for the farm are shown in Figure 7.10 with the red line representing the $C_{99.5\ 1hr}$ Queensland odour guideline, and the red crosses representing the location of selected sensitive receptors. A K factor of 1.7 was used for the modelling.

Table 7.45 : Farm E Summary

Item	Information
Number of birds (potential)	200,000
Is a permanent windbreak wall/berm wall fitted?	No
Is a vegetative windbreak wall established?	Yes, vegetative screen has been planted on the farm
Number of sheds	5
Proximity to other farms	No nearby farms

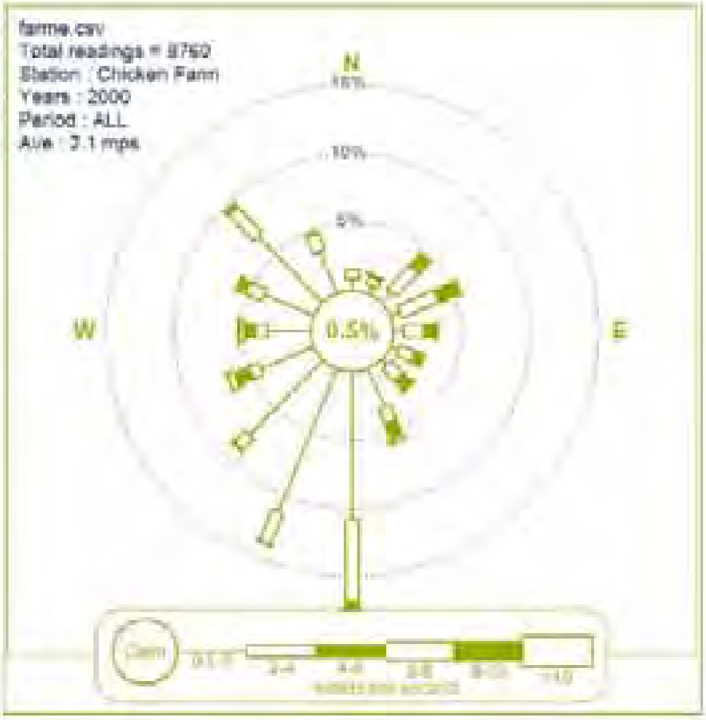


Figure 7.9 : Wind Rose - Farm E

Figure 7.10 : Farm E - Model Output

A summary of the various S factors applicable to the farm, as requested by DEEDI are summarised below in Table 7.46 through Table 7.55.

Table 7.46 : Queensland S Factor Inputs - Farm E

Shed design and management factors	
Shed design	New tunnel
Drinking system	Nipple/cup
Automated shed environment controller	Yes
Inspect/replace litter daily	Yes
Average litter depth at start of batch	50mm
Maximum shed speed m/s	2.5m/s+

Table 7.47 : Queensland S Factor Inputs for Land Use - Farm E

Receptor	Receptor type/buffer type
Receptor 1	Sensitive land use - house
Receptor 2	Sensitive land use - house
Receptor 3	Sensitive land use - house
Receptor 4	Sensitive land use - house
Receptor 5	Sensitive land use - house

Table 7.48 : Queensland S Factor Inputs for Surface Roughness - Farm E

Receptor	Surface roughness between farm and receptor
Receptor 1	Undulating hills (note significant terrain influence between site and receptor)
Receptor 2	Level wooded
Receptor 3	Level wooded
Receptor 4	Level wooded
Receptor 5	Few trees long grass

Table 7.49 : Queensland S Factor Inputs for Terrain - Farm E

Receptor	Terrain between farm and receptor
Receptor 1	Sloping
Receptor 2	Flat
Receptor 3	Flat
Receptor 4	Flat
Receptor 5	Sloping

Table 7.50 : South Australian S Factor Inputs for Receptor Type - Farm E

Receptor	Receptor Type
Receptor 1	Rural dwelling
Receptor 2	Rural dwelling
Receptor 3	Rural dwelling
Receptor 4	Rural dwelling
Receptor 5	Rural dwelling

Table 7.51 : South Australian S Factor Inputs for Manure management - Farm E

Receptor	Manure handling
Receptor 1	Taken off site
Receptor 2	Taken off site
Receptor 3	Taken off site
Receptor 4	Taken off site
Receptor 5	Taken off site

Table 7.52 : New South Wales S Factor Inputs for Receptor Type - Farm E

Receptor	Receptor Type
Receptor 1	Single rural residence
Receptor 2	Single rural residence
Receptor 3	Single rural residence
Receptor 4	Single rural residence
Receptor 5	Single rural residence

Table 7.53 : New South Wales S Factor Inputs for Terrain - Farm E

Receptor	Terrain between farm and receptor
Receptor 1	Undulating
Receptor 2	Flat
Receptor 3	Flat
Receptor 4	Flat
Receptor 5	Flat

Table 7.54 : New South Wales 5 Factor Inputs for Terrain Type - Farm E

Receptor	Vegetation between farm and receptor
Receptor 1	Few trees long grass
Receptor 2	Level wooded
Receptor 3	Level wooded
Receptor 4	Level wooded
Receptor 5	Few trees long grass

Table 7.55 : New South Wales 5 Factor Inputs for Wind Frequency Factor - Farm E

Wind frequency toward receptor	Percentage
Receptor 1	12.0
Receptor 2	9.4
Receptor 3	20.6
Receptor 4	22.4
Receptor 5	34.6

8 SUMMARY

A series of model runs have been summarised. These included both historical model runs, as well as the scenarios summarised in Section 6.

The model runs in Section 6 showed differences which are attributable to:

- Source representation (point source, non buoyant point source, or volume source)
- Number of birds
- Wind speed and direction data (including low wind speed events) and
- Terrain influences.

Overall, there were differences between the model runs which examined production and ambient temperature emissions from the sheds. When the production temperature was used as the exhaust temperature from the sheds the predicted area of impact was less than that where ambient temperature was used. In reality, the air exhausted from a meat chicken shed during winter especially will be warmer than the surrounding area, particularly under night time or morning conditions. This was confirmed by the CFD modelling performed by PAEHolmes for DEEDI (PAEHolmes Job 2655) and anecdotal evidence from both researchers and farm operators. On this basis thermal buoyancy should be in included in modelling.

Where the volume source was used in the modelling, the influence of terrain from the source was less obvious than for the point source representation where terrain influences were more clearly observed.

9 REFERENCES

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Appendix 7: Report for Calpuff modelling hypothetical broiler farms

(Consultant: ANE)

Air Noise Environment Pty. Ltd., 2009. Poultry Farm Research Project – Air Dispersion Modelling, Project 2143, June 2009.

Department Of Employment, Economic Development And Innovation

POULTRY FARM RESEARCH PROJECT - AIR DISPERSION MODELLING

June 2009

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04						
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Where site inspections, testing or fieldwork have taken place, the report is based on the information made available by the client or their nominees during the visit, visual observations and any subsequent discussions with regulatory authorities. The validity and comprehensiveness of supplied information has not been independently verified and, for the purposes of this report, it is assumed that the information provided to Air Noise Environment Pty Ltd is both complete and accurate. It is further assumed that normal activities were being undertaken at the site on the day of the site visit(s).

CONTENTS

1 INTRODUCTION

1.1 BACKGROUND TO PROJECT

The Department of Employment, Economic Development and Innovation (DEEDI) is conducting a research investigation to evaluate the influence of thermal buoyancy on the dispersion of odour plumes emitted from broiler sheds, including the modelling of these emissions. Funding has been provided from the poultry industry through the RIRDC.

To date, DEEDI have commissioned a study to analyse the effects of thermal buoyancy on emissions from broiler sheds using CFD modelling. Where possible, results were compared against CALPUFF modelling using similar inputs. This modelling was undertaken by Pacific Air and Environment (PAE). The results indicated that thermal buoyancy was quite pronounced in the CFD modelling (where emission temperatures were more than 2°C warmer than ambient). However, CALPUFF results indicated that very little rise occurred. It was suggested that this was primarily due to building downwash and the time-weighted average nature of CALPUFF modelling results.

The next stage of this investigation is to model some 'typical' broiler farming scenarios with a range of inputs to evaluate the influence of selected modelling inputs, including:

- emission temperature,
- land use & terrain, and possibly
- farm size (number of birds).

Combinations of these inputs are to provide a unique analyse of the influence of emission temperatures for a range of modelling inputs.

1.2 SCOPE OF PROJECT

As part of this research project, Air Noise Environment Pty Ltd were commissioned by the DEEDI to undertake air dispersion modelling of odour emissions from poultry sheds. Specifically the scope of the project was to undertake predictive dispersion modelling of a number of scenarios for each of two farm locations. Each farm location was to be selected to represent a potential site in an existing poultry farming area of south-east Queensland.

A specific modelling methodology and odour emission estimation technique was identified by DEEDI for use in the modelling. It is noted that the methodology and emission rates adopted by DEEDI have been developed by Pacific Air and Environment Pty Ltd (PAE), and these have not been validated by Air Noise Environment Pty Ltd. It is further noted that the adopted emission rates are significantly lower than recently published research data for well managed poultry farms[1]. Therefore, whilst the results of the modelling are considered appropriate for assessing differences in modelling methodology, the odour concentrations presented in this report may need to be increased by a factor of 2 - 3 to represent actual operating conditions at modern, well managed poultry farms.

[1] *Erin M Gallagher, Neale A Hudson, Mark W Dunlop, Gavin Paraci, Jae Ho Sohn, Michael G Atzeni, David Duperouzel, Gary Collman and Peter Nicholas (2007) 'Odour Emissions from Tunnel Ventilated Poultry Housing', 14th IUAPPA World Congress, Brisbane 2007.*

2 DEEDI REQUIREMENTS

2.1 OVERVIEW

The scope of the assessment was defined by the DEEDI in a formal briefing document (refer to Appendix A). This document provides specific inputs to be adopted for the purposes of the modelling. The following sections provide a summary of the information provided in this document and adopted for this modelling exercise.

2.2 FARM DESCRIPTION

The DEEDI document required a tunnel ventilated poultry farm to be modelled with various inputs to assess the influence of these (especially emission temperatures) on predicted odour concentrations for compliance with Queensland Environmental Protection Agency odour assessment goals[1].

Table 2.1 presents a summary of the hypothetical farm design to be considered by the modelling.

TABLE 2.1: SUMMARY OF ASSUMED FARM DESIGN PARAMETERS

Design Parameter	Assumed Value
Shed Length	153 m
Shed Width	15 m (internal) 15.3 m (external)
Shed Height	4.5 m (roof apex) 2.7 m (wall height)
Number of Birds per Shed	43750
Maximum Ventilation Rate	112 m³/s
Ventilation Fans	16 x Euroemme EM50, 1.0 hp fans

2.3 FARM LOCATIONS

DEEDI requested that the farm be modelled at two different locations. Suitable options include modelling the farm at a different location within the same Calmet domain or positioning the farm in a completely different Calmet domain. The domain was requested to cover one of the dominant broiler growing areas in South-east Queensland, preferably near Beaudesert, Esk/Coominya or Caboolture/Donnybrook/Wamuran.

For the purposes of the modelling it was agreed with DEEDI that the modelling would include a farm in each of two poultry farming areas for which meteorological modelling for proposed poultry farms has previously been undertaken by Air Noise Environment. The project considered dispersion of odour emissions from a hypothetical poultry farm located in the Redlands and Caboolture areas.

1 Queensland EPA (2004) 'Odour Impact Assessment from Developments'

2.4 MODELLING CASES

The DEEDI requested that a total of three cases were considered for each farm location (six cases in total). Table 2.2 presents a summary of the modelling cases considered.

TABLE 2.2: SUMMARY OF MODELLING CASES

Case number	Farm Size (number of birds)	Farm location	Emission Temperature	Source description
1	350,000 (8 sheds)	1	Ambient	Quasi-point (PAE method)
2	350,000	1	Production	Quasi-point
3	350,000	2	Ambient	Quasi-point
4	350,000	2	Production	Quasi-point
5	350,000	1	Ambient	Volume
6	350,000	2	Ambient	Volume

In addition it was requested that, where possible, the modelling consider two alternative farm designs within each modelling case. Specifically, it was requested that, where possible, modelling of a composite farm be undertaken such that predictions could be obtained for both a 175,000 bird farm (i.e. four sheds) and a 350,000 bird farm (i.e. eight sheds). For the purposes of this project the modelling was set up to incorporate this request.

As per the DEEDI project brief (refer Appendix A) it was assumed that each broiler shed was 150 m long, 15 m wide (internal, 15.3 m external) with a wall height 2.7 m, roof apex of 4.5 m, and ceiling baffles to 2.4 m above litter surface. It was assumed that each shed housed 43,750 birds with a maximum ventilation rate of 112 m³/s.

2.5 EMISSIONS DATA

Appropriate emissions data for use in predictive dispersion modelling has been the focus of significant research in Australia. For the purposes of the modelling the DEEDI requested that emissions from the hypothetical farm be estimated based on a methodology developed by PAE. This methodology utilised data relating to the number of birds within the shed, the age of the birds and the ventilation rate to estimate odour emissions.

In estimating these emissions the DEEDI requested that an assumed K factor (a factor developed to represent the effectiveness of odour management measures at a given farm) of 2. In addition it was requested that the emissions estimates consider typical thinning regimes and target temperatures as used by one of the major integrators in the industry (e.g. Inghams).

Figure 2.1 presents a summary of the batch cycle variable emission profile, calculated using the PAE methodology and a K factor of 2, utilised for the modelling. As noted previously, this methodology results in lower odour emission rates than the most recently published research[4].

[4] Erin M. Gallagher, Neale A. Hudson, Mark W. Dunlop, Gavin Parcsi, Jae Ho Sohn, Michael G. Atzeni, David Duperouzel, Gary Collman and Peter Nicholas (2007) "Odour Emissions from Tunnel Ventilated Poultry Housing", 14th IUAPPA World Congress, Brisbane 2007.

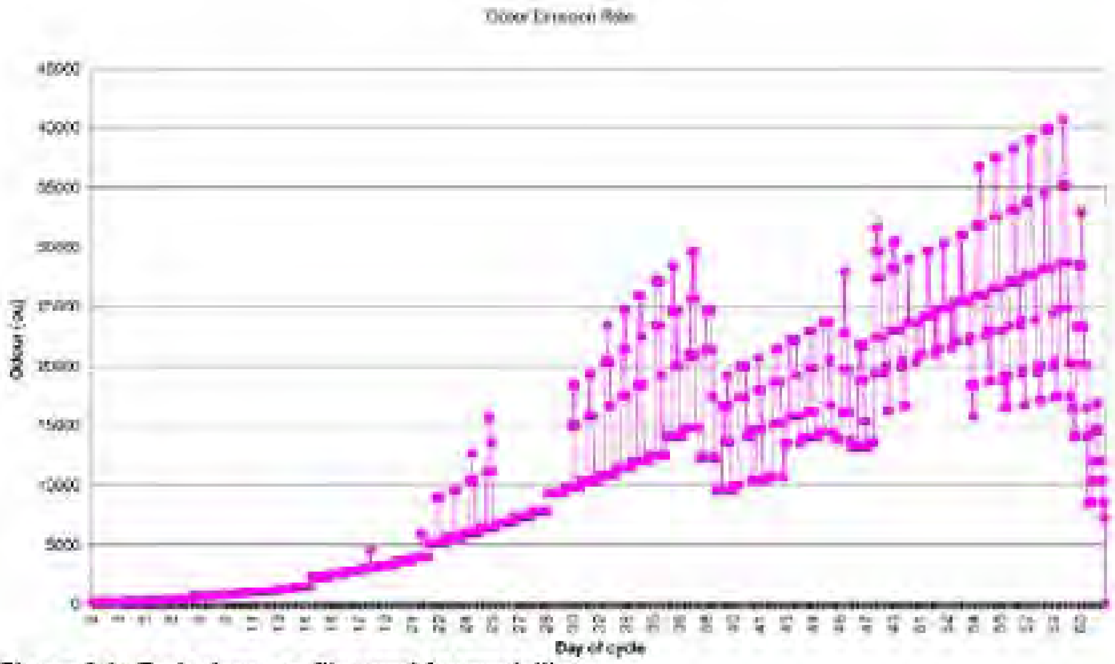

Figure 2.1: Emissions profile used for modelling

2.6 MODEL SETUP

The air dispersion modelling undertaken for each of the farms was requested to include the following:

- plume downwash,
- no vertical emission velocity; and
- terrain resolution of 100 m.

3 MODELLING METHODOLOGY

3.1 METEOROLOGICAL MODELLING

3.1.1 Overview

CALMET is a meteorological model which includes a diagnostic wind field generator containing objective analysis and parameterised treatments of slope flows, kinematic terrain effects, terrain blocking effects and a divergence minimisation procedure, and micrometeorological model for overland and overwater boundary layers. The terrain handling effects included within the CALMET meteorological processor are able to resolve complex terrain influences on local wind fields including consideration of katabatic flows.

3.1.2 Model Selection

For the assessment of emissions from the nearby poultry farm, the development of a suitable meteorological dataset is particularly important. This is complicated by the absence of three dimensional meteorological datasets for the region, with only surface meteorology and some limited upper air meteorological parameters measured.

Given this, the development of a meteorological dataset for the assessment requires the reliance on a meteorological model. Models, such as CALMET, permits the development of localised meteorological datasets, based on a range of synoptic and observational weather inputs. The model predicts the regional flows important to dispersion, such as sea breezes and terrain-induced flows, against a background of larger-scale meteorology provided by synoptic analyses.

The output of this model, when used with a diagnostic meteorological model, such as Calmet, provides a meteorological dataset, capable of considering the complex flow fields such as the sea breeze circulation with return flow aloft, which is unlikely to be captured in the available observational data, to be introduced into the diagnostic wind field results. An evaluation with CAPTEX tracer data indicated that the better spatial and temporal resolution offered by the hourly prognostic wind fields can improve the performance of the dispersion modelling on regional scales[4].

The following sections provide details of the data sources and methodology utilised for the prediction of a three dimensional meteorological dataset and wind field for the assessment of contaminant dispersion.

3.1.3 Modelling Domain

The CALMET modelling undertaken for the project utilised two model runs for each area considered (ie Caboolture and Redlands). The first model run considered in outer grid of 20 km x 20 km in size with a grid resolution of 0.2 km. The results of this model run were then used as an initial guess input into a smaller inner grid of 6 km x 6 km with a grid resolution of 0.1 km. This methodology allowed for a reduction in overall model run times while allowing the potential influence of surrounding terrain features to be considered by the model. Table 3.1 presents a summary of the modelling domain dimensions considered in the modelling.

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4 *US EPA (1995), "Testing of meteorological and dispersion models for use in regional air quality modeling." Report prepared for U.S. EPA by Sigma Research/EARTH TECH, Concord, MA.*

TABLE 3.1: SUMMARY OF MODELLING DOMAINS

Modelling Grid	Grid Location	Easting	Northing
Caboolture – Outer Grid (20 x 20 km at 0.2 km grid resolution)	North-eastern corner	483500	7000000
	South-western corner	503500	7020000
Redlands – Outer Grid (20 x 20 km at 0.2 km grid resolution)	North-eastern corner	513215	6934664
	South-western corner	533215	6954664
Caboolture - Inner Grid (6 x 6 km at 0.1 km grid resolution)	North-eastern corner	487567	7009984
	South-western corner	493567	7015984
Redlands - Inner Grid (6 x 6 km at 0.1 km grid resolution)	North-eastern corner	522245	6942214
	South-western corner	528245	6948214

3.1.4 Observational Data

A number of meteorological monitoring stations are located in the Greater Brisbane area, and these include stations operated by the Bureau of Meteorology (BoM) and the Queensland Department of Environment and Resource Management (DERM) (formerly the Environmental Protection Agency). Details of the meteorological monitoring stations considered for inclusion in the CALMET modelling completed for the project are summarised in Table 3.1

TABLE 3.1: METEOROLOGICAL STATIONS

Station Name	Easting (km)	Northing (km)
Caboolture (Cases 1, 2 and 5)		
Beerburrum	498.157	7018.141
Redcliffe	508.983	6989.244
Brisbane Aero	512.820	6970.203
Spitfire Channel	526.776	7007.990
Nambour DPI	494.028	7053.497
Maroochydore Airport	508.978	7058.123
Redlands (Cases 3, 4 and 6)		
EPA – Pinkenba	511.940	6960.983
EPA – Rocklea	499.871	6953.298
EPA – South Brisbane	503.171	6959.468
EPA – Woolloongabba	503.457	6958.459
Amberley	471.481	6943.786
Archerfield	500.702	6950.000
Gold Coast Seaway	542.001	6909.712

Station Name	Easting (km)	Northing (km)
Brisbane Aero	512.820	6970.203
Brisbane	503.632	6960.309
Banana Bank	532.870	6954.452

3.1.5 Missing Data

Of the meteorological stations identified in Table 3.1, upper air (ie, cloud cover and ceiling height) data is only available for two stations, Brisbane Airport and Amberley. The upper air dataset for Brisbane Airport is 77 % complete, and has significantly fewer missing data points than the Amberley dataset which is only 10 % complete.

The data completeness for the surface observations for the monitoring stations identified in Table 3.1 is generally in excess of 90 % for the BoM Stations. Data completeness is more variable for the DERM stations.

To allow the CALMET model to run, there are a number of approaches that can be adopted for filling of missing data. Methods include interpolation approaches completed manually, or the use of prognostic models or data inputs that are utilised internally within CALMET for the purposes of estimating the missing data values. One such prognostic dataset that can be used is the MM5 meteorological model. A prognostic meteorological dataset in MM5 format has recently been released for Australia, generated by Atmospheric Studies Group at TRC, in the United States. ASC are the current maintainers of the CALPUFF model. MM5 data provides a high quality prognostic data input that can be utilised directly within the CALMET model for data filling.

MM5 is a widely-used three-dimensional numerical meteorological model which contains non-hydrostatic dynamics, a variety of physics options for parameterising cumulus clouds, micro physics, the planetary boundary layer and atmospheric radiation. MM5 has the capability to perform Four Dimensional Data Assimilation (FDDA). MM5 is capable of simulating a variety of meteorological phenomena such as tropical cyclones, severe convective storms, sea-land breezes, and terrain forced flows such as mountain valley wind systems. MM5 data can be used in conjunction with CALMET/CALPUFF to facilitate the use of advanced non-steady-state air quality modelling techniques in areas with sparse or no meteorological observations.

For the purposes of the modelling the MM5 data was utilised to provide an initial guess input to the outer grid CALMET model.

3.1.6 CALMET Parameterisation

For the purposes of the modelling, CALMET was initialised with a total of 10 vertical layers with layer boundaries at 0 m, 20 m, 60 m, 100 m, 200 m, 300 m, 500 m, 1000 m, 1500 m, 2000 m respectively.

Additional parameterisation allowed for by CALMET includes specification of the minimum and maximum mixing heights. This provides the model with realistic boundaries for calculation of the region of the atmosphere within which contaminants will generally disperse. For the purposes of the project, minimum mixing heights were set to 50 m and maximum mixing heights to 3,000 m. These mixing heights are the recommended values for use in the model, and are representative of the range of mixing heights that have been established as typical for Queensland[8]

3.1.7 Terrain and Landuse

Digital terrain height data for a grid at 100 m resolution for the grid domain of 20 km x 20 km centred on the project was included in the meteorological modelling. The data utilised was obtained from the NASA Shuttle Terrain Database. This database has a grid resolution of approximately 0.09 km.

The landuse data was sourced from the USGS (United States Geological Survey) and the coastline information was obtained from the United States National Geophysical Data Centre.

3.1.8 Station Biases

CALMET provides the user with the ability to assign biases to upper air and surface station monitoring data. These biases provide the meteorological model with the ability to place greater emphasis on surface meteorological stations where significant terrain features are likely to significantly influence localised wind flows. Specification of these biases is of considerable importance where upper air data is collected at a site remote from the surface monitoring stations that may not be representative for some atmospheric levels.

For the purposes of the modelling, biases of −0.5 (which forces the initial guess (or estimation) towards the surface station observations) were applied to the vertical atmospheric levels at heights of 20 m, 30 m and 50 m. Biases were set to +0.5 for the upper most layers (2,000 m, 3,000 m and 4,000 m). For all other layers, biases were set to 0 (layers 80 m, 160 m, 250 m, 500 m, 1,000 m, 1,500 m), as the only significant source of upper atmospheric data was for the Brisbane Airport dataset.

3.2 CALPUFF DISPERSION MODELLING

For the purposes of the assessment, the Calpuff dispersion model has been utilised to assess the potential impacts of emissions from the expanded farm. Calpuff is a non-steady state Lagrangian Gaussian puff model able to incorporate effects dispersion effects associated with complex terrain, overwater transport, coastal interaction effects and building downwash.

The CALPUFF modelling system treats emissions as a series of puffs. These puffs are then dispersed throughout the modelling area and allowed to grow and bend with spatial variations in meteorology. In doing so, the model is able to retain a memory of the plume's movement throughout a single hour and from one hour to the next while continuing to better approximate the effects of the complex air flows noted in the project area.

CALPUFF utilises the meteorological processing and prediction model CALMET to provide three dimensional wind field predictions for the area of interest. The final wind field developed by the model (for consideration by CALPUFF) includes an approximation of the effects of local topography, the effects of varying surface temperatures (as is observed in land and sea bodies) and surface roughness (resulting from varied land uses and vegetation cover in an area). The CALPUFF model is able to resolve complex terrain influences on local wind fields including consideration of katabatic

[8] *HLA-Envirosciences, Queensland Meteorological Data Files for Air Quality Planning, June 1995, prepared for the Queensland Department of Environment and Heritage.*

flows and terrain blocking along with sea breeze recirculation effects associated with the region.

Post processing of modelled emissions is undertaken using the Calpost package. This allows the rigorous analysis of pollutant predictions generated by the Calpuff system. In particular Calpost is able to provide an analysis of predicted pollutant concentrations for a range of averaging periods from 1 hour to 1 year.

The Calpuff modelling domain incorporated the portion of the domain utilised by Calmet surrounding the project site. Gridded receptor positions were including with a scaling factor of 2 providing a gridded receptor point every 50 m both latitudinally and longitudinally.

4 FARM 1 - CABOOLTURE

4.1 FARM LOCATION AND DESIGN

Figure 4.1 presents the location considered for hypothetical Farm 1. The adopted farm location is in the Caboolture area and has a number of other poultry farms operating in the area surrounding the site.

Figure 4.1: Shed location and surrounding landuses for farm 1

Figure 4.2 presents the shed layout adopted for the purposes of the modelling of emissions from Farm 1. For the purposes of the modelling, emissions from a 175,000 bird farm has been modelled from Sheds 1 – 4 only with emissions from a 350,000 bird farm modelled from Sheds 1 – 8.

Figure 4.2: Shed layout adopted for farm 1

4.2 TERRAIN

Figure 4.3 presents the terrain surrounding the hypothetical Farm 1. As can be seen the terrain immediately surrounding the farm is dominated by relatively flat agricultural uses along with two small hills to the east and west of the proposed farm. It is expected that these terrain features may result in some influence on local wind fields at the farm.

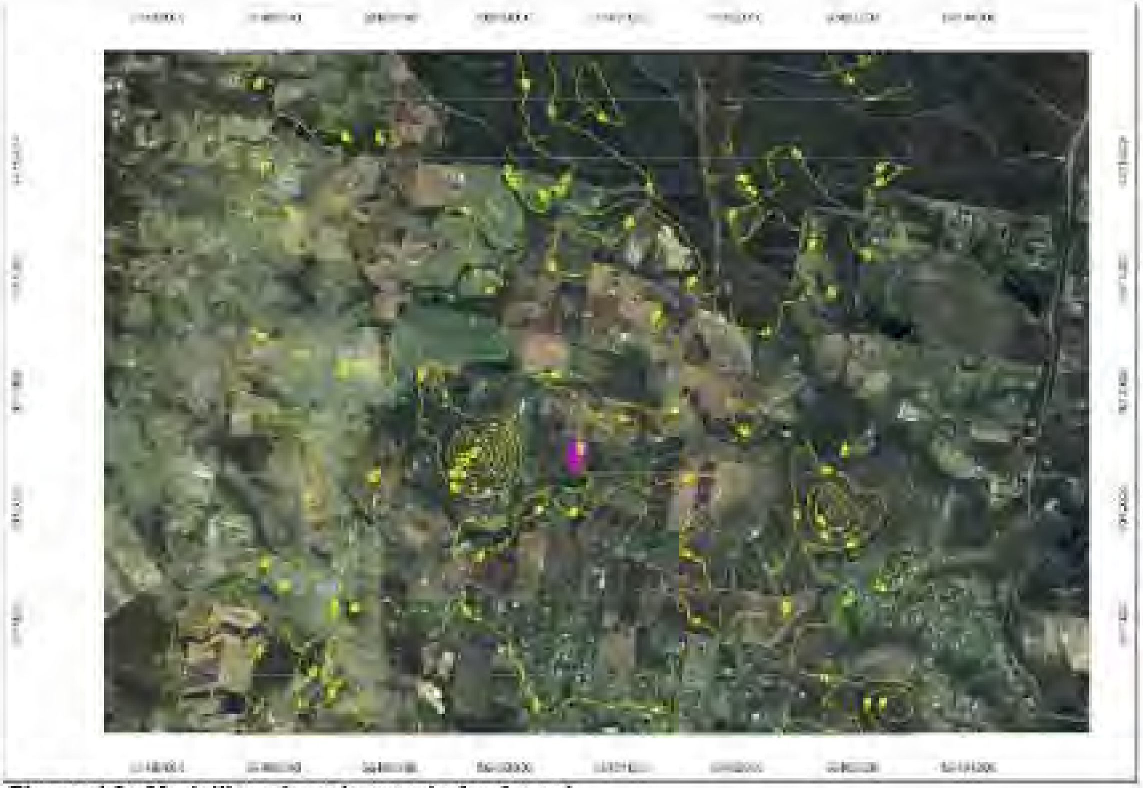

Figure 4.3: Modelling domain terrain for farm 1

4.3 PREDICTED METEOROLOGY

Figure 4.4 presents an annual predicted windrose and Figure 4.5 presents seasonal predicted windroses for the hypothetical Farm 1 location. As can be seen from this information, the predicted wind fields are dominated by wind conditions typical for much of the south-east Queensland region including:

- winds from easterly sectors during spring, summer and autumn months; and
- winds from westerly sectors during the autumn and winter months.

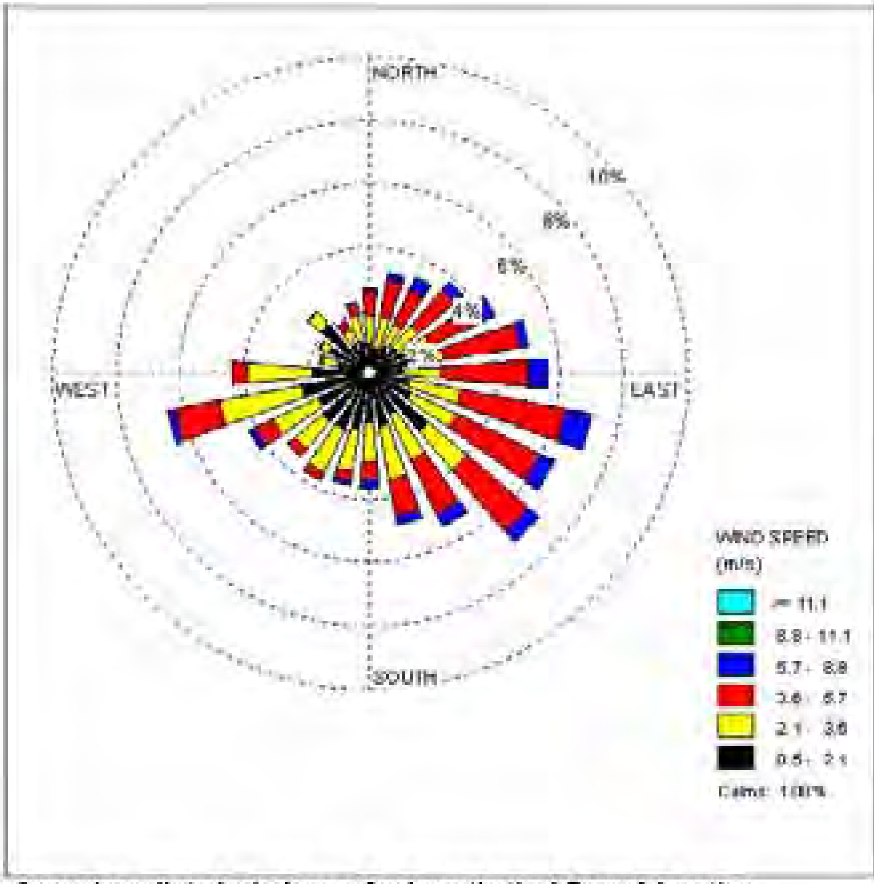

Figure 4.4: Annual predicted windroses for hypothetical Farm1 location

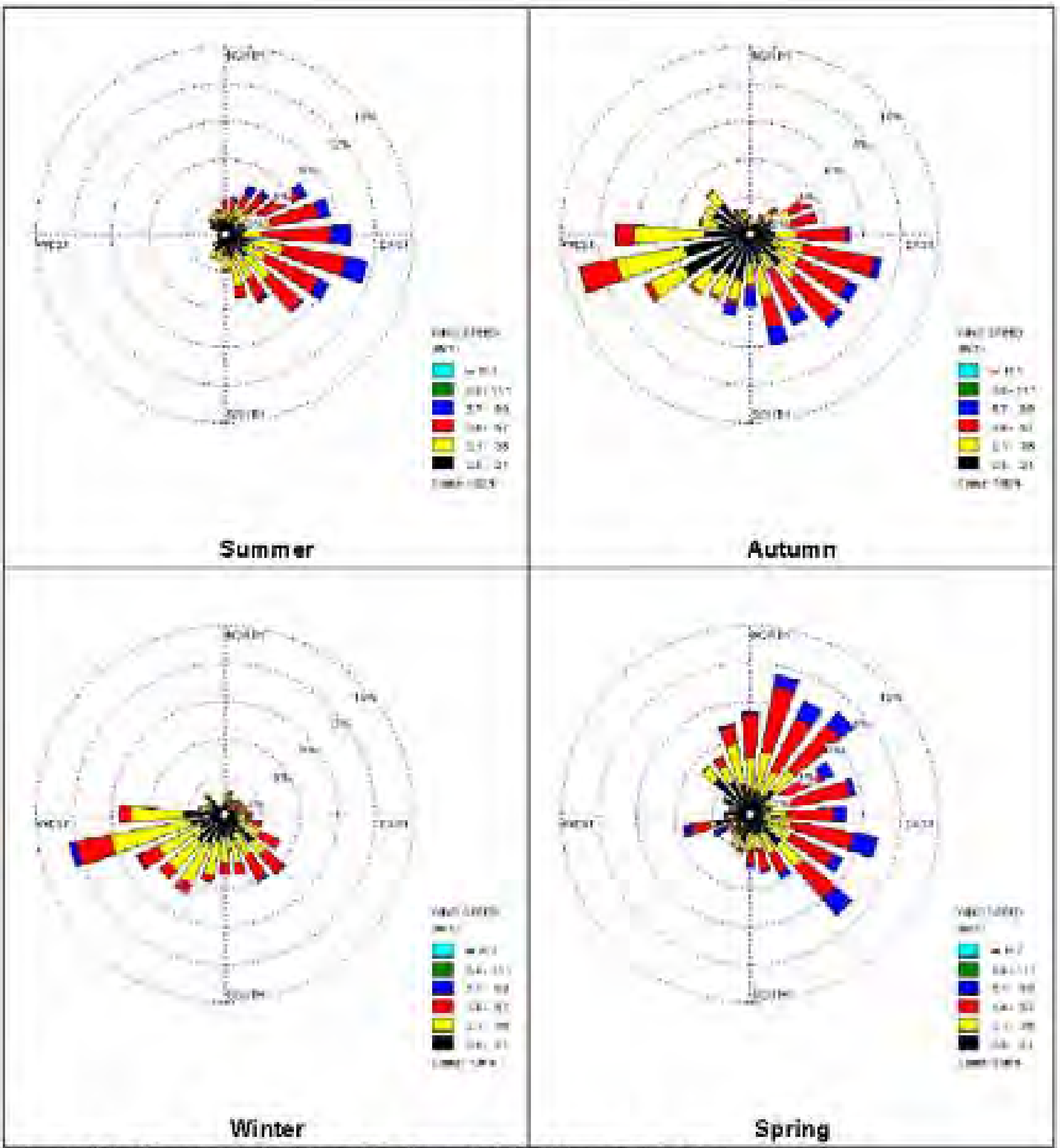

Figure 4.5: Seasonal windroses for hypothetical Farm 1 location

Table 4.1 presents a summary of predicted stability classes for the hypothetical farm 1 location. As can be seen from this information calm winds are predicted to occur for approximately 1 % of the year with the majority of these conditions occurring during early morning hours.

TABLE 4.1: SUMMARY OF PREDICTED STABILITY CLASSES FOR FARM 1

Hour	Stability Class					
	A	B	C	D	E	F
0	0.0 %	0.0 %	0.0 %	0.7 %	1.1 %	2.4 %
1	0.0 %	0.0 %	0.0 %	0.7 %	1.2 %	2.2 %
2	0.0 %	0.0 %	0.0 %	0.8 %	1.1 %	2.4 %
3	0.0 %	0.0 %	0.0 %	0.9 %	1.3 %	1.9 %
4	0.0 %	0.0 %	0.0 %	0.9 %	1.4 %	1.9 %
5	0.0 %	0.0 %	0.8 %	1.4 %	0.9 %	1.3 %
6	0.0 %	0.2 %	1.1 %	2.2 %	0.4 %	0.4 %
7	0.0 %	0.4 %	1.7 %	2.1 %	0.0 %	0.0 %
8	0.1 %	1.6 %	1.6 %	1.0 %	0.0 %	0.0 %
9	0.1 %	1.7 %	1.5 %	0.9 %	0.0 %	0.0 %
10	0.3 %	2.1 %	1.2 %	0.6 %	0.0 %	0.0 %
11	0.3 %	2.2 %	1.1 %	0.6 %	0.0 %	0.0 %
12	0.1 %	1.9 %	1.7 %	0.6 %	0.0 %	0.0 %
13	0.0 %	0.9 %	2.5 %	0.7 %	0.0 %	0.0 %
14	0.0 %	0.4 %	2.8 %	1.0 %	0.0 %	0.0 %
15	0.0 %	0.2 %	2.5 %	1.5 %	0.0 %	0.0 %
16	0.0 %	0.0 %	0.8 %	3.3 %	0.0 %	0.0 %
17	0.0 %	0.0 %	0.3 %	2.4 %	0.3 %	1.2 %
18	0.0 %	0.0 %	0.0 %	1.2 %	0.9 %	2.1 %
19	0.0 %	0.0 %	0.0 %	0.6 %	1.3 %	2.2 %
20	0.0 %	0.0 %	0.0 %	0.6 %	0.9 %	2.8 %
21	0.0 %	0.0 %	0.0 %	0.6 %	1.0 %	2.5 %
22	0.0 %	0.0 %	0.0 %	0.8 %	1.3 %	2.3 %
23	0.0 %	0.0 %	0.0 %	0.6 %	1.0 %	2.6 %

4.4 PREDICTED ODOUR CONTOURS

4.4.1 Case 1

4.4.1.1 Four Shed Farm

Figure 4.6 presents predicted 99.5th percentile odour concentrations for Case 1 (emissions modelled as stack sources with emission temperature set to ambient temperature) with a total of four poultry sheds operating.

Figure 4.6: Predicted 99.5th percentile odour concentrations for Case 1, four poultry shed scenario (OU)

4.4.1.2 Eight Shed Farm

Figure 4.7 presents predicted 99.5th percentile odour concentrations for Case 1 (emissions modelled as stack sources with emission temperature set to ambient temperature) with a total of eight poultry sheds operating.

Figure 4.7: Predicted 99.5th percentile odour concentrations for Case 1, eight poultry shed scenario (OU)

4.4.2 Case 2

4.4.2.1 Four Shed Farm

Figure 4.8 presents predicted 99.5th percentile odour concentrations for Case 2 (emissions modelled as stack sources with emission temperature set to production temperature) with a total of four poultry sheds operating.

Figure 4.8: Predicted 99.5th percentile odour concentrations for Case 2, four poultry shed scenario (OU)

4.4.2.2 Eight Shed Farm

Figure 4.9 presents predicted 99.5th percentile odour concentrations for Case 2 (emissions modelled as stack sources with emission temperature set to production temperature) with a total of four poultry sheds operating.

Figure 4.9: Predicted 99.5th percentile odour concentrations for Case 2, eight poultry shed scenario (OU)

4.4.3 Case 5

4.4.3.1 Four Shed Farm

Figure 4.10 presents predicted 99.5th percentile odour concentrations for Case 5 (emissions modelled as volume sources) with a total of eight poultry sheds operating.

Figure 4.10: Predicted 99.5th percentile odour concentrations for Case 5, four poultry shed scenario (OU)

4.4.3.2 Eight Shed Farm

Figure 4.11 presents predicted 99.5th percentile odour concentrations for Case 5 (emissions modelled as volume sources) with a total of four poultry sheds operating.

Figure 4.11: Predicted 99.5th percentile odour concentrations for Case 5, four poultry shed scenario (OU)

4.4.4 Summary of Outcomes

Review of the results of the modelling presented for Cases 1, 2 and 5 above for the hypothetical Farm 1 (Caboolture) location indicate the following:

- Modelling of stack sources with emission temperature set to the shed production temperature (Case 2) results in a less extensive 99.5th percentile ground level odour concentrations when compared with the same modelling undertaken with the emission temperature set to ambient temperature (Case 1). This indicates that while the sources have been modelled with no vertical momentum flux, the thermal buoyancy, when included in the modelling, resulted in improved predicted dispersion. It should be noted however that this does not validate the use of thermal buoyancy in the modelling, rather that a detailed investigation is required to determine the impact of the thermal buoyancy of the horizontally directed plume.
- Modelling of emissions from the poultry sheds as volume sources (Case 5) results in a predicted reduction in the extent of the 99.5th percentile ground level 2.5 odour unit contour in

comparison with the same emissions when modelled as point sources (Case 1). This could be a function of the building downwash utilised in the modelling of emissions from the point sources.

5 FARM 2 - REDLANDS

5.1 FARM LOCATION AND DESIGN

Figure 5.1 presents the location considered for hypothetical Farm 2. The adopted farm location is in the Redlands area and has a significant number of other poultry farms operating in the area surrounding the site.

Figure 5.1: Shed location and surrounding landuses for farm 2

Figure 5.2 presents the shed layout adopted for the purposes of the modelling of emissions from Farm 2. For the purposes of the modelling, emissions from a 175,000 bird farm has been modelled from Sheds 1 – 4 only with emissions from a 350,000 bird farm modelled from Sheds 1 – 8.

Figure 5.2: Shed layout adopted for farm 2

5.2 TERRAIN

Figure 5.3 presents the terrain surrounding the hypothetical Farm 2. As can be seen the terrain immediately surrounding the farm is relatively flat with no significant terrain features expected to have a significant impact on local wind fields. It is noted however that the proximity of the Farm 2 site to the coast is likely to result in a significant sea breeze as is observed through much of the coastal region of south-east Queensland. Landuses in the area surrounding the farm location are dominated by agricultural and rural residential landuses.

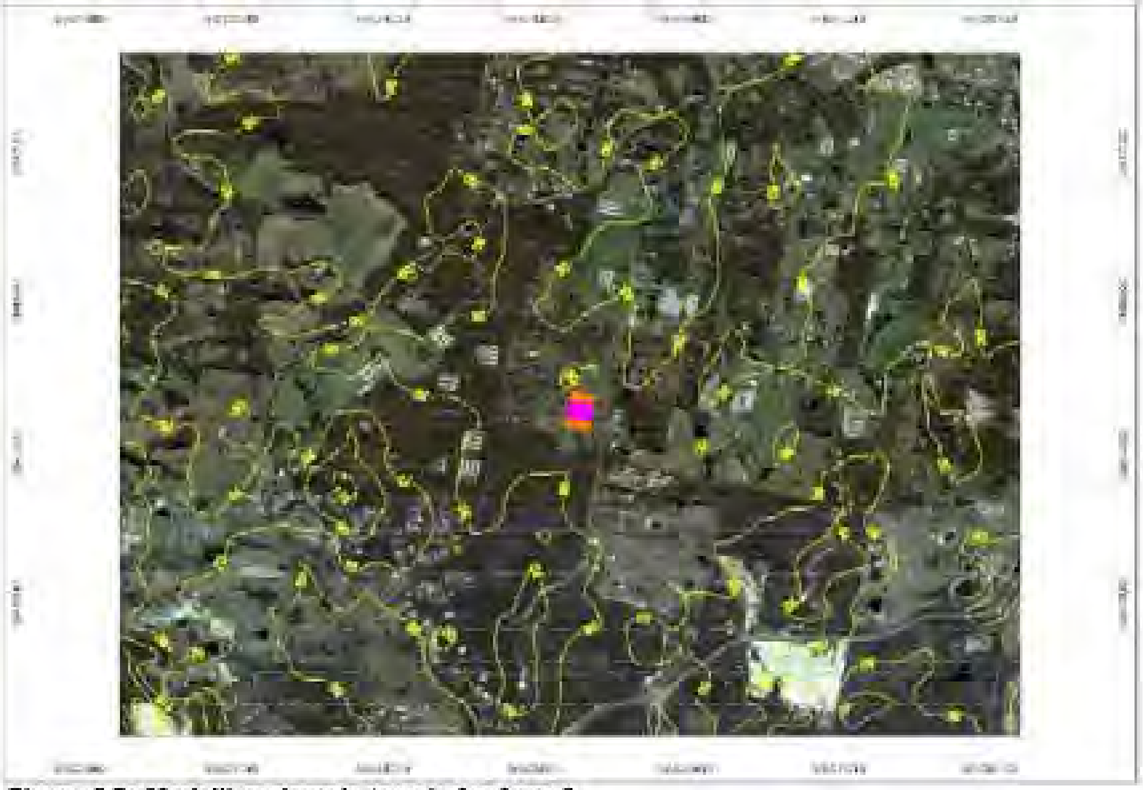

Figure 5.3: Modelling domain terrain for farm 2

5.3 PREDICTED METEOROLOGY

Figure 5.4 presents an annual predicted windrose and Figure 5.5 presents seasonal predicted windroses for the hypothetical Farm 2 location. As can be seen from this information, the predicted wind fields are dominated wind conditions typical for much of the south-east Queensland region including:

- winds from easterly sectors during summer months;
- winds from easterly and north-easterly sectors during summer months, and
- winds from southerly and south-westerly sectors during the autumn and winter months.

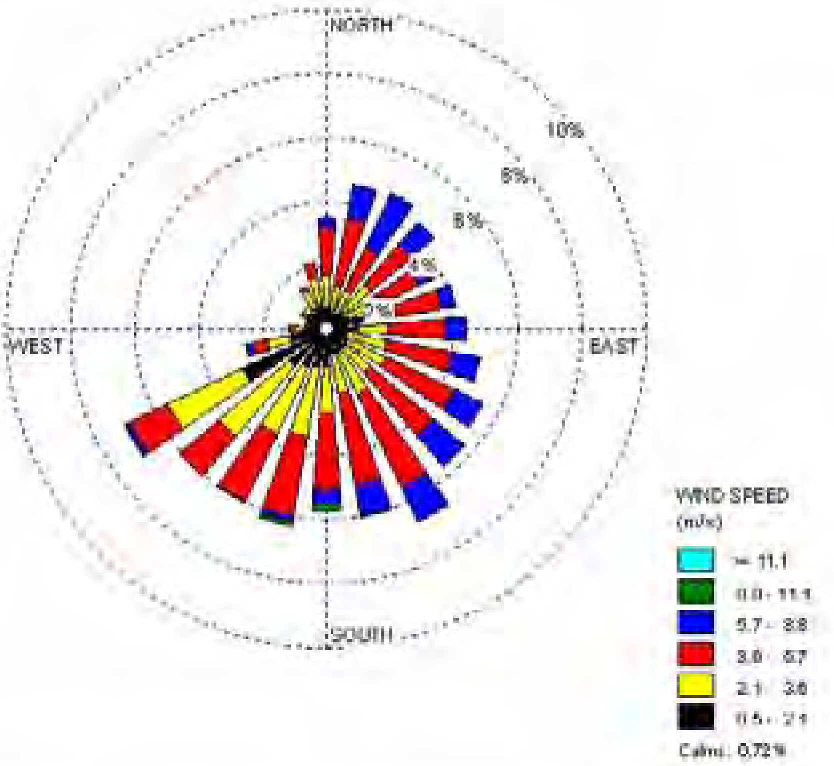

Figure 5.4: Annual predicted windroses for hypothetical Farm 1 location

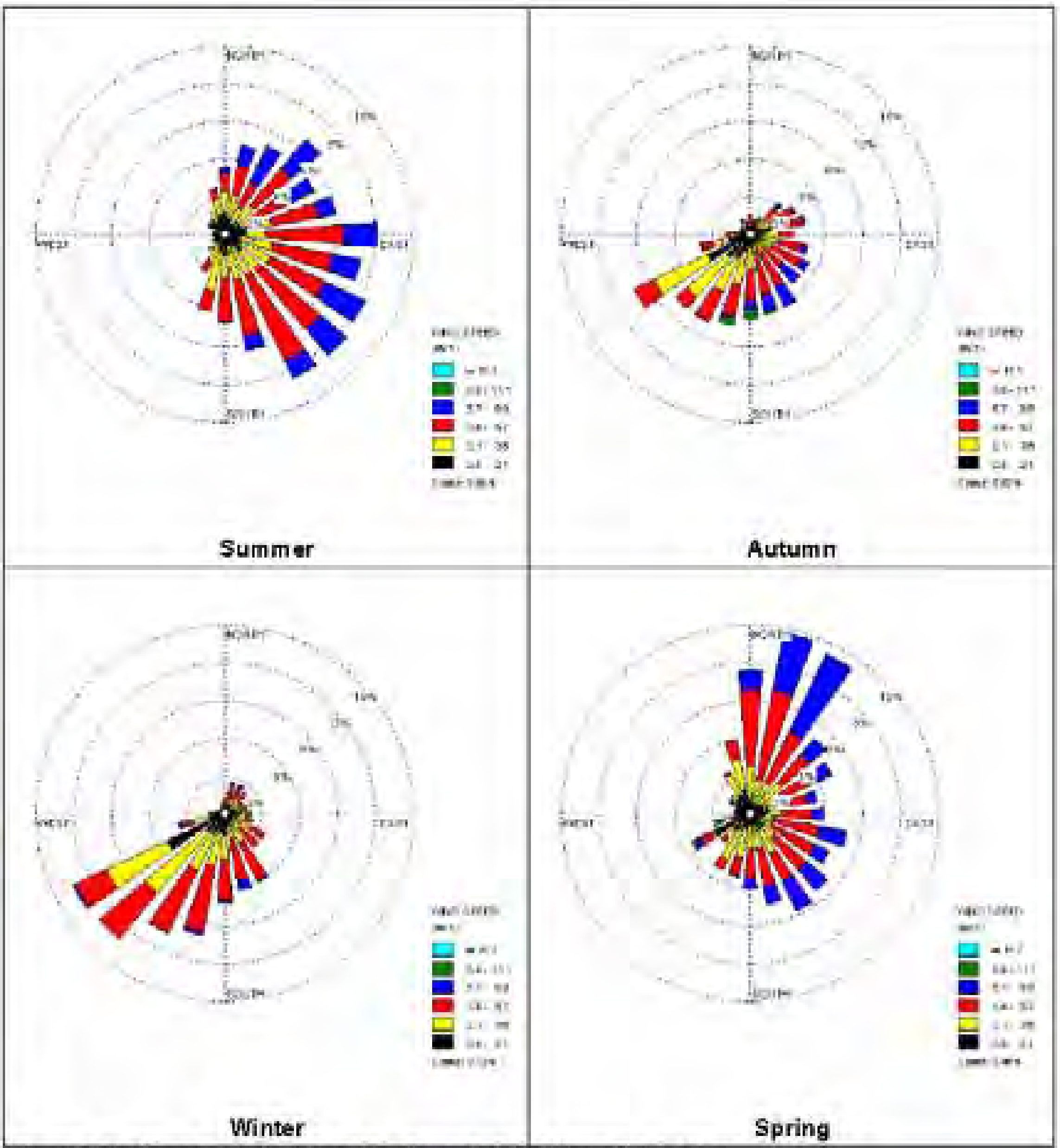

Figure 5.5: Seasonal windroses for hypothetical Farm 2 location

Table 5.1 presents a summary of predicted stability classes for the hypothetical farm 1 location. As can be seen from this information calm winds are predicted to occur for approximately 1 % of the year with the majority of these conditions occurring during early morning hours.

TABLE 5.1: SUMMARY OF PREDICTED STABILITY CLASSES FOR FARM 2

Hour	Stability Class					
	A	B	C	D	E	F
0	0.0 %	0.0 %	0.0 %	1.0 %	1.5 %	1.7 %
1	0.0 %	0.0 %	0.0 %	1.0 %	1.6 %	1.6 %
2	0.0 %	0.0 %	0.0 %	1.1 %	1.6 %	1.5 %
3	0.0 %	0.0 %	0.0 %	1.1 %	1.7 %	1.3 %
4	0.0 %	0.0 %	0.0 %	1.1 %	1.7 %	1.4 %
5	0.0 %	0.0 %	0.3 %	2.0 %	1.1 %	0.8 %
6	0.0 %	0.1 %	0.7 %	2.7 %	0.4 %	0.2 %
7	0.0 %	0.3 %	1.6 %	2.3 %	0.0 %	0.0 %
8	0.0 %	1.3 %	1.8 %	1.0 %	0.0 %	0.0 %
9	0.2 %	1.6 %	1.5 %	0.9 %	0.0 %	0.0 %
10	0.3 %	2.1 %	1.1 %	0.7 %	0.0 %	0.0 %
11	0.2 %	2.0 %	1.4 %	0.6 %	0.0 %	0.0 %
12	0.1 %	1.6 %	1.9 %	0.6 %	0.0 %	0.0 %
13	0.0 %	0.8 %	2.3 %	1.1 %	0.0 %	0.0 %
14	0.0 %	0.2 %	1.9 %	2.1 %	0.0 %	0.0 %
15	0.0 %	0.1 %	1.0 %	2.3 %	0.0 %	0.0 %
16	0.0 %	0.0 %	0.4 %	3.8 %	0.0 %	0.0 %
17	0.0 %	0.0 %	0.1 %	2.6 %	0.8 %	0.7 %
18	0.0 %	0.0 %	0.0 %	1.4 %	1.7 %	1.1 %
19	0.0 %	0.0 %	0.0 %	1.0 %	1.6 %	1.3 %
20	0.0 %	0.0 %	0.0 %	1.0 %	1.8 %	1.4 %
21	0.0 %	0.0 %	0.0 %	1.0 %	1.8 %	1.4 %
22	0.0 %	0.0 %	0.0 %	1.0 %	1.6 %	1.6 %
23	0.0 %	0.0 %	0.0 %	1.0 %	1.5 %	1.6 %

5.4 PREDICTED ODOUR CONTOURS

5.4.1 Case 3

5.4.1.1 Four Shed Farm

Figure 5.6 presents predicted 99.5th percentile odour concentrations for Case 3 (emissions modelled as stack sources with emission temperature set to ambient temperature) with a total of four poultry sheds operating.

Figure 5.6: Predicted 99.5th percentile odour concentrations for Case 3, four poultry shed scenario (OU)

5.4.1.2 Eight Shed Farm

Figure 5.7 presents predicted 99.5th percentile odour concentrations for Case 3 (emissions modelled as stack sources with emission temperature set to ambient temperature) with a total of eight poultry sheds operating.

Figure 5.7: Predicted 99.5th percentile odour concentrations for Case 3, eight poultry shed scenario (OU)

5.4.2 Case 4

5.4.2.1 Four Shed Farm

Figure 5.8 presents predicted 99.5th percentile odour concentrations for Case 4 (emissions modelled as stack sources with emission temperature set to production temperature) with a total of four poultry sheds operating.

Figure 5.8: Predicted 99.5th percentile odour concentrations for Case 4, four poultry shed scenario (OU)

5.4.2.2 Eight Shed Farm

Figure 5.9 presents predicted 99.5th percentile odour concentrations for Case 3 (emissions modelled as stack sources with emission temperature set to production temperature) with a total of eight poultry sheds operating.

Figure 5.9: Predicted 99.5th percentile odour concentrations for Case 4, eight poultry shed scenario (OU)

5.4.3 Case 6

5.4.3.1 Four Shed Farm

Figure 5.10 presents predicted 99.5th percentile odour concentrations for Case 8 (emissions modelled as volume sources) with a total of four poultry sheds operating.

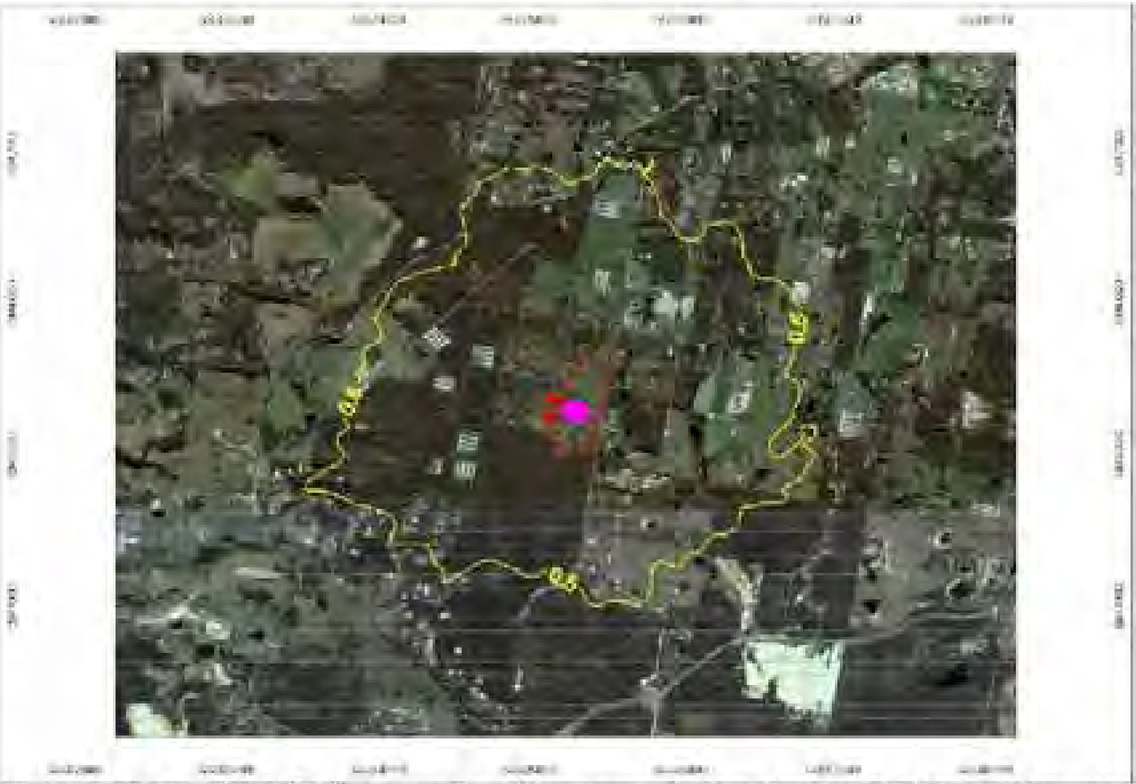

Figure 5.10: Predicted 99.5th percentile odour concentrations for Case 6, four poultry shed scenario (OU)

5.4.3.2 *Eight Shed Farm*

Figure 5.11 presents predicted 99.5th percentile odour concentrations for Case 6 (emissions modelled as volume sources) with a total of eight poultry sheds operating.

Figure 5.11: Predicted 99.5th percentile odour concentrations for Case 6, four poultry shed scenario (OU)

5.4.4 Summary of Results

Review of the results of the modelling presented for Cases 3, 4 and 6 above for the hypothetical Farm 2 (Redlands) location indicate the following:

- Modelling of stack sources with emission temperature set to the shed production temperature (Case 4) results in a less extensive predicted 99.5th percentile ground level odour concentrations when compared with the same modelling undertaken with the emission temperature set to ambient temperature (Case 3). This indicates that while the sources have been modelled with no vertical momentum flux, the thermal buoyancy, when included in the modelling, resulted in improved predicted dispersion. It should be noted however that this does not validate the use of thermal buoyancy in the modelling, rather that a detailed investigation is required to determine the impact of the thermal buoyancy on the horizontally directed plume.
- Modelling of emissions from the poultry sheds as volume sources (Case 6) results in a slight

predicted reduction in the extent of the 99.5th percentile ground level 2.5 odour unit contour in comparison with the same emissions when modelled as point sources (Case 3). This could be a function of the building downwash utilised in the modelling of emissions from the point sources.

APPENDIX A

DEEDI PROJECT BRIEF

CALPUFF modelling of a tunnel ventilated broiler farm: thermal buoyancy effects

Prepared by Mark Dunlop
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3 March 2009

Objectives

The objective of this modelling exercise is to:

1. Evaluate the effect of emission temperature on predicted levels of odour impact from broiler farms according to the Qld EPA odour impact criteria.

Background

DPI&F is conducting a research investigation to evaluate the influence of thermal buoyancy on the dispersion of odour plumes emitted from broiler sheds, including the modelling of these emissions. Funding has been provided from the poultry industry through RIRDC.

To date, DPI&F have commissioned a study to analyse the effects of thermal buoyancy on emissions from broiler sheds using CFD modelling. Where possible, results were compared against CALPUFF modelling using similar inputs. This modelling was undertaken by Pacific Air and Environment. The results indicated that thermal buoyancy was quite pronounced in the CFD modelling (where emission temperatures were more than 2°C warmer than ambient). However, CALPUFF results indicated that very little rise occurred. It was suggested that this was primarily due to building downwash and the time-weighted average nature of CALPUFF modelling results.

The next stage of this investigation will be to model some 'typical' broiler farming scenarios with a range of inputs to evaluate the influence of selected modelling inputs, including:

- emission temperature;
- land use & terrain; and possibly
- farm size (number of birds).

Combinations of these inputs will provide a unique analysis of the influence of emission temperatures for a range of modelling inputs.

CALPUFF Modelling

A poultry farm will be modelled with various inputs to assess the influence of these (especially emission temperatures) on predicted separation distances.

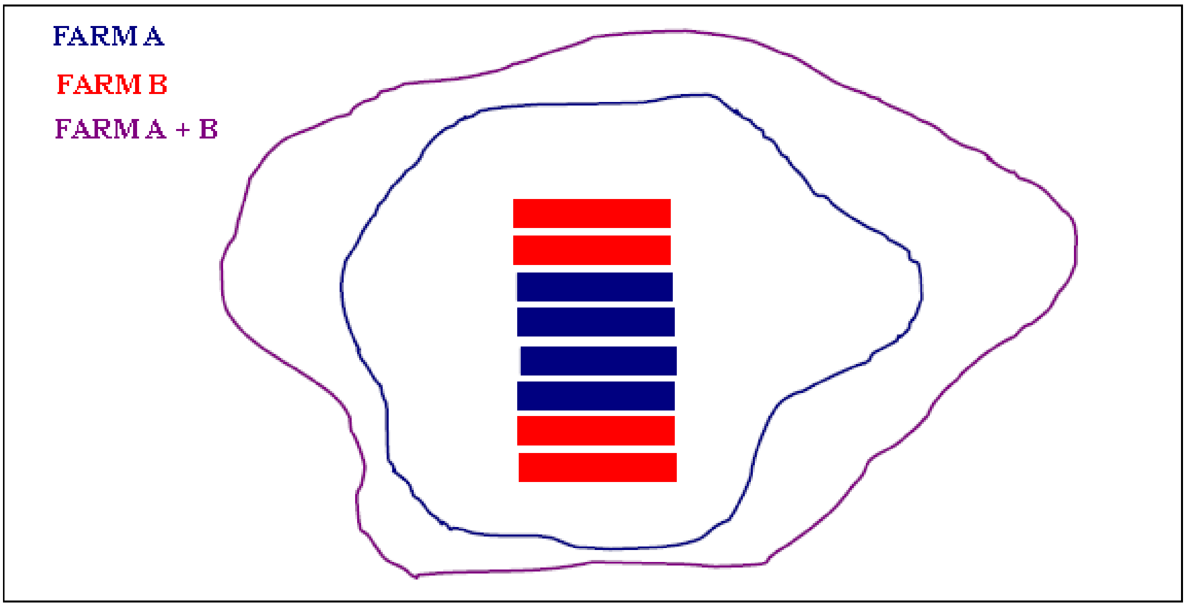
It will be assumed that each broiler shed is 153 m long, 15 m wide (internal, 15.3 m external), wall height 2.7 m, roof apex 4.5 m, ceiling baffles hang to 2.4 m above litter surface. Using these dimensions, it is assumed that each shed houses 43,750 birds, requiring maximum ventilation rate to be 112 m^3/s. This ventilation rate could be achieved using 16, Euroemme EM50, 1.0hp fans.

DPI&F requests that the farm be modelled at two different locations. Suitable options include modelling the farm at a different location within the same Calmet domain or positioning the farm in a completely different Calmet domain. The domain must cover one of the dominant broiler growing areas in SE Qld, preferably near Beaudesert, Esk/Coominya or Caboolture/Donnybrook/Wamuran . If repositioning the farm within the same Calmet domain, please select a site with different land use and terrain profiles (especially the direction of drainage flows). Please advise which Calmet terrains you have available.

DPI&F proposes the following modelling cases.

Case number	Farm Size (number of birds)	Farm location	Emission Temperature	Source description
1	350,000 (8 sheds)	A	Ambient	Quasi-point (PAE method)
2	350,000	A	Production	Quasi-point
3	350,000	B	Ambient	Quasi-point
4	350,000	B	Production	Quasi-point
5	350,000	A	Ambient	Volume
6	350,000	B	Ambient	Volume

It has been suggested that the farm with 175,000 birds can be modelled simultaneously and efficiently by utilising a composite farm setup with the impacts from both farms added together to give a farm which is half/double the size while using the same computing power. See the below figure. If this is possible please indicate prices for modelling just the 350,000 bird farm and a composite farm to provide results for 175,000 birds and 350,000 birds.



Model Inputs

Develop emission files using the PAE method, assuming a K factor of 2.

Adopt a thinning regime as used by one of the major integrators e.g. Inghams.

Use production target temperatures as use by one of the major integrators e.g Inghams.

Model setup

Plume downwash will be included, configured in your preferred manner.

Vertical emission velocity will be set to 0 m/s.

Terrain resolution 100 m.

Required information from outputs

DPI&F requires a comprehensive summary:

- of **ALL** modelling inputs and parameter selections (including detailed description of the thinning regime, production target temperature assumptions and building plume downwash)
- about the terrain.
- about the land use types throughout the modelling terrain.
- Wind patterns (please include a windrose)
- of the odour impact contours (to address the Qld odour impact criteria, 2.5OU and 5OU as a minimum, plus additional contours so that distances can be scaled up or down depending on odour emission rate assumptions).

Variation to the modelling parameters

If you disagree with the proposed parameters, would like to suggest alternative parameters, or are able to suggest a more efficient way to undertake the modelling, please contact Mark Dunlop 07 4688 1280 to discuss the matter.

Appendix 8: Existing farms - Separation distance formula calculations

(Hypothetical farms)

Existing Farm A – separation distances to receptors as calculated with separation distance formulas

Qld Formula

Separation Distance Queensland Formula

Bird Numbers	Receptor Number	Direction	Receptor Type	Surface Roughness	Topography/ Terrain	Shed/Farm Rating	S1	S2	S3	S4	Distance to 2.5 OU Boundary	Available Distance to Receptor	Distance Required (from S Factor)
200000	1	SE	Sensitive land use	Long grass, few trees	Flat	0	1	26	1	1	276	1330	625
200000	2	E	Sensitive land use	Long grass, few trees	Flat	0	1	26	1	1	143	1650	625
200000	3	NE	Sensitive land use	Long grass, few trees	Flat	0	1	26	1	1	143	1750	625
200000	4	N	Sensitive land use	Long grass, few trees	Broad valley/drainage (0.1-1%) downslope	0	1	26	1	1.6	255	1900	999
200000	5	N	Sensitive land use	Long grass, few trees	Broad valley/drainage (0.1-1%) downslope	0	1	26	1	1.6	337	1580	999
200000	6	NW	Sensitive land use	Long grass, few trees	Broad valley/drainage (0.1-1%) downslope	0	1	26	1	1.6	306	1040	999
200000	7	NW	Sensitive land use	Long grass, few trees	Broad valley/drainage (0.1-1%) downslope	0	1	26	1	1.6	255	740	999
200000	Farthest OU Boundary	N	Sensitive land use	Long grass, few trees	Broad valley/drainage (0.1-1%) downslope	0	1	26	1	1.6	337	337	999

SA Formula

Separation Distance South Australian Formula

Bird Numbers	Receptor Number	Direction to Receptor	Type of Poultry Farm	Receptor Type	Litter/Manure Handling	Surface Roughness	Topography/Terrain	S1	S2	S3	S4	S5	Distance Available	Distance Required
200000	1	SW	Broiler	Rural	Taken off site	Long grass, few trees	Flat	1	1	1	1	1	1330	553
200000	2	E	Broiler	Rural	Taken off site	Long grass, few trees	Flat	1	1	1	1	1	1650	553
200000	3	NE	Broiler	Rural	Taken off site	Long grass, few trees	Flat	1	1	1	1	1	1750	553
200000	4	N	Broiler	Rural	Taken off site	Long grass, few trees	Broad valley/drainage (downslope of site)	1	1	1	1	1.6	1900	885
200000	5	N	Broiler	Rural	Taken off site	Long grass, few trees	Broad valley/drainage (downslope of site)	1	1	1	1	1.6	1580	885
200000	6	NW	Broiler	Rural	Taken off site	Long grass, few trees	Broad valley/drainage (downslope of site)	1	1	1	1	1.6	1040	885
200000	7	NW	Broiler	Rural	Taken off site	Long grass, few trees	Broad valley/drainage (downslope of site)	1	1	1	1	1.6	740	885

Alternatives - Receptor 4, flat terrain, separation distance equals 553 m.

NSW Formula

Separation Distance New South Wales Formula

Bird Numbers	Receptor Number	Direction to receptor	Shed Factor	Receptor Type	Topography/ Terrain	Surface Roughness	Wind Frequency	S1	S2	S3	S4	S5	Distance Available	Distance Required
200000	1	SW	Controlled fan vent without barriers	Single rural residence	Flat	Few trees, long grass	Normal wind conditions	980	0.3	1	0.9	1	1330	1268
200000	2	E	Controlled fan vent without barriers	Single rural residence	Flat	Few trees, long grass	Normal wind conditions	980	0.3	1	0.9	1	1650	1268
200000	3	NE	Controlled fan vent without barriers	Single rural residence	Flat	Few trees, long grass	Normal wind conditions	980	0.3	1	0.9	1	1750	1268
200000	4	N	Controlled fan vent without barriers	Single rural residence	Flat	Few trees, long grass	Normal wind conditions	980	0.3	1	0.9	1	1900	1268
200000	5	N	Controlled fan vent without barriers	Single rural residence	Flat	Few trees, long grass	Normal wind conditions	980	0.3	1	0.9	1	1580	1268
200000	6	NW	Controlled fan vent without barriers	Single rural residence	Flat	Few trees, long grass	Normal wind conditions	980	0.3	1	0.9	1	1040	1268
200000	7	NW	Controlled fan vent without barriers	Single rural residence	Flat	Few trees, long grass	Normal wind conditions	980	0.3	1	0.9	1	740	1268

Vic Formula

Separation Distance Victorian Formula

Bird Numbers	Distance Required (calculated from separation distance formula)
200000	472

Existing Farm B – separation distances to receptors as calculated with separation distance formulas

Qld Formula

Separation Distance Queensland Formula

Bird Numbers	Receptor Number	Direction	Receptor Type	Surface Roughness	Topography/ Terrain	Shed/Farm Rating	S1	S2	S3	S4	Distance to 2.5 OU Boundary	Available Distance to Receptor	Distance Required (from S Factor)
200000	1	SW	Sensitive land use	Level wooded country	Flat	0	1	26	0.85	1	895	1780	531
200000	2	NW	Sensitive land use	Level wooded country	Flat	0	1	26	0.85	1	743	1840	531
200000	3	NW	Sensitive land use	Level wooded country	Flat	0	1	26	0.85	1	533	2130	531
200000	4	N	Sensitive land use	Level wooded country	Flat	0	1	26	0.85	1	381	1410	531
200000	5	N	Sensitive land use	Long grass, few trees	Flat	0	1	26	1	1	438	1590	625
200000	6	NE	Sensitive land use	Long grass, few trees	Flat	0	1	26	1	1	914	1650	625
200000	7	NE	Sensitive land use	Level wooded country	Flat	0	1	26	0.85	1	1105	1850	531
200000	8	NE	Sensitive land use	Level wooded country	Flat	0	1	26	0.85	1	1524	1630	531
200000	farthest OU boundary	E	Sensitive land use	Level wooded country	Flat	0	1	26	0.85	1	1924	1924	531

SA Formula

Separation Distance South Australian Formula

Bird Numbers	Receptor Number	Direction to Receptor	Type of Poultry Farm	Receptor Type	Litter/Manure Handling	Surface Roughness	Topography/ Terrain	S1	S2	S3	S4	S5	Distance Available	Distance Required
200000	1	SW	Broiler	Rural	Taken off site	Level wooded country	Flat	1	1	1	0.85	1	1780	470
200000	2	NW	Broiler	Rural	Taken off site	Level wooded country	Flat	1	1	1	0.85	1	1840	470
200000	3	NW	Broiler	Rural	Taken off site	Level wooded country	Flat	1	1	1	0.85	1	2130	470
200000	4	N	Broiler	Rural	Taken off site	Level wooded country	Flat	1	1	1	0.85	1	1410	470
200000	5	N	Broiler	Rural	Taken off site	Long grass, few trees	Flat	1	1	1	1	1	1590	553
200000	6	NE	Broiler	Rural	Taken off site	Long grass, few trees	Flat	1	1	1	1	1	1650	553
200000	7	NE	Broiler	Rural	Taken off site	Level wooded country	Flat	1	1	1	0.85	1	1850	470
200000	8	NE	Broiler	Rural	Taken off site	Level wooded country	Flat	1	1	1	0.85	1	1630	470

NSW Formula

Separation Distance New South Wales Formula

Bird Numbers	Receptor Number	Direction to receptor	Shed Factor	Receptor Type	Topography/ Terrain	Surface Roughness	Wind Frequency	S1	S2	S3	S4	S5	Distance Available	Distance Required
200000	1	SW	Controlled fan vent without barriers	Single rural residence	Undulating	Wooded country	Normal wind conditions	980	0.3	0.9	0.7	1	1780	888
200000	2	NW	Controlled fan vent without barriers	Single rural residence	Flat	Wooded country	Normal wind conditions	980	0.3	1	0.7	1	1840	986
200000	3	NW	Controlled fan vent without barriers	Single rural residence	Flat	Wooded country	Normal wind conditions	980	0.3	1	0.7	1	2130	986
200000	4	N	Controlled fan vent without barriers	Single rural residence	Flat	Wooded country	Normal wind conditions	980	0.3	1	0.7	1	1410	986
200000	5	N	Controlled fan vent without barriers	Single rural residence	Flat	Few trees, long grass	Normal wind conditions	980	0.3	1	0.9	1	1590	1268
200000	6	NE	Controlled fan vent without barriers	Single rural residence	Flat	Few trees, long grass	Normal wind conditions	980	0.3	1	0.9	1	1650	1268
200000	7	NE	Controlled fan vent without barriers	Single rural residence	Flat	Wooded country	Normal wind conditions	980	0.3	1	0.7	1	1850	986
200000	8	NE	Controlled fan vent without barriers	Single rural residence	Flat	Wooded country	Normal wind conditions	980	0.3	1	0.7	1	1630	986

Alternatives - Receptor 1, flat terrain, separation distance equals 986 m

Vic Formula

Separation Distance Victorian Formula

Bird Numbers	Distance Required (calculated from separation distance formula)
200000	472

Existing Farm C – separation distances to receptors as calculated with separation distance formulas

Qld Formula

Separation Distance Queensland Formula

Bird Numbers	Receptor Number	Direction	Receptor Type	Surface Roughness	Topography/ Terrain	Shed/Farm Rating	S1	S2	S3	S4	Distance to 2.5 OU Boundary	Available Distance to Receptor	Distance Required (from S Factor)
200000	1	NE	Senstivie land use	Long grass, few trees	Sloping terrain (1-2%) downslope	0	1	26	1	1.5	349	1694	937
200000	2	N	Senstivie land use	Long grass, few trees	Sloping terrain (1-2%) downslope	0	1	26	1	1.5	358	1860	937
200000	3	NW	Senstivie land use	Level wooded country	Sloping terrain (1-2%) downslope	0	1	26	0.85	1.5	413	1414	796
200000	4	W	Senstivie land use	Level wooded country	Sloping terrain (1-2%) downslope	0	1	26	0.85	1.5	670	1200	796
200000	5	SE	Senstivie land use	Long grass, few trees	Sloping terrain (1-2%) downslope	0	1	26	1	1.5	284	837	937
200000	Farthest OU boundary	SW	Senstivie land use	Long grass, few trees	Sloping terrain (1-2%) downslope	0	1	26	1	1.5	835	835	937

Alternatives - receptor 3, flat terrain, separation distance 531 m

SA Formula

Separation Distance South Australian Formula

Bird Numbers	Receptor Number	Direction to Receptor	Type of Poultry Farm	Receptor Type	Litter/Manure Handling	Surface Roughness	Topography/ Terrain	S1	S2	S3	S4	S5	Distance Available	Distance Required
200000	1	NE	Broiler	Rural	Taken off site	Long grass, few trees	Sloping	1	1	1	1	1.5	1694	829
200000	2	N	Broiler	Rural	Taken off site	Long grass, few trees	Sloping	1	1	1	1	1.5	1860	829
200000	3	NW	Broiler	Rural	Taken off site	Level wooded country	Sloping	1	1	1	0.85	1.5	1414	705
200000	4	W	Broiler	Rural	Taken off site	Level wooded country	Sloping	1	1	1	0.85	1.5	1200	705
200000	5	SE	Broiler	Rural	Taken off site	Long grass, few trees	Sloping	1	1	1	1	1.5	837	829

Alternatives - receptor 3, flat terrain, separation distance 470 m

NSW Formula

Separation Distance New South Wales Formula

Bird Numbers	Receptor Number	Direction to receptor	Shed Factor	Receptor Type	Topography/ Terrain	Surface Roughness	Wind Frequency	S1	S2	S3	S4	S5	Distance Available	Distance Required
200000	1	NE	Controlled fan vent without barriers	Single rural residence	Flat	Few trees, long grass	Normal wind conditions	980	0.3	1	0.9	1	1694	1268
200000	2	N	Controlled fan vent without barriers	Single rural residence	Flat	Few trees, long grass	Normal wind conditions	980	0.3	1	0.9	1	1860	1268
200000	3	NW	Controlled fan vent without barriers	Single rural residence	Flat	Wooded country	Normal wind conditions	980	0.3	1	0.7	1	1414	986
200000	4	W	Controlled fan vent without barriers	Single rural residence	Flat	Wooded country	Normal wind conditions	980	0.3	1	0.7	1	1200	986
200000	5	SE	Controlled fan vent without barriers	Single rural residence	Flat	Few trees, long grass	Normal wind conditions	980	0.3	1	0.9	1	837	1268

Vic Formula

Separation Distance Victorian Formula

Bird Numbers	Distance Required (calculated from separation distance formula)
200000	472

Existing Farm D – separation distances to receptors as calculated with separation distance formulas

Qld Formula

Separation Distance Queensland Formula

Bird Numbers	Receptor Number	Direction	Receptor Type	Surface Roughness	Topography/ Terrain	Shed/Farm Rating	S1	S2	S3	S4	Distance to 2.5 OU Boundary	Available Distance to Receptor	Distance Required (from S Factor)
240000	1	S	Senstivie land use	Long grass, few trees	Sloping terrain (1-2%) upslope	0	1	26	1	1	532	700	697
240000	2	N	Senstivie land use	Long grass, few trees	Sloping terrain (1-2%) downslope	0	1	26	1	1.5	944	900	1045
240000	3	NW	Senstivie land use	Long grass, few trees	Sloping terrain (1-2%) downslope	0	1	26	1	1.5	667	740	1045
240000	4	NW	Senstivie land use	Long grass, few trees	Sloping terrain (1-2%) downslope	0	1	26	1	1.5	651	740	1045
240000	Farthest OU boundary	N	Senstivie land use	Long grass, few trees	Sloping terrain (1-2%) downslope	0	1	26	1	1.5	1087	1087	1045

SA Formula

Separation Distance South Australian Formula

Bird Numbers	Receptor Number	Direction to Receptor	Type of Poultry Farm	Receptor Type	Litter/Manure Handling	Surface Roughness	Topography/ Terrain	S1	S2	S3	S4	S5	Distance Available	Distance Required
240000	1	S	Broiler	Rural	Taken off site	Long grass, few trees	Sloping	1	1	1	1	1	700	611
240000	2	N	Broiler	Rural	Taken off site	Long grass, few trees	Sloping	1	1	1	1	1.5	900	917
240000	3	NW	Broiler	Rural	Taken off site	Long grass, few trees	Sloping	1	1	1	1	1.5	740	917
240000	4	NW	Broiler	Rural	Taken off site	Long grass, few trees	Sloping	1	1	1	1	1.5	740	917

NSW Formula

Separation Distance New South Wales Formula

Bird Numbers	Receptor Number	Direction to receptor	Shed Factor	Receptor Type	Topography/Terrain	Surface Roughness	Wind Frequency	S1	S2	S3	S4	S5	Distance Available	Distance Required
240000	1	S	Controlled fan vent without barriers	Single rural residence	hills and valleys (between site and	Few trees, long grass	Normal wind conditions	980	0.3	0.7	0.9	1	700	1010
240000	2	N	Controlled fan vent without	Single rural residence	Low relief	Few trees, long grass	Normal wind conditions	980	0.3	1.2	0.9	1	900	1732
240000	3	NW	Controlled fan vent without	Single rural residence	Low relief	Few trees, long grass	Normal wind conditions	980	0.3	1.2	0.9	1	740	1732
240000	4	NW	Controlled fan vent without	Single rural residence	Low relief	Few trees, long grass	Normal wind conditions	980	0.3	1.2	0.9	1	740	1732

Vic Formula

Separation Distance Victorian Formula

Bird Numbers	Distance Required (calculated from separation distance formula)
240000	520

Existing Farm E – separation distances to receptors as calculated with separation distance formulas

Qld Formula

Separation Distance Queensland Formula

Bird Numbers	Receptor Number	Direction	Receptor Type	Surface Roughness	Topography/ Terrain	Shed/Farm Rating	S1	S2	S3	S4	Distance to 2.5 OU Boundary	Available Distance to Receptor	Distance Required (from S Factor)
200000	1	W	Senstivie land use	Undulating hills	Sloping terrain (1-2%) upslope	0	1	26	0.93	1	162	370	581
200000	2	S	Senstivie land use	Level wooded country	Flat	0	1	26	0.85	1	267	1030	531
200000	3	SE	Senstivie land use	Level wooded country	Flat	0	1	26	0.85	1	448	926	531
200000	4	E	Senstivie land use	Level wooded country	Flat	0	1	26	0.85	1	714	1623	531
200000	5	NE	Senstivie land use	Long grass, few trees	Sloping terrain (1-2%) downslope	0	1	26	1	1.5	610	1075	937
200000	Farthest OU boundary	NE	Senstivie land use	Long grass, few trees	Flat	0	1	26	1	1	762	762	625

Alternatives - receptor 1, flat terrain, separation distance 625 m
receptor 5, flat terrain, separation distance 625 m

SA Formula

Separation Distance South Australian Formula

Bird Numbers	Receptor Number	Direction to Receptor	Type of Poultry Farm	Receptor Type	Litter/Manure Handling	Surface Roughness	Topography/ Terrain	S1	S2	S3	S4	S5	Distance Available	Distance Required
200000	1	W	Broiler	Rural	Taken off site	Undulating hills	Sloping	1	1	1	0.93	1	370	514
200000	2	S	Broiler	Rural	Taken off site	Level wooded country	Flat	1	1	1	0.85	1	1030	470
200000	3	SE	Broiler	Rural	Taken off site	Level wooded country	Flat	1	1	1	0.85	1	926	470
200000	4	E	Broiler	Rural	Taken off site	Level wooded country	Flat	1	1	1	0.85	1	1623	470
200000	5	NE	Broiler	Rural	Taken off site	Long grass, few trees	Sloping	1	1	1	1	1.5	1075	829

NSW Formula

Separation Distance New South Wales Formula

Bird Numbers	Receptor Number	Direction to receptor	Shed Factor	Receptor Type	Topography/Terrain	Surface Roughness	Wind Frequency	S1	S2	S3	S4	S5	Distance Available	Distance Required
200000	1	W	Controlled fan vent with barriers	Single rural residence	Undulating (between site and receptor)	Few trees, long grass	Normal wind conditions	690	0.3	0.9	0.9	1	370	804
200000	2	S	Controlled fan vent with barriers	Single rural residence	Flat	Wooded country	Normal wind conditions	690	0.3	1	0.7	1	1030	695
200000	3	SE	Controlled fan vent with barriers	Single rural residence	Flat	Wooded country	Normal wind conditions	690	0.3	1	0.7	1	926	695
200000	4	E	Controlled fan vent with barriers	Single rural residence	Flat	Wooded country	Normal wind conditions	690	0.3	1	0.7	1	1623	695
200000	5	NE	Controlled fan vent with barriers	Single rural residence	Flat	Few trees, long grass	Normal wind conditions	690	0.3	1	0.9	1	1075	893

Alternatives - receptor 1, flat terrain, separation distance 893 m

Vic Formula

Separation Distance Victorian Formula

Bird Numbers	Distance Required (calculated from separation distance formula)
200000	472

Appendix 9: Hypothetical farms - Separation distance formula calculations

(Hypothetical farms)

Hypothetical Farms Domain A – Separation distances calculated using separation distance formula and comparison with Calpuff modelling outputs

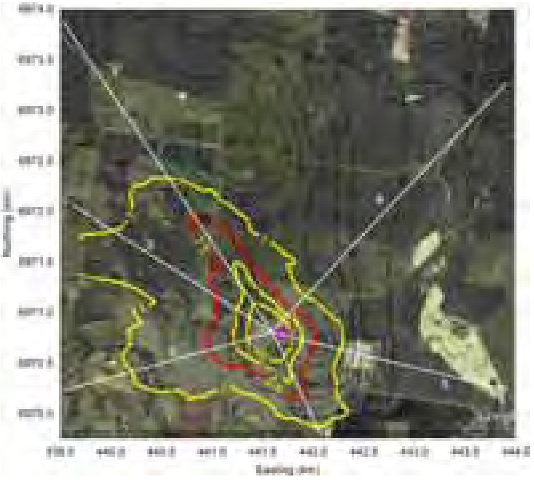
Hypothetical Broiler Farm Separation Distances – Domain A, Position [illegible]

Bird Numbers	Receptor Number	Receptor Type S2	Surface Roughness S3	Topography/Terrain S4	S1	S2	S3	S4	Distance Required (determined by S Factor)	Ambient Temperature: Distance to 2.5 OU Boundary	Ambient Temperature: Is S Factor further than the 2.5 OU Boundary	Production Temperature: Distance to 2.5 OU Boundary	Production Temperature: Is S Factor further than the 2.5 OU Boundary	Volume Source: Distance to 2.5 OU Boundary	Volume Source: Is S Factor fu than the 2.5 Boundar
175000	1	Sensitive land use	Level wooded country	Flat	1	26	0.85	1	490	1320	No	535	No	945	No
175000	2	Sensitive land use	Level wooded country	Sloping terrain (1-2%) downslope	1	26	0.85	1.5	735	630	Yes	505	Yes	690	Yes
175000	3	Sensitive land use	Long grass, few trees	Sloping terrain (1-2%) downslope	1	26	1	1.5	865	630	Yes	566	Yes	470	Yes
175000	4	Sensitive land use	Long grass, few trees	Sloping terrain (1-2%) downslope	1	26	1	1.5	865	708	Yes	504	Yes	945	No
175000	5	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	576	440	Yes	409	Yes	410	Yes
175000	6	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	576	315	Yes	283	Yes	380	Yes
350000	1	Sensitive land use	Level wooded country	Flat	1	26	0.85	1	743	1732	No	1640	No	1200	No
350000	2	Sensitive land use	Level wooded country	Sloping terrain (1-2%) downslope	1	26	0.85	1.5	1114	1670	No	725	Yes	1010	Yes
350000	3	Sensitive land use	Long grass, few trees	Sloping terrain (1-2%) downslope	1	26	1	1.5	1311	1025	Yes	787	Yes	790	Yes
350000	4	Sensitive land use	Long grass, few trees	Sloping terrain (1-2%) downslope	1	26	1	1.5	1311	1135	Yes	692	Yes	1070	Yes
350000	5	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	874	567	Yes	535	Yes	535	Yes
350000	6	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	874	503	Yes	472	Yes	520	Yes

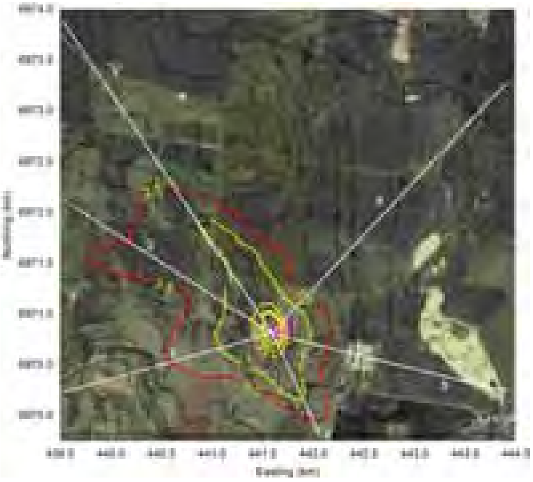
Hypothetical Broiler Farm Separation Distances – Domain A, Position [illegible]

Bird Numbers	Receptor Number	Receptor Type S2	Surface Roughness S3	Topography/Terrain S4	S1	S2	S3	S4	Distance Required (determined by S Factor)	Ambient Temperature: Distance to 2.5 OU Boundary	Ambient Temperature: Is S Factor further than the 2.5 OU Boundary	Production Temperature: Distance to 2.5 OU Boundary	Production Temperature: Is S Factor further than the 2.5 OU Boundary	Volume Source: Distance to 2.5 OU Boundary	Volume Source: Is S Factor fu than the 2.5 Boundar
175000	1	Sensitive land use	Long grass, few trees	Sloping terrain (1-2%) downslope	1	26	1	1.5	865	450	Yes	395	Yes	380	Yes
175000	2	Sensitive land use	Heavy timber	Sloping terrain (1-2%) downslope	1	26	0.77	1.5	666	415	Yes	415	Yes	360	Yes
175000	3	Sensitive land use	Level wooded country	Flat	1	26	0.85	1	490	485	Yes	450	Yes	395	Yes
175000	4	Sensitive land use	Level wooded country	Sloping terrain (1-2%) upslope	1	26	0.85	1	490	415	Yes	375	Yes	790	No
175000	5	Sensitive land use	Long grass, few trees	Sloping terrain (1-2%) upslope	1	26	1	1	576	377	Yes	470	Yes	450	Yes
175000	6	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	576	1205	No	520	Yes	880	No
350000	1	Sensitive land use	Long grass, few trees	Sloping terrain (1-2%) downslope	1	26	1	1.5	1311	720	Yes	630	Yes	540	Yes
350000	2	Sensitive land use	Heavy timber	Sloping terrain (1-2%) downslope	1	26	0.77	1.5	1009	630	Yes	610	Yes	520	Yes
350000	3	Sensitive land use	Level wooded country	Flat	1	26	0.85	1	743	720	Yes	630	Yes	630	Yes
350000	4	Sensitive land use	Level wooded country	Sloping terrain (1-2%) upslope	1	26	0.85	1	743	555	Yes	470	Yes	935	No
350000	5	Sensitive land use	Long grass, few trees	Sloping terrain (1-2%) upslope	1	26	1	1	874	555	Yes	560	Yes	540	Yes
350000	6	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	874	1490	No	1205	No	1295	No

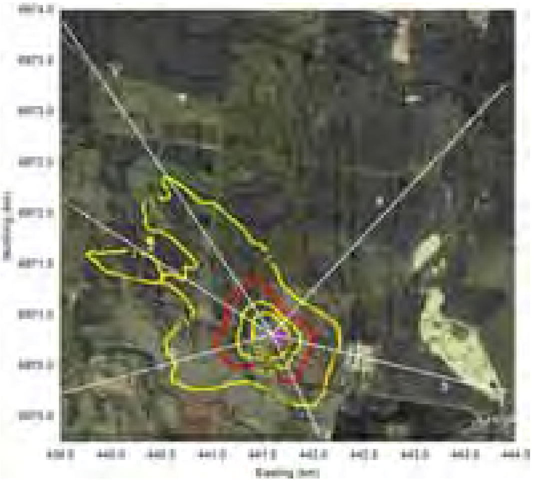
Hypothetical farms – Domain A Position 1 – graphical outputs of Calpuff predictions



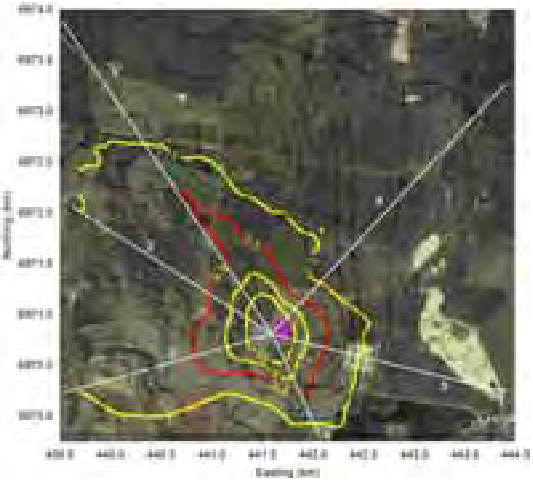
Appendix 9 Figure 1: 4 sheds ambient emission temperature



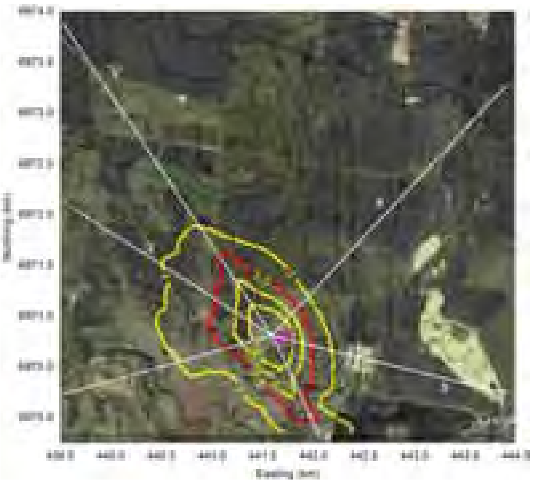
Appendix 9 Figure 2: 8 sheds ambient emission temperature



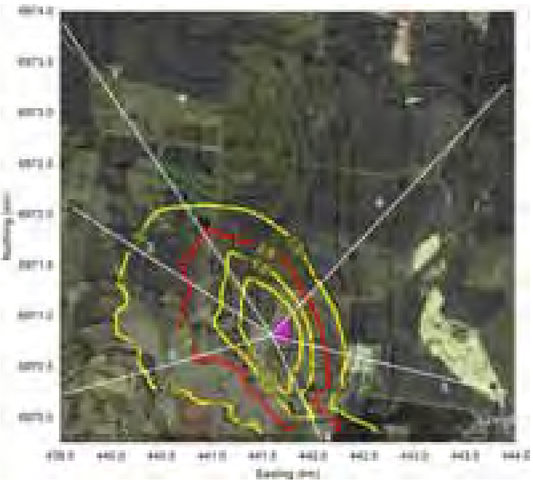
Appendix 9 Figure 3: 4 sheds production emission temperature



Appendix 9 Figure 4: 8 sheds production emission temperature



Appendix 9 Figure 5: 4 sheds volume source configuration

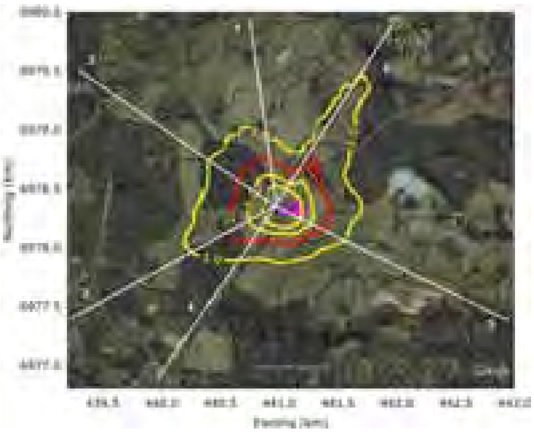


Appendix 9 Figure 6: 8 sheds volume source configuration

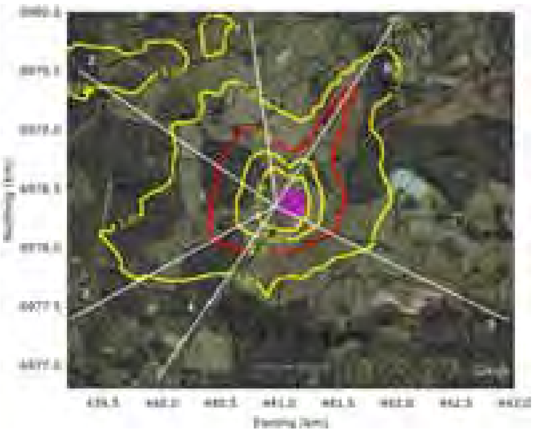
Hypothetical farms – Domain A Position 2 – graphical outputs of Calpuff predictions

Appendix 9 Figure 7: 4 sheds ambient emission temperature

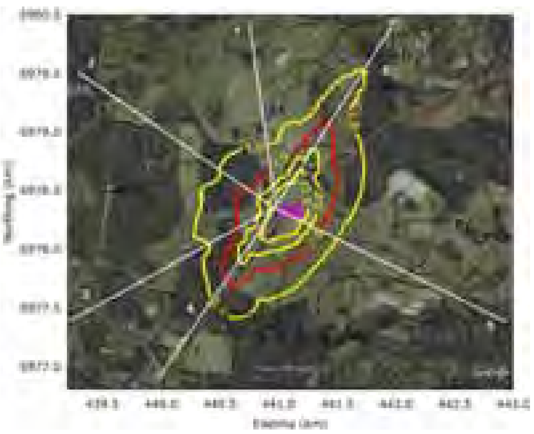
Appendix 9 Figure 8: 8 sheds ambient emission temperature



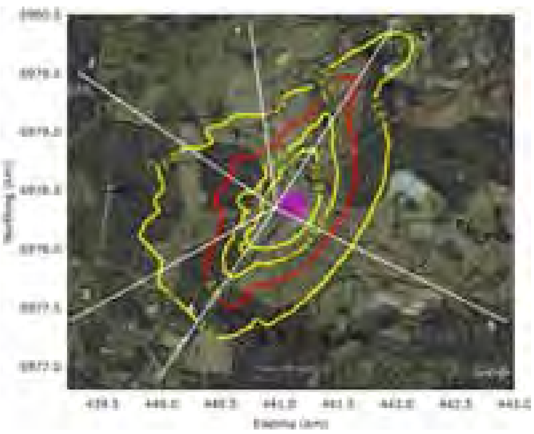
Appendix 9 Figure 9: 4 sheds production emission temperature



Appendix 9 Figure 10: 8 sheds production emission temperature



Appendix 9 Figure 11: 4 sheds volume source configuration



Appendix 9 Figure 12: 8 sheds volume source configuration

Hypothetical Farms Domain B – Separation distances calculated using separation distance formula and comparison with Calpuff modelling outputs

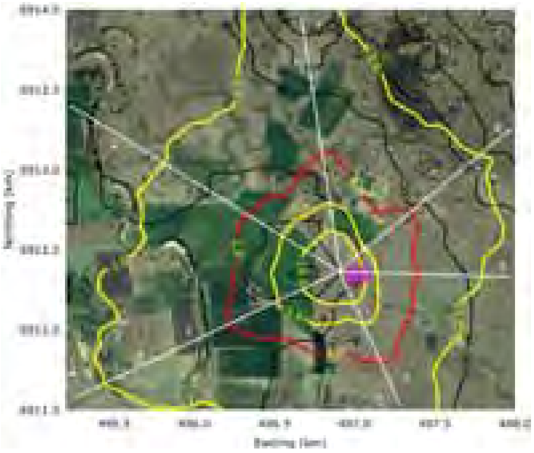
Hypothetical Broiler Farm Separation Distances - Domain B, Position 1

										Ambient Temperature		Production Temperature		Volume Source	
Bird Numbers	Receptor Number	Receptor Type S2	Surface Roughness S3	Topography/Terrain S4	S1	S2	S3	S4	Distance Required (determined by S Factor)	Distance to 2.5 OU Boundary	Is S Factor further than the 2.5 OU Boundary	Distance to 2.5 OU Boundary	Is S Factor further than the 2.5 OU Boundary	Distance to 2.5 OU Boundary	Is S Factor further than the 2.5 OU Boundary
175000	1	Sensitive land use	Long grass, few trees	Sloping terrain (1-2%) downslope	1	26	1	1.5	865	725	Yes	430	Yes	820	Yes
175000	2	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	576	635	No	410	Yes	860	No
175000	3	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	576	780	No	465	Yes	875	No
175000	4	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	576	670	No	335	Yes	931	No
175000	5	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	576	505	Yes	280	Yes	745	No
175000	6	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	576	560	Yes	225	Yes	820	No
350000	1	Sensitive land use	Long grass, few trees	Sloping terrain (1-2%) downslope	1	26	1	1.5	1311	1695	No	1770	No	1625	No
350000	2	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	874	1080	No	782	Yes	1920	No
350000	3	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	874	1190	No	690	Yes	1420	No
350000	4	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	874	1045	No	390	Yes	1120	No
350000	5	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	874	840	Yes	560	Yes	1025	No
350000	6	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	874	1005	No	465	Yes	1175	No

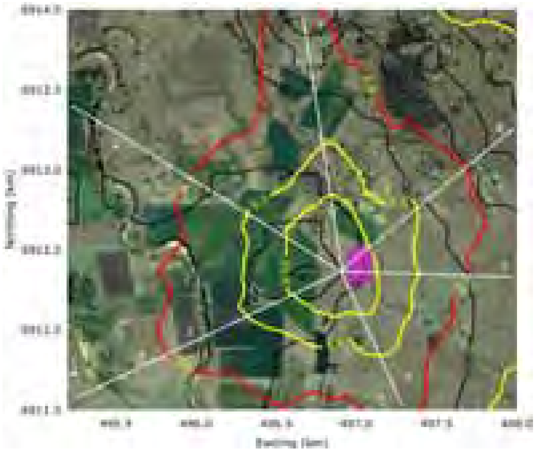
Hypothetical Broiler Farm Separation Distances - Domain B, Position 2

										Ambient Temperature		Production Temperature		Volume Source	
Bird Numbers	Receptor Number	Receptor Type S2	Surface Roughness S3	Topography/Terrain S4	S1	S2	S3	S4	Distance Required (determined by S Factor)	Distance to 2.5 OU Boundary	Is S Factor further than the 2.5 OU Boundary	Distance to 2.5 OU Boundary	Is S Factor further than the 2.5 OU Boundary	Distance to 2.5 OU Boundary	Is S Factor further than the 2.5 OU Boundary
175000	1	Sensitive land use	Long grass, few trees	Sloping terrain (1-2%) upslope	1	26	1	1	576	1000	No	900	No	975	No
175000	2	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	576	1180	No	1000	No	1155	No
175000	3	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	576	615	No	410	Yes	770	No
175000	4	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	576	820	No	565	Yes	975	No
175000	5	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	576	1285	No	1205	No	1282	No
175000	6	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	576	1205	No	1155	No	1075	No
350000	1	Sensitive land use	Long grass, few trees	Sloping terrain (1-2%) upslope	1	26	1	1	874	1845	No	1745	No	1665	No
350000	2	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	874	1720	No	1745	No	1665	No
350000	3	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	874	820	Yes	641	Yes	925	No
350000	4	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	874	1280	No	871	Yes	1230	No
350000	5	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	874	2051	No	1975	No	1925	No
350000	6	Sensitive land use	Long grass, few trees	Flat	1	26	1	1	874	1975	No	1925	No	2050	No

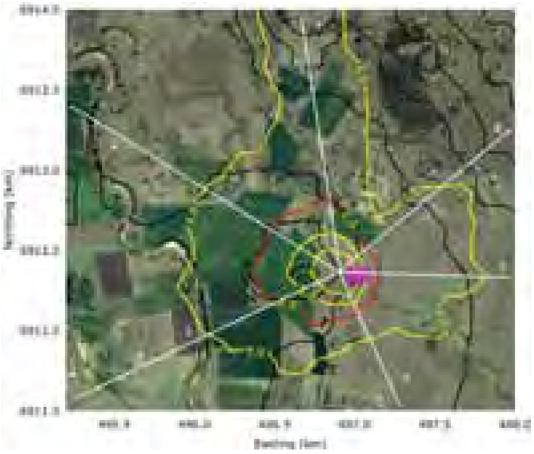
Hypothetical farms – Domain B Position 1 – graphical outputs of Calpuff predictions



Appendix 9 Figure 13: 4 sheds ambient emission temperature



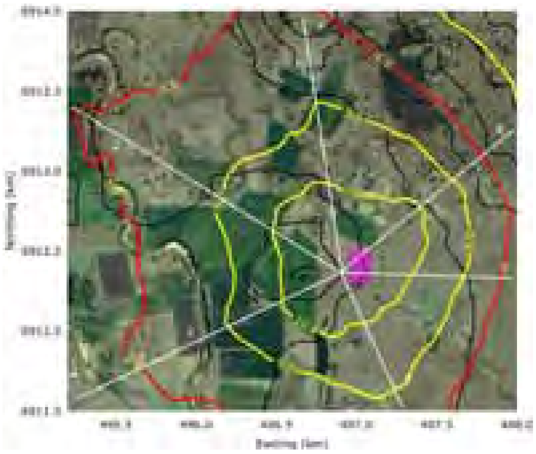
Appendix 9 Figure 14: 8 sheds ambient emission temperature



Appendix 9 Figure 15: 4 sheds production emission temperature

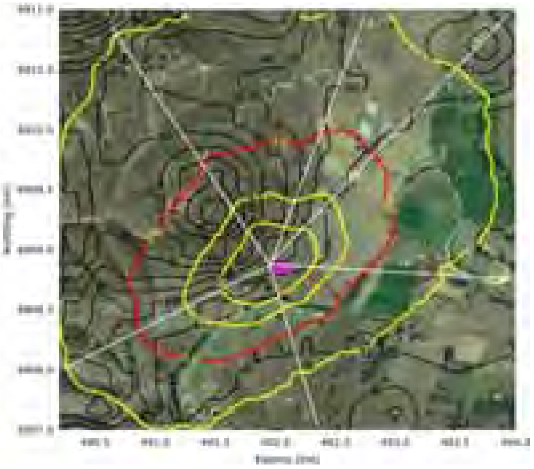
Appendix 9 Figure 16: 8 sheds production emission temperature

Appendix 9 Figure 17: 4 sheds volume source configuration

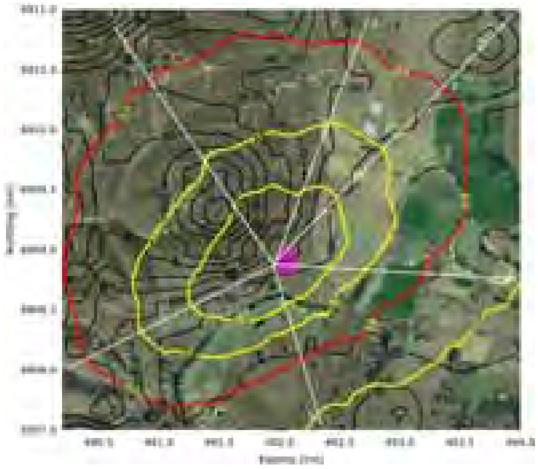


Appendix 9 Figure 18: 8 sheds volume source configuration

Hypothetical farms – Domain B Position 2 – graphical outputs of Calpuff predictions

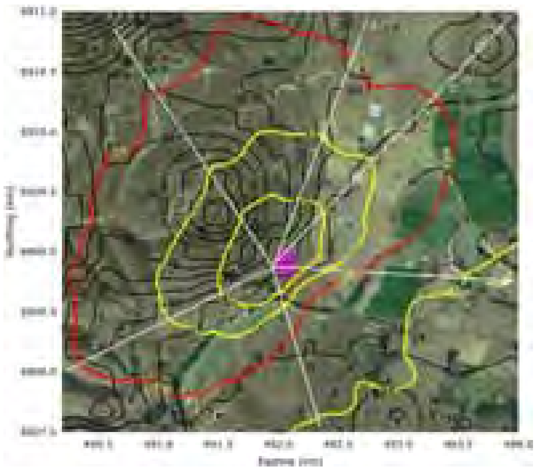


Appendix 9 Figure 19: 4 sheds ambient emission temperature

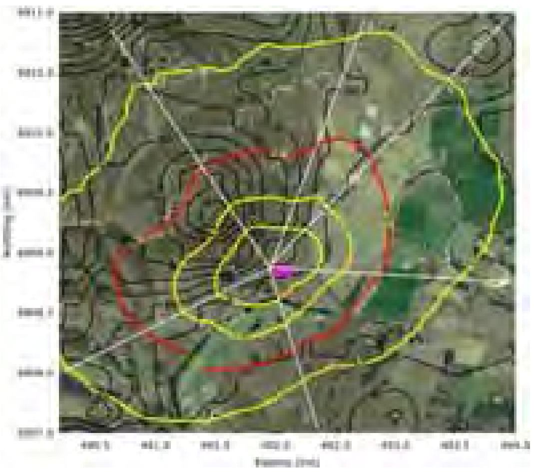


Appendix 9 Figure 20: 8 sheds ambient emission temperature

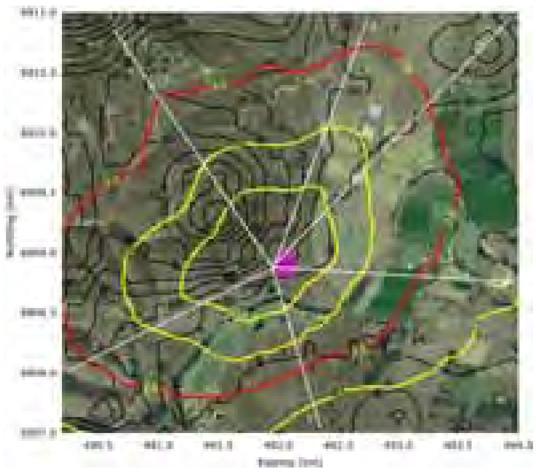
Appendix 9 Figure 21: 4 sheds production emission temperature



Appendix 9 Figure 22: 8 sheds production emission temperature



Appendix 9 Figure 23: 4 sheds volume source configuration



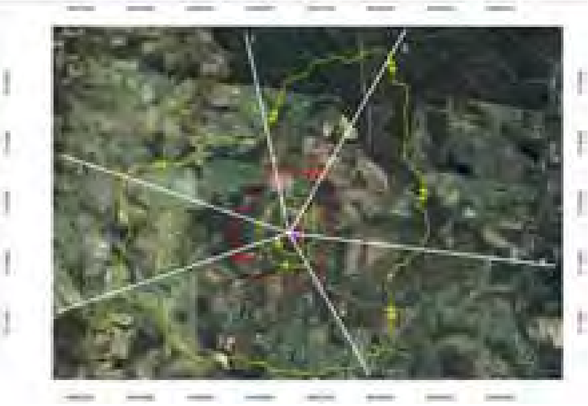
Appendix 9 Figure 24: 8 sheds volume source configuration

Hypothetical Farms Domain C – Separation distances calculated using separation distance formula and comparison with Calpuff modelling outputs

Hypothetical Broiler Farm Separation Distances - Domain C

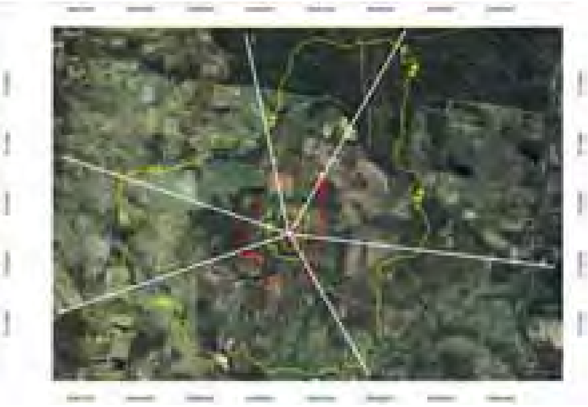
										Ambient Temperature		Production Temperature		Volume Source	
Bird Numbers	**Receptor Number**	**Receptor Type S2**	**Surface Roughness S3**	**Topography/Terrain S4**	**S1**	**S2**	**S3**	**S4**	**Distance Required (determined by S Factor)**	**Distance to 2.5 OU Boundary**	**Is S Factor further than the 2.5 OU Boundary**	**Distance to 2.5 OU Boundary**	**Is S Factor further than the 2.5 OU Boundary**	**Distance to 2.5 OU Boundary**	**Is S Factor further than the 2.5 OU Boundary**
175000	1	Sensitive land use	Level wooded country	Flat	1	26	0.85	1	490	1045	No	1080	No	185	Yes
175000	2	Sensitive land use	Heavy timber	Sloping terrain (1-2%) upslope	1	26	0.77	1	444	1005	No	1045	No	185	Yes
175000	3	Sensitive land use	Heavy timber	Sloping terrain (1-2%) upslope	1	26	0.77	1	444	1045	No	930	No	225	Yes
175000	4	Sensitive land use	Level wooded country	Flat	1	26	0.85	1	490	970	No	1005	No	205	Yes
175000	5	Sensitive land use	Level wooded country	Flat	1	26	0.85	1	490	785	No	560	No	185	Yes
175000	6	Sensitive land use	Level wooded country	Flat	1	26	0.85	1	490	1195	No	1005	No	185	Yes
350000	1	Sensitive land use	Level wooded country	Flat	1	26	0.85	1	743	1305	No	1305	No	525	Yes
350000	2	Sensitive land use	Heavy timber	Sloping terrain (1-2%) upslope	1	26	0.77	1	673	1567	No	1605	No	375	Yes
350000	3	Sensitive land use	Heavy timber	Sloping terrain (1-2%) upslope	1	26	0.77	1	673	1830	No	1790	No	375	Yes
350000	4	Sensitive land use	Level wooded country	Flat	1	26	0.85	1	743	1530	No	1380	No	305	Yes
350000	5	Sensitive land use	Level wooded country	Flat	1	26	0.85	1	743	1305	No	1120	No	225	Yes
350000	6	Sensitive land use	Level wooded country	Flat	1	26	0.85	1	743	1865	No	1565	No	450	Yes

Hypothetical farms – Domain C – graphical outputs of Calpuff predictions

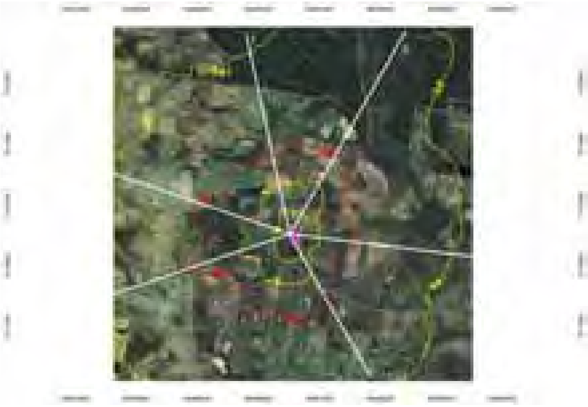


Appendix 9 Figure 25: 4 sheds ambient emission temperature

Appendix 9 Figure 26: 8 sheds ambient emission temperature

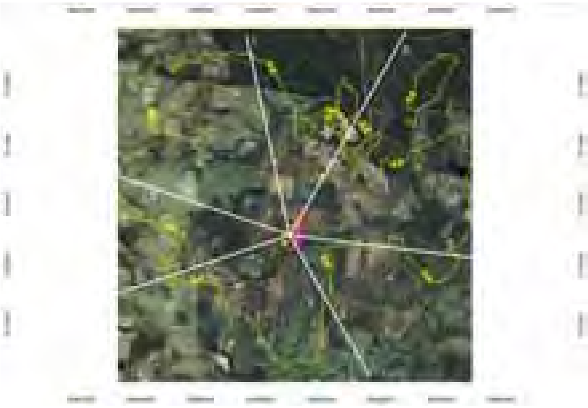


Appendix 9 Figure 27: 4 sheds production emission temperature



Appendix 9 Figure 28: 8 sheds production emission temperature

Appendix 9 Figure 29: 4 sheds volume source configuration



Appendix 9 Figure 30: 8 sheds volume source configuration

Hypothetical Farms Domain D – Separation distances calculated using separation distance formula and comparison with Calpuff modelling outputs

Hypothetical Broiler Farm Separation Distances - Domain D

Bird Numbers	Receptor Number	Receptor Type S2	Surface Roughness S3	Topography/Terrain S4	S1	S2	S3	S4	Distance Required (determined by S Factor)	Ambient Temperature: Distance to 2.5 OU Boundary	Ambient Temperature: Is S Factor further than the 2.5 OU Boundary	Production Temperature: Distance to 2.5 OU Boundary	Production Temperature: Is S Factor further than the 2.5 OU Boundary	Volume Source: Distance to 2.5 OU Boundary	Volume Source: Is S Factor further than the 2.5 OU Boundary
175000	1	Sensitive land use	Level wooded country	Flat	1	26	0.85	1	490	515	No	430	Yes	60	Yes
175000	2	Sensitive land use	Level wooded country	Sloping terrain (1-2%) upslope	1	26	0.85	1	490	371	Yes	285	Yes	60	Yes
175000	3	Sensitive land use	Level wooded country	Sloping terrain (1-2%) upslope	1	26	0.85	1	490	460	Yes	315	Yes	60	Yes
175000	4	Sensitive land use	Level wooded country	Sloping terrain (1-2%) upslope	1	26	0.85	1	490	540	No	371	Yes	285	Yes
175000	5	Sensitive land use	Level wooded country	Flat	1	26	0.85	1	490	400	Yes	315	Yes	285	Yes
175000	6	Sensitive land use	Level wooded country	Flat	1	26	0.85	1	490	485	Yes	460	Yes	315	Yes
350000	1	Sensitive land use	Level wooded country	Flat	1	26	0.85	1	743	660	Yes	515	Yes	457	Yes
350000	2	Sensitive land use	Level wooded country	Sloping terrain (1-2%) upslope	1	26	0.85	1	743	485	Yes	485	Yes	455	Yes
350000	3	Sensitive land use	Level wooded country	Sloping terrain (1-2%) upslope	1	26	0.85	1	743	828	No	600	Yes	660	Yes
350000	4	Sensitive land use	Level wooded country	Sloping terrain (1-2%) upslope	1	26	0.85	1	743	660	Yes	660	Yes	742	Yes
350000	5	Sensitive land use	Level wooded country	Flat	1	26	0.85	1	743	715	Yes	630	Yes	742	Yes
350000	6	Sensitive land use	Level wooded country	Flat	1	26	0.85	1	743	630	Yes	571	Yes	685	Yes

Hypothetical farms – Domain D – graphical outputs of Calpuff predictions

Appendix 9 Figure 31: 4 sheds ambient emission temperature

Appendix 9 Figure 32: 8 sheds ambient emission temperature

Appendix 9 Figure 33: 4 sheds production emission temperature

Appendix 9 Figure 34: 8 sheds production emission temperature

Appendix 9 Figure 35: 4 sheds volume source configuration

Appendix 9 Figure 36: 8 sheds volume source configuration

Separation Distances for Broiler Farms

— Verifying methods and investigating the effects of thermal buoyancy —

by Mark Dunlop, David Duperouzel and Lyle Pott

Publication No. 10/073

Meat chicken farms are often built close to feed supply and meat processing infrastructure, with associated markets and labour force. Positioning poultry farms close to essential infrastructure usually means that the farms are also close to urban and rural-residential developments.

Close proximity of neighbours to poultry farms can result in adverse impacts, primarily due to odour. Odour impacts are recognised as an issue by the Australian chicken meat industry and are most effectively minimised through the provision of adequate separation distance between farms and neighbours, which allows odour dispersion.

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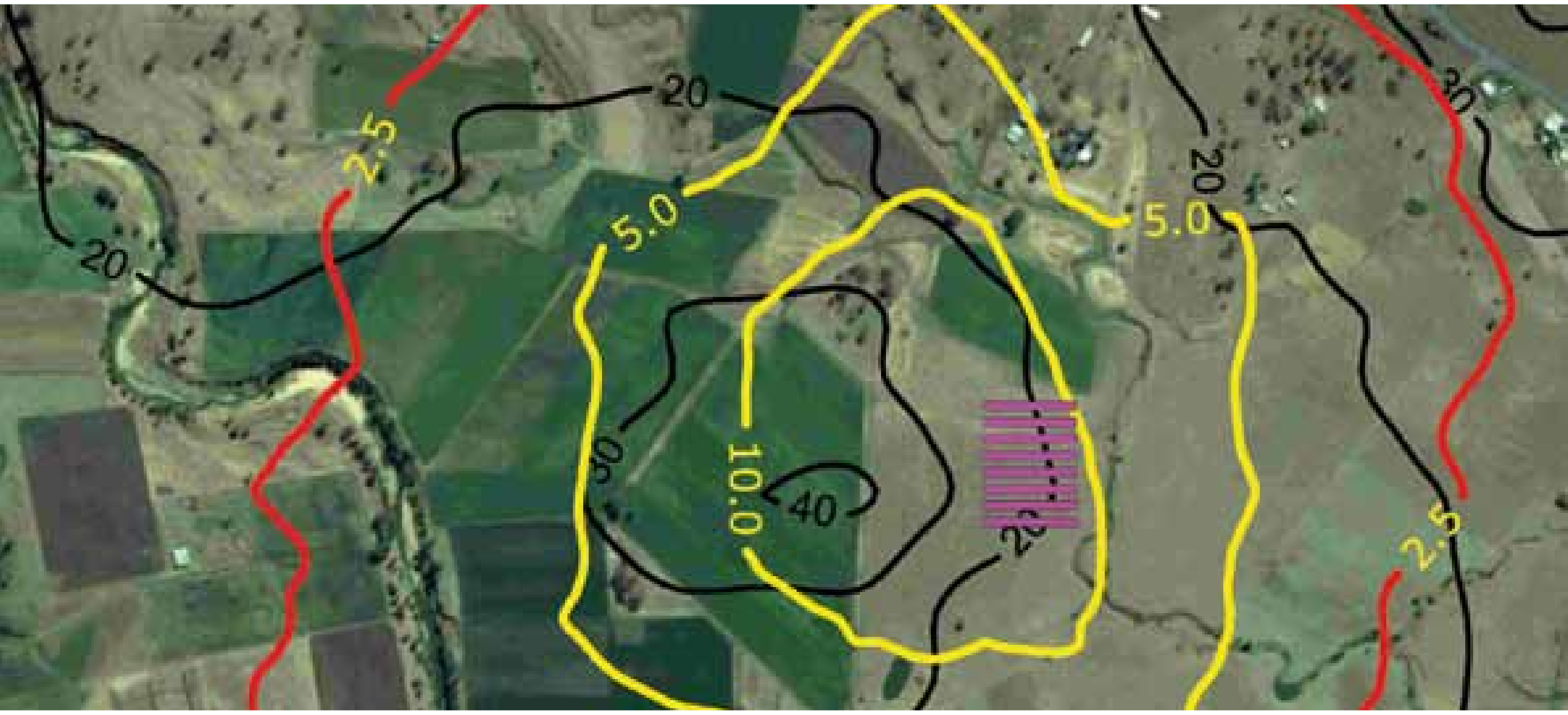

Cover photo: Hypothetical farm in a broiler growing area south oif Brisbane, including terrain contours; odour contours (modelled with 175,000 birds with ambient emission temperature) using Qld odour guidelines; and the six transects for application of the separation distance formula

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