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Environmental Impact Assessment of Biomass Power Station WA in terms of Noise Impacts

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ABSTRACT

An environmental impact assessment was conducted for a Biomass Power Station to be situated near a rural township. The proposed facility is to consist of a plantation waste fuelled bubbling fluidized bed boiler with emissions control achieved through an array of baghouse fabric filters to generate 40 MW of power.. This paper will describe the motivation and sustainability characteristics of this renewable energy infrastructure development and the veracity of the use of TAPM version 3 and version 4 (The Air Pollution Model, prognostic numerical model developed by the CSIRO) generated meteorological data to assist in the prediction of noise propagation using standard models that account for meteorological effects on outdoor noise propogation.

INTRODUCTION

A 40MW baseload Biomass Power Station (BPS) is proposed for a site 10 km south of the township of Manjimup in South West Western Australia (WA) by the proponents of the project Western Australia Biomass Pty Ltd. The direct fired design fuel for this power plant is plantation waste sourced from plantation forests near the proposed site. Connell Wagner was engaged by the proponents to perform the Environmental Impact Assessment. The Public Environmental Review (PER) included a detailed study of the noise and air quality impact of the proposed facility. Following the submission of the PER more specialist studies were initiated to study the risk of adverse air quality impacts on two major local industries (viticulture and horticulture) and human health. The sustainable characteristics of the Biomass Power Station and the reason for it being granted renewable status are discussed preliminarily.

The primary aim of the paper is to study the veracity of the use of meteorological data generated by the TAPM prognostic numerical model to determine meteorological effects for an environmental noise assessment. The TAPM prognostic meteorological model developed by the Centre for Marine and Atmospheric Research of the CSIRO was used to generate the meteorological dataset. The latest release of TAPM is version 3 (v3), this is due to be followed by the release of v4 this year. Preliminary guidance regarding the veracity of the meteorological dataset generated by v4 from the developers (Hurley, 2007) for the Kwinana region of WA is discussed. Given this version has not yet been publicly released a detailed assessment of the difference between the datasets generated by TAPM v3 and v4 could not be made. The assessment thus draws on the assumption that given all other things remains equal, the same trends noted for the Kwinana study should hold for other regions such as that being considered. The impact of the new version of TAPM on the assessment of meteorological effects on environmental noise propagation is the primary consideration of this assessment.

SUSTAINABILITY

The use of renewable sources of fuel for power generation is essential to starve social dependence on fossil fuels for electricity. The Federal Government requires wholesale purchasers of baseload power to be able to meet the Mandatory Renewable Energy Target (MRET) of 9,500 GWh by 2010. The Western Australia State Government has set a target for 15% of electricity on Western Australia's main South West electricity grid to come from renewable energy sources by 2020. A Biomass Power Station in South West (SW) Western Australia therefore furthers the attainment of this goal.

Biomass is inherently a renewable source of energy, the combustion of which in a boiler for electrical throughput has proven to be a greenhouse neutral activity given the realisation of certain economies of scale. The proposed plant achieves these economies of scale, given its size, and the fact that the fuel source is close to the plant. This is as carbon emissions from the fossil fuelled transportation of the green fuel are able to be offset by the electricity generated due to the proximity of the fuel source to the power station. Apart from the general sustainability characteristics of biomass power plants, the development of this plant in SW WA is particularly advantageous given:

- the current practice of open uncontrolled combustion of plantation waste leading to high air emissions of noxious organic and in-organic air pollutants;

- uncontrolled combustion of plantation waste in the open limits the potential for carbon dioxide emissions from this combustion to be offset by the generation of electricity;

- the decomposition of combustible organic matter in the open is a large source of greenhouse gas emissions in the form of methane; which has 23 times the global warming potential of CO_2 over a 100 year time horizon.

The Garnaut Report has identified that Biomass is an important fuel source that should be part of a strategy in being able to achieve the MRET. The implementation of an emissions trading scheme will allow for electricity generated by this means to become more feasible and economically competitive.

The potential scarcity of existing infrastructure to allow for the decentralisation of new infrastructure was a concern that the Garnaut report raised. However, the Biomass Power Station will be able to easily access existing system in the area. Therefore the presence of existing infrastructure leads to lower costs of entry into the renewable energy market in this region. The Biomass Power Station was given renewable status by the Australian Greenhouse Office.

METEOROLOGY

Meteorological Effects

The definition of the effects of meteorology on outdoor noise propagation is best understood through the analysis of vertical temperature gradient and wind speed profile which are the primary determinants of the curvature of sound waves through the atmosphere. A temperature gradient that leads to an increase in temperature with height above ground level (AGL) results in sound waves being refracted downwards, resulting in increased sound pressure levels close to the ground. Positive vertical wind speed gradients that blow from source to receiver results in an equivalent acoustic effect. On the contrary wind speeds blowing from the receiver to the source have the opposite effect and result in reduced noise levels at the receiver.

Typically stability classes and temperature inversions are predicted based on datasets such as that published by the NSW DECC in its Industrial Noise Policy (Appendix E) for the Hunter region and other empirical equations and tables including those published by Bies and Hansen (2003).

The modelling of site specific meteorology is therefore advantageous when assessing meteorological effects on environmental noise propagation. Complex parameters including variables such as stability class and vertical temperature (dT/dz) and wind speed gradients (dw/dz) can be easily predicted in a three dimensional gridded modelling domain within a meteorological model. Upper air meteorology and stability class parameters can also be determined at any point within the modelling domain.

The alternative to quantifying upper air meteorological information data by modelling is to deploy a weather balloon. This is not feasible as the Bureau of Meteorology only deploys weather balloons at major regional meteorological stations diurnally. Therefore the probability of the availability of site specific upper air information is very low. The advantages of a prognostic meteorological model that predicts these parameters on a spatially and temporally varying basis are therefore obvious. A description and evaluation of the veracity of the CSIRO developed prognostic meteorological model, "The Air Pollution Model" and the forthcoming release of version 4 of the code follows.

THE AIR POLLUTION MODEL

The Air Pollution Model (TAPM), a prognostic meteorological model was used to account for complex terrain effects in the study area and to pre-process synoptic analyses into spatially varying hourly meteorological data. TAPM produces meteorological data, upper air information and temperature profiles for a simulation period in three dimensions for all the grid points across the modelling domain by solving the Navier-Stokes equations.

The Navier-Stokes equations are a set of nonlinear partial differential equations (pde) that treat incompressible flow. They describe the motion of viscous fluids. The vector form of the equation is given below. The left hand side of the equation explains the interia of the fluid flow by its acceleration and convective acceleration; which equates to the pressure gradient, viscous and other forces.

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v}\cdot\nabla\mathbf{v}\right) = -\nabla p + \mu\nabla^2\mathbf{v} + \mathbf{f}$$

This synoptic information analyses are the initial conditions for the Navier-Stokes pde's which are solved to yield the final three dimensional gridded meteorological data. This information is representative of local topography, land use, surface roughness and temperature effects caused by water bodies.

The resolution of the default land use and terrain data is low. This in some instances may lead to the generation of erroneous results for near field assessments regions with large undulating terrain features that could lead to wind channelling over short distances. The model allows the user to edit the default land use and terrain data within the graphic user interface as well as input higher resolution digital elevation models and land use data to better account for terrain and surface roughness effects.

The TAPM nesting grid (mesh) was determined for this model via consideration of the required terrain resolution within the radius of influence (approximately five kilometres). The required terrain resolution was achieved via use of a nested grid with a minimum spacing of 600 metres which reflects the gentle, rolling gradient of the local topography.

Table 1 TAPM configuration parameters
Source: Connell Wagner, 2008

Reference Year	2001*
Grid	41 x 41 x 25 (nx x ny x nz)
Nesting	20 – 5 – 1.8 – 0.6 km

* evaluation of TAPM meteorological data was conducted using 2002 observed dataset given missing hours in 2001 data.

The following sub-sections evaluate the improvements made in the turbulence and land use schemes in TAPM v4 to improve the predictions of wind speed magnitude and directionality through stable atmospheric conditions. The model's ability to predict wind speed is evaluated through the comparison of wind roses and the frequency distribution of wind speeds. The observed wind speeds from the nearest site-representative Bureau of Meteorology weather station are used as the comparative dataset. The veracity of the model's predictions of temperature inversions and atmospheric stability is evaluated through time and wind speed dependant stability class frequency distributions and concurrence of these distributions with what is expected from theoretical understanding of the atmosphere.

TAPM v4

There is some conjecture regarding the ability of the current version (v3) of TAPM to predict a sufficient frequency of calm wind speeds through stable meteorological conditions at 10 m AGL, when running the model with the default parameters. The modification of the default land use data and inclusion of observed assimilation data from the various BoM automatic weather stations in proximity to the study area has previously been shown to improve the agreement between modelled and observed datasets in some cases.

The CSIRO Centre for Marine and Atmospheric Research has demonstrated the resolution of these issues in the forthcoming release of TAPM v4 (Hurley, 2007). This version has a new land surface scheme (LSS) which takes into account variations in soil types, soil moisture content, soil surface temperatures and leaf area index. The leaf area index is the ratio of the total upper leaf vegetation surface area and the surface area of the land on which the vegetation grows. The new land surface scheme allows the soil temperature and moisture content to vary with time and changes in rainfall, solar radiation and bio-chemical processes from interaction with vegetation. TAPM v3 on the other hand approached soil analysis from a less rigorous approach with fewer soil types and a different turbulence scheme.

The following statements can be made following the comparison of the v4 and v3 modelled meteorological dataset with observed data for Kwinana, WA (Hurley, 2007).

- Coastal dispersion (AGL 10 m):
  - v4 modelled mean wind speeds are below the v3 modelled and observed means;
  - v4 modelled standard deviation of wind speeds and temperatures are below the v3 modelled and observed standard deviations;
  - the v4 modelled root mean square error is lower than that calculated based on the v3 results.

A complete explicit evaluation of the modelled results using v4 for the Manjimup region was not possible given t. Therefore the above trends were assumed to occur in other regions. This assumption is considered reasonable, as the issue of the under prediction of the frequency of low wind speeds was raised by numerous air quality consultants around Australia. Hurley (2007) has been able to demonstrate that the new version of TAPM performs better than v3 for a number of annual meteorological verification datasets both in Australia and regions of the UK, Netherlands and the USA.

EVALUATION OF THE METEOROLOGICAL PREDICTIONS OF TAPM V3 IN SW WA

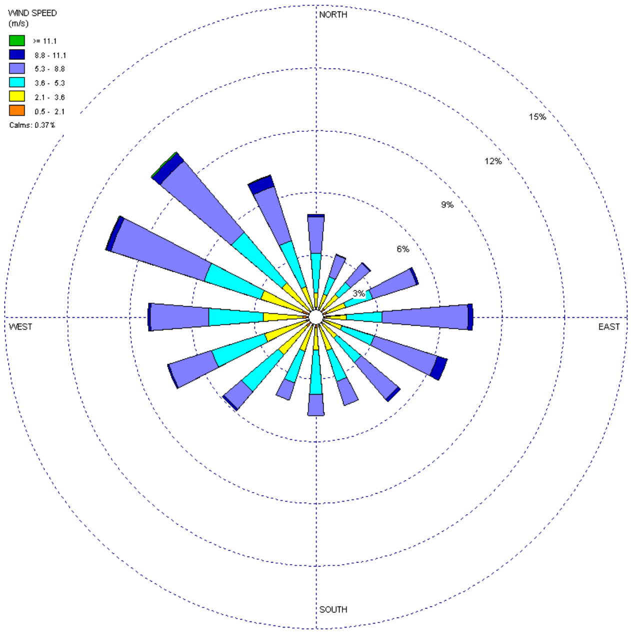
Wind Speed

The ability of TAPM v3 to accurately predict wind speed (modelled for 2002) is evaluated through the comparison of observed and modelled wind roses. The modelled year, 2002 was selected for evaluative purposes as there were a large number of missing hours through the 2001 Manjimup AWS observed dataset. The meteorological model was run with the configuration parameters outlined in Table 1.

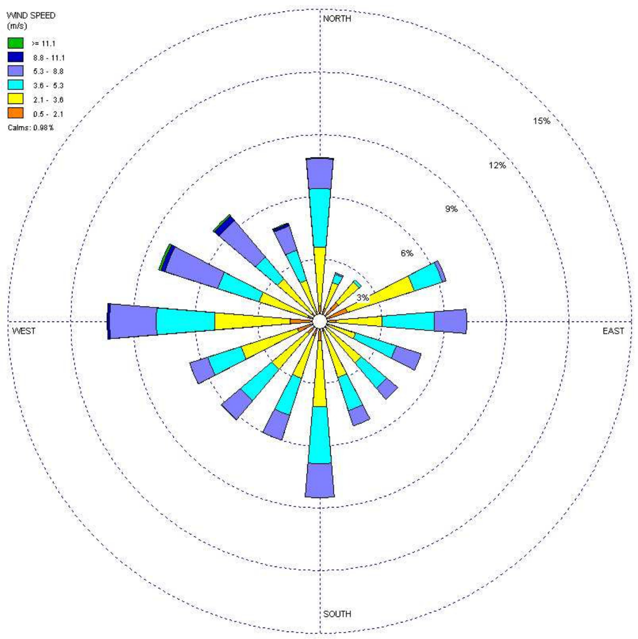
The TAPM generated wind rose and the contemporaneous observed roses are shown in Figure 1 (a) and (b) respectively. The predicted and observed wind roses show the frequency of wind speeds in a given direction and the magnitude as well as frequency of the wind speeds. The assessment of the predicted conditions against that observed demonstrates that prevailing wind speeds blow from all directions except the north east quadrant. There is a reasonable level of correlation between the modelled and observed conditions. However TAPM tends to under predict the frequency of calm conditions and over predict the frequency of wind speeds blowing from the North West.

It is important to note that BoM monitored wind speeds are generally based on data recorded over the last 15 min of every hour. This methodology is not compliant with Australian Standards and could potentially lead to inaccuracies in the observed data. Furthermore, the high stall speed on the BoM anemometers results in the data being skewed towards low wind speeds. The use of meteorological data, in particular wind speeds observed at EPA air monitoring stations are generally considered to be more accurate. This is because they follow the Australian Standards stipulated for the monitoring of wind speed; i.e. have lower stall settings and more importantly monitor over an entire hour to determine the hourly average wind speeds.

(a)



(b)



Source: (Connell Wagner, 2008)

Figure 1 Site specific 2002 - annual wind rose (a) TAPM modelled and (b) observed BoM.

The modelled and observed wind class frequency distributions are shown in Figure 2. The frequency distribution shows that TAPM tends to under predict calm conditions and over predict the frequency of high wind speeds. These are all general traits of what was common with TAPM v3.

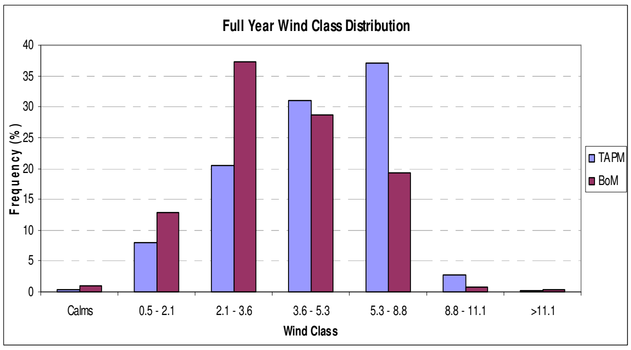


Figure 2 Comparison of BoM monitored and TAPM predicted wind class frequency distributions.

A statistical analysis of the predicted and observed datasets shows that the predicted average and standard deviations are higher than they are for the observed dataset. The analysis of the results from the meteorological simulation at Kwinana using TAPM v4 indicate that the results likely to be observed from the more detailed land surface scheme in v4 for Manjimup will result in $P_{avg} < O_{avg}$ and $P_{std} < O_{std}$.

Nevertheless, the root mean square error and index of agreement statistics (Table 2) demonstrate very good correlation between the observed and predicted conditions. An index of agreement (IOA) of 1.0 indicates perfect correlation and an IOA of 0.5 is generally considered to be a good benchmark to attain. The root mean square error is also within the bounds of acceptability given the level that was achieved for the simulation by P. Zawar-Reza et al. (2005) and Hurley (2007) for Kwinana.

Table 2 Statistics of the TAPM simulation for Manjimup, WA.

$\mathbf{P_{avg}}$	4.78
$\mathbf{O_{avg}}$	4.05
$\mathbf{P_{std}}$	1.93
$\mathbf{O_{std}}$	1.75
IOA	0.93
RMSE	1.61

O – Observed
P – Predicted
IOA – Index of agreement
RMSE – Root mean square error

Applying the trends from the comparison of the results from v4 to v3 and that observed it can be said that the predicted annual average wind conditions using TAPM v4 in any one area are likely to be lower that that predicted by v3. The meteorological effects on noise transmission cannot be considered based on wind speed data alone.

Atmospheric Stability

The degree of stability in the atmosphere is determined by the temperature difference between an "air parcel" and the air surrounding it. This difference can cause the "air parcel" to move vertically. The movement is characterised by four basic conditions that describe the general stability of the atmosphere. In stable conditions, vertical movement is inhibited, whereas in unstable conditions the "air parcel" tends to move upward or downward and continue that movement. When conditions neither encourage nor discourage that movement beyond the rate of adiabatic heating or cooling they are considered neutral. When conditions are extremely stable, cooler air near the surface is trapped by a layer of warmer air above it; this condition is known as a temperature inversion and results in virtually no vertical air motion.

The Pasquill-Gifford (P-G) stability category scheme is generally used to describe the degree of stability in the atmosphere. Stability classes under the P-G scheme are designated a letter from A-F (and sometimes G). The categories range from highly unstable (A) to extremely stable (G). Category A represents a strong lapse condition where there is a large temperature decrease with height whereas Category G represents a temperature inversion where temperature increases with height, such events maybe observed early on a clear morning, during calm conditions.

There are a number of methods for determining stability classes, with Turner's method being the most common. This method estimates the effects of net radiation on stability from solar altitude, total cloud cover and ceiling height. The stability class frequency distribution is estimated as a function of wind speed and is shown in Figure 3. The predicted data shows that neutral-stable conditions are dominant through conditions when wind speeds are greater than approximately 3.0 m/s (at 25 m AGL) in magnitude. The predicted distribution of atmospheric stability with wind speed is typical of that expected based on the principle of movement of air within the planetary boundary layer.

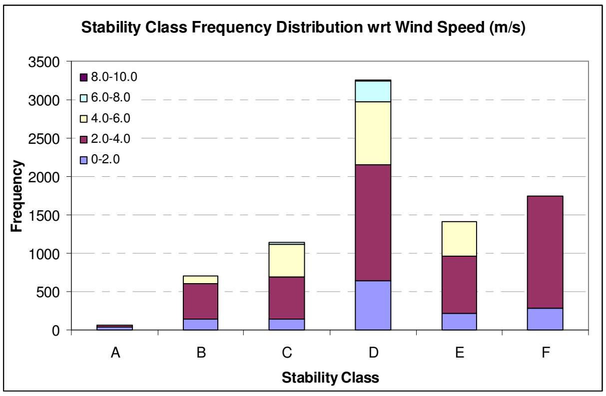


Figure 3 Stability class frequency distribution with respect to wind speed.

The frequency distribution of stability class with time of day is shown in Figure 4. Neutral and stable classes are observed through the night time, as expected. Throughout the day however the stability class shifts from neutral-stable to neutral-unstable due to the convective nature of the boundary layer. The convection arises from the solar irradiation of the earth's surface, resulting in enhanced mixing.

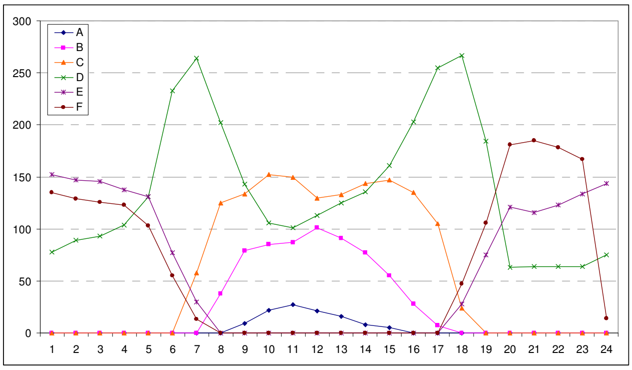


Figure 4 Stability class frequency distribution with respect to the hour of day.

The wind speed-stability class frequency distribution as well as the temporal-stability class frequency distribution must be assessed in conjunction with the stability class rose (Figure 5) and the location of the nearest noise sensitive receiver relative to the noise source. This information can then be used to determine the most realistic average level of meteorological attenuation that the receiver is likely to receive through any given year. This will identify the frequency and extent of the worse case noise propagation meteorological conditions that will occur at each sensitive noise receiver.

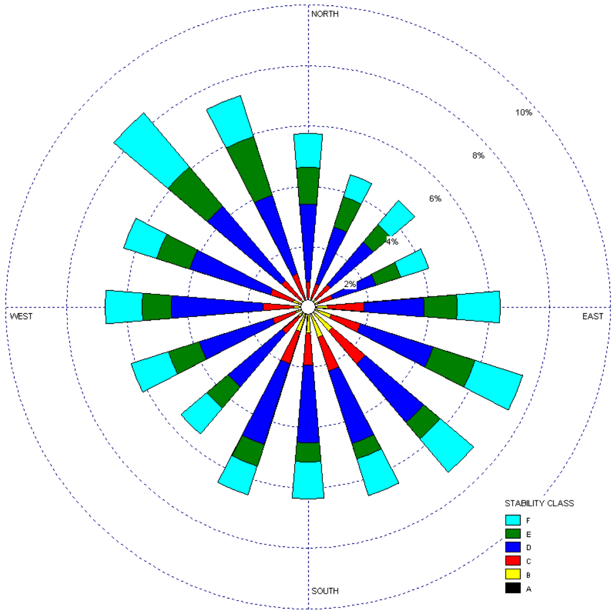


Figure 5 Stability class rose.

Impact of TAPM v4

The prediction of lower average wind speeds by TAPM v4 is likely to lead to the prevalence of a higher frequency of neutral to stable conditions that correspond to low wind speeds and calm conditions especially at night time. The primary issue of conjecture with TAPM v3 was with regards to its inability to predict a sufficient frequency of calm wind speeds at ground level through stable atmospheric conditions.

The prediction of a higher frequency of calm conditions during stable atmospheric conditions might lead to the selection of meteorological category four or five under the CONCAWE methodology as opposed to the worst case category six (Bies and Hansen, 2003). This might lead to a reduction in the level of conservatism in environmental noise assessments for some regions around Australia. This is as CONCAWE meteorological category six is generally selected uniformly as the worst case as was the case for the noise assessment for this project even with the use of TAPM generated meteorological data.

The use of the improved turbulence and land surface schemes in TAPM v4 has been shown by Hurley (2007) to lead to greater accuracy in predicted meteorological data. Thus the assessor can have greater confidence in using the data generated through this scheme to come to a conclusion on the worst case meteorological effects through a particular project area, than he or she would have had with meteorological data predicted through the v3 scheme. A corollary to the above is the exclusion of overt conservatism in noise assessments through the informed, confident selection of non-worst case CONCAWE meteorological categories.

WIDER USE OF TAPM

The advantages of the use of TAPM generated meteorological data have been demonstrated. An assessor can have confidence in analysing meteorological effects based on TAPM meteorological data given the accuracy of the model predictions in relation to observed wind speeds and the expected distribution of wind speed and stability class with the time of day, given knowledge of the movement of air within the planetary boundary layer. The CSIRO has also demonstrated that the accuracy in TAPM's predictions have been further improved with the release of TAPM v4 this year.

The increasing use of TAPM generated meteorological datasets by non air quality professionals will require the development of more informed standards and regulations to enable standardised procedures that direct the setup and interpretation of meteorological models. The development of a finite element outdoor noise propagation tool that is embedded with TAPM v4 will further enhance the veracity of environmental noise assessments. It is hoped that given sufficient funding this tool can be developed in conjunction with the Centre for Marine and Atmospheric Research of the CSIRO and in collaboration with all relevant stakeholders.

It is believed that the procurement of fewer overtly conservative and more accurate environmental noise impact assessments a minimisation of capital expenditure costs borne by proponents of major infrastructure projects to satisfy environmental noise guidelines would result. The development of such a tool will allow for environmental approvals to be expedited given the decreased probability of conjecture regarding modelling techniques.

CONCLUSION

This paper has analysed the use of TAPM generated meteorological data for environmental noise assessments in terms of the impact of the new land surface and turbulence scheme released with v4 of the prognostic meteorological and air dispersion model. The meteorological data generated by TAPM v3 for an environmental noise assessment of a proposed Biomass Power Station was used as a base to enable a comparison of the modelled results with that observed at the nearest representative weather station. Although an explicit assessment involving the generation of contemporaneous meteorological data for this region with TAPM v4 was not possible due to a delay in the release of the software by CSIRO, an implicit assessment was conducted following the qualification of assumptions.

The primary conclusion that can be drawn from the comparison of the performance of TAPM v3 and TAPM v4 is that the average and standard deviation of wind speeds predicted by the latest release are lower. Furthermore assessors can be more confident in their assessment of meteorological effects using TAPM v4 modelled wind speed and atmospheric stability data, given lower root mean square errors and higher indices of agreement between modelled and observed data. Therefore it is believed that the use of TAPM modelled meteorological data to determine meteorological effects on noise propagation may lead to the avoidance of overt conservatism in environmental noise assessments.

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