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THE EFFECT OF METEOROLOGY AND TERRAIN ON NOISE PPROPAGATION - COMPARISON OF FIVE MODELLING METHODOLOGIES

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1. Introduction

Meteorological conditions can have important effects on noise propagation. For relatively short source-receiver distances, these effects are small and generally ignored, as a conservative assumption. However, when considering noise impacts from large industrial complexes, such as petrochemical facilities and electrical power plants, the potential impact zone and corresponding source-receiver distances can be quite large (>2 km). Not including meteorological and terrain effects can result in severe over- or underestimations of off-site sound levels, affecting mitigation requirements and project costs.

This paper illustrates the effects of these parameters (and of model selection) on predicted noise levels, by comparing modelling results from five calculation algorithms, including basic modelling (considering distance attenuation and barrier effects only), basic modelling including atmospheric attenuation, ISO-9613 [1,2], ISO-9613 with CONCAWE meteorological effects [3,4], and the Environmental Noise Model (ENM) [5]. A quick review of meteorological conditions affecting noise propagation is given. A comparison is made between the five techniques based on a modelled electrical power plant. Finally, the effect of meteorological conditions on hourly sound levels throughout the day is illustrated.

2. Review of Meteorology and Terrain Parameters that Affect Sound Propagation

The meteorological and terrain parameters which affect sound propagation can be broken down into four main categories including temperature effects, wind effects, air absorption, and ground effects. When these are combined with the effects of geometric spreading, barriers, and other shielding factors, a detailed prediction of environmental noise impacts can be made.

2.1 Temperature Effects

Atmospheric temperature gradients in the air can refract sound waves either towards or away from the ground. These temperature gradients are termed the "lapse rate". A positive lapse rate indicates that temperature is increasing with height - also known as an atmospheric thermal "inversion". Because sound velocity increases with increasing temperature, under normal negative temperature gradient conditions, sound waves are diverted away from the ground, creating a sound "shadow zone". Under inversion conditions, sound waves are diverted towards the ground, increasing sound levels. This effect is shown schematically in Figure 1 [1].

Atmospheric lapse rates are inherently incorporated into Pasquill-Gifford (P-G) Stability Classes, which are widely used in air pollution dispersion modelling. As such, this information is generally available directly from most meteorological services, such as Environment Canada. These values can also be estimated based on available weather data for the area or direct measurements. Experienced meteorologists or firms specializing in atmospheric dispersion modelling can provide assistance. Table 1 presents the ranges of allowable wind speeds and lapse rates versus stability classes [4,6].

2.2 Wind Effects

Wind and sound velocities are direction dependant and additive. As a result, sound propagation is faster with the wind, and slower against the wind. Wind speeds vary with height, due to the friction effects of the earth's surface. The result-

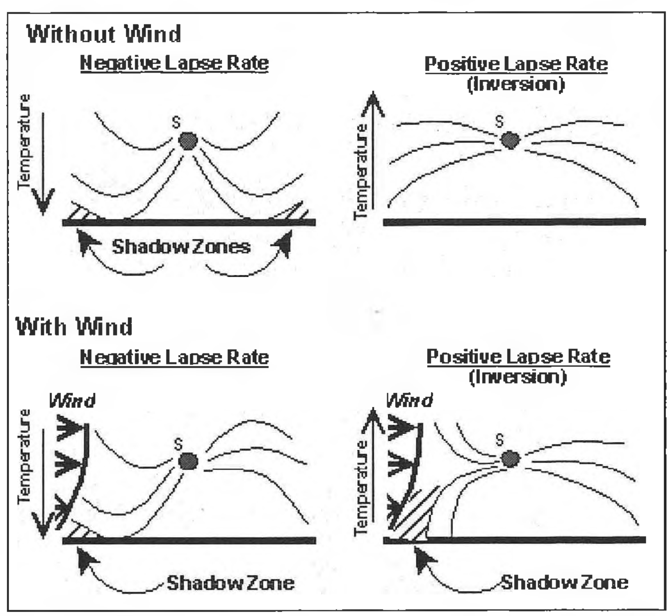

Figure 1: Schematic representation of the effects of air temperature gradients and wind on sound propagation [1].

Table 1: Pasquill-Gifford (P-G) Stability Classes Based on Lapse Rates and Wind Speeds [4,6]

Stability Class	Range of Vertical Temperature Gradient (°C/100m)	Range of Allowable Wind Speeds	
		(m/s)	(km/h)
A (1)	< -1.9	≤ 3	≤ 11
B (2)	-1.9 to -1.7	≤ 5	≤ 18
C (3)	-1.7 to -1.5	≥ 2	≥ 7
D (4)	-1.5 to -0.5	≥ 3	≥ 11
E (5)	-0.5 to 1.5	≤ 5	≤ 18
F (6)	1.5 to 4 0	≤ 2	≤ 7
G (7)	> 4.0	≤ 2	≤ 7

ing variation in sound propagation speed with height and direction creates a sound shadow zone. Sound level attenuations of up to 30 dB are possible [5]. Wind effects are illustrated in Figure 1. Note that sound propagating in the direction of the wind is bent back towards the earth. This can reduce or completely eliminate any barrier attenuation

Most advanced noise propagation algorithms, including the CONCAWE and ENM models, assume that temperature and wind effects are additive (see Figure 1) [4,5].

2.3 Air Absorption

Atmospheric absorption results from the absorption of sound energy by molecules making up the air – most notably nitrogen, oxygen, and water vapour. Atmospheric absorption results in relatively negligible attenuation at low frequencies, but can produce extremely significant attenuation for mid to high frequencies over relatively short distances (>500 m) [1].

2.4 Ground Effects

Ground attenuation results from the "absorption" and scattering effects of the ground plane, as well as from the interference between the ground reflected ray and the direct ray. Both theoretical and empirical models can be used to characterize ground attenuation effects [2,4,5].

3. Comparison of Modelling Methodologies

Noise impacts from a typical power plant have been modelled using five different modelling algorithms:

- "Basic" attenuation model (geometric spreading and barrier effects only);
- "Basic" model including atmospheric attenuation [1];
- ISO-9613 [1,2];
- ISO-9613 with CONCAWE meteorological effects [3,4]; and
- ENM [5].

The attenuation effects considered by each model type are summarized in Table 2.

Table 2: Attenuation Effects Considered by the Models

Parameter	Model				
	Basic Model	Basic Model With Atm. Absorp.	ISO-9613	CONCAWE [1]	ENM
Geometric Spreading	✔	✔	✔	✔	✔
Barrier Effects	✔	✔	✔	✔	✔
Atmospheric Absorption		✔	✔	✔	✔
Ground Attenuation			✔	✔	✔
Temperature Gradients			✔ [2]	✔	✔
Specific Wind Speed/ Directions				✔	✔

Notes: [1] ISO-9613 with "Cmet" parameter replaced with "Kmet" parameter from CONCAWE
[2] ISO-9613 results represent values under well-developed temperature inversions

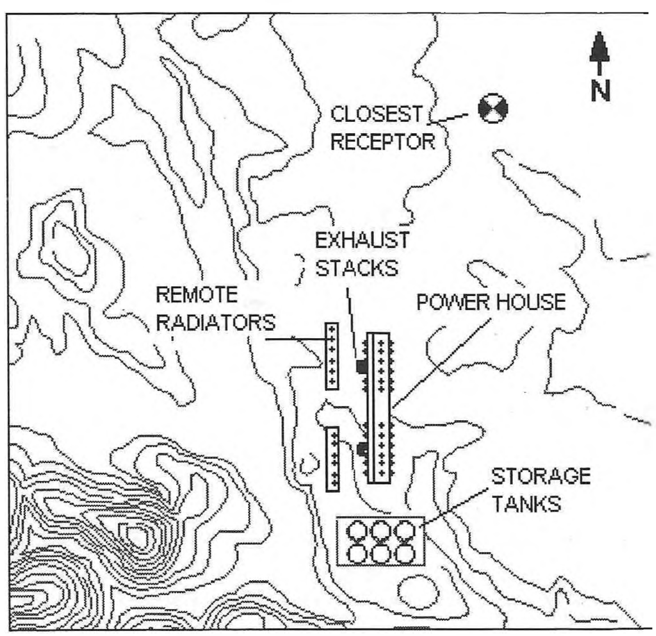

Figure 2: Plant Layout with Elevation Contours

The ISO-9613 model was designed to be representative of mild temperature inversion conditions, for light winds blowing from the source to the receiver, and does not consider specific wind speeds or directions [2]. Ground attenuation in the ISO-9613 model is based on empirical data, while ENM model uses a theoretical framework. Meteorological attenuation in the "CONCAWE" model is based on the P-G Stability Class [4]. Wind speed, wind direction, and lapse rate are entered directly into the ENM model as input parameters.

Table 3: Modelled Meteorological Parameters

Stability Class	Modelled Temperature Gradient (°C/100m) [1]	Modelled Wind Speeds	
		(m/s)	(km/h)
A (1)	- 2.0	3	11
B (2)	- 1.7	5	18
C (3)	- 1.5	5	18
D (4)	- 1.0	5	18
E (5)	1.0	5	18
F (6)	2.5	2	7
G (7)	4.0	2	7

Notes: [1] Stability Class used as CONCAWE model input, not lapse rate.

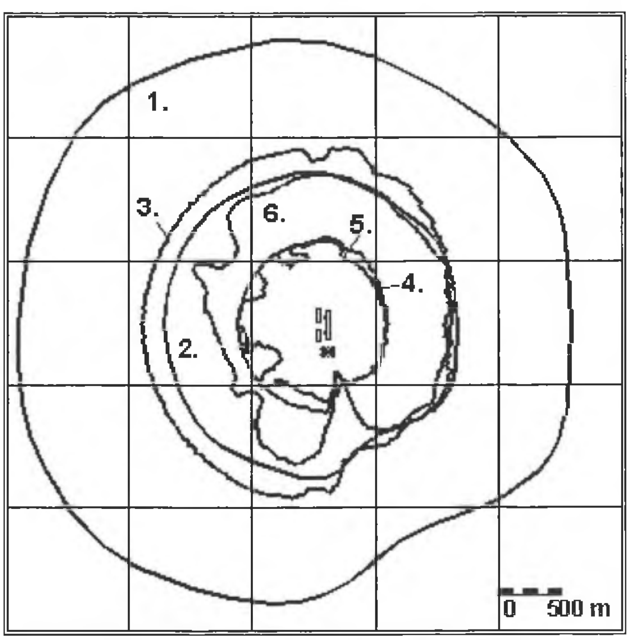

Figure 3: Modelling results, calm winds, 50 dBA contours shown. Each square is 1 km by 1 km. *1.* Basic modelling; *2.* Basic modelling with atmospheric attenuation; *3.* ISO-9613, ground attenuation G=0; *4.* ISO-9613, with G=1; *5.* ISO-9613, G=1, complex terrain; *6.* ENM with soft ground, calm winds and E stability class.

The modelled facility is a 300 MW power plant powered by 24 diesel-fired engines. A plan view is shown in Figure 2. The major noise sources are the exhaust stacks and remote radiators, which are all located to the west of the powerhouse building. Combustion and ventilation air intakes are located long the west and east facades of the powerhouse building. Modelled meteorological parameters are shown in Table 3. Contour 3 shows the ISO-9613 prediction for the plant for hard ground conditions (G=0), and highlights an issue with the model. The major plant noise sources are located to the west (left), and are unscreened (no barriers). The contour to the west of the plant extends farther than the Contour 2 basic model case. This is due to the effect of the "mid-ground" A_m component of the ground attenuation factor A_{gr}, which, depending on source-receiver geometry, can add up to 3 dB to the predicted levels. We believe that this is the component meant to simulate thermal inversion effects when no barriers are present.

The contour to the east (right) of the plant pulls inward to just within the base case Contour 2. In the easterly direction, the plant is acting as a noise barrier for the dominant stack and remote radiator noise sources. In the ISO-9613 model, the ground attenuation term A_{gr} is cancelled out when a barrier is modelled. The A_{bar} barrier attenuation term incorporates a "K_{met}" meteorological correction factor, which is intended to simulate the effects of thermal inversions on barrier effectiveness. If this parameter was working properly, Contour 3 would be expected to extend past Contour 2 in the easterly direction as well.

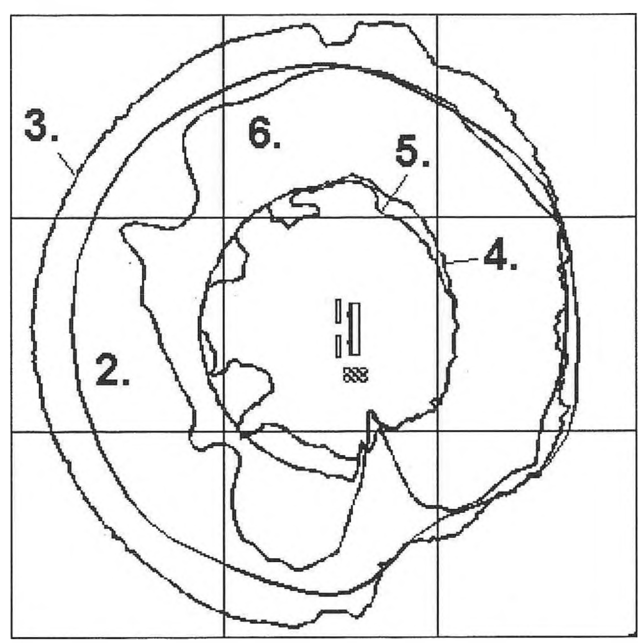

Figure 4: Detail of modelling results. *2.* Basic modelling with atmospheric attenuation; *3.* ISO-9613, ground attenuation G=0; *4.* ISO-9613, with G=1; *5.* ISO-9613, G=1, complex terrain; *6.* ENM with calm winds and E stability class.

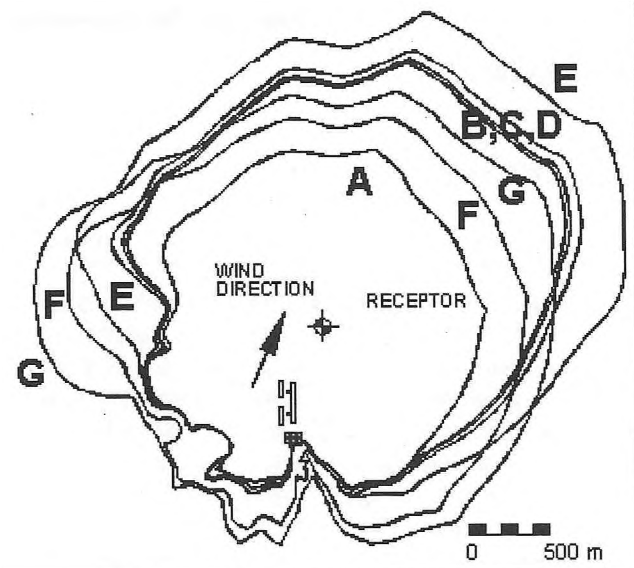

Figure 5: ENM modelling results all stability classes, SSW winds, meteorological conditions as per Table 3.

Contours 4 and 5 were predicted using the ISO-9613 algorithm assuming soft ground. Contour 5 shows the effects of complex terrain on the calculation results. Contour 6 is calculated using ENM, and assumes calm winds and an E stability class (mild inversion)

Figure 5 shows contours predicted using ENM, for SSW winds, based on the meteorological data presented in Table

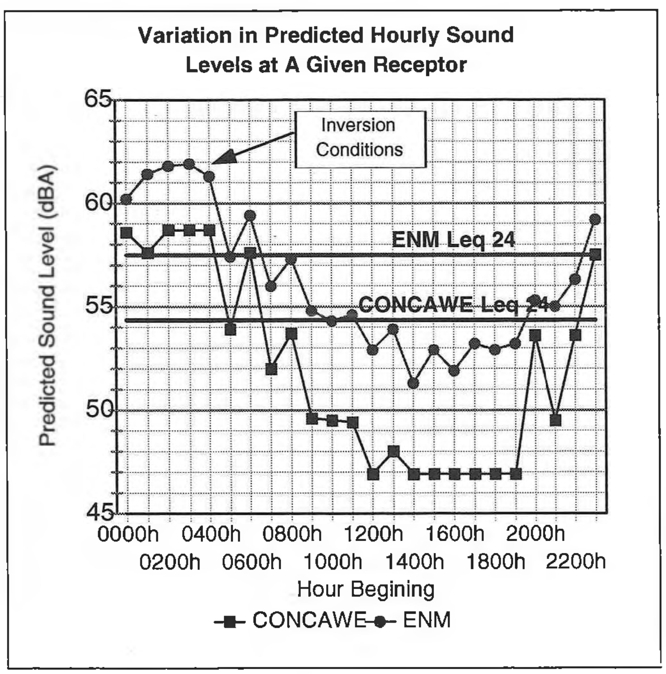

Figure 6: Comparison of ENM and CONCAWE results at a typical receptor over a typical summer day. Heavy lines show resulting L_{eq} 24 levels.

3. The effects of temperature inversions and wind speeds can be clearly seen. The E stability class results are worst-case, in that they extend the farthest out. While F and G stabilities have higher magnitude lapse rates, wind speeds under these classes are much less, resulting in contours covering less area than for the E stability class.

Figure 6 shows a comparison of predicted results from the "CONCAWE" and ENM models, for a single receptor over a typical summer day, covering a variety of stability classes, wind speeds and wind directions. The ENM results are considerably greater, ranging from 2 to 6 dB, depending on meteorological conditions.

4. Conclusions

Significant differences in predicted noise levels can result, depending on which noise propagation algorithm is used in the modelling. Noise modellers should be aware of the limitations of the models they use. It should always be kept in mind that "all models are wrong, but some are useful." Over the distances involved, no model could be expected to be completely accurate. Still, the differences between the ENM and CONCAWE results seem to be extreme. Verification modelling and measurements of the facility of interest are always recommended.

5. References

[1] International Organization for Standardization (ISO-9613-1, "Acoustics – Attenuation of sound outdoors – Part 1: Calculation of the absorption of sound by the atmosphere," 1993.

[2] International Organization for Standardization (ISO-9613-1, "Acoustics – Attenuation of sound outdoors – Part 2: General method of calculation," 1996.

[3] DataKustik GmbH, "CadnaA Computer Aided Noise Abatement Manual v3.2," 2002.

[4] CONCAWE Report No. 4/81, "The propagation of noise from petroleum and petrochemical complexes to neighbouring communities," 1981.

[5] Tonin, R., "Estimating noise levels from petrochemical plants, mines and industrial complexes," Acoustics Australia, Vol. 13 No. 2.

[6] New South Wales Environmental Protection Authority, "NSW Industrial Noise Policy," 2000.