The effects of vegetation on road traffic noise

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ABSTRACT

In Australia road traffic noise is generally described as L_{Aeq}, and is typically assessed using the *Calculation of Road Traffic Noise (CoRTN)* standardised calculation procedures (with some modifications). However, the *CoRTN* methodology, like most other noise propagation algorithms, neglects the effects of highly vegetated areas on sound propagation. The aim of this study was to review available literature as well as to obtain specific experimental data to provide a better understanding of noise transmission when significant vegetation is present. The excess attenuation of traffic noise through 10 to 20m of trees (tree spacing <0.5m) was found to be typically 2 to 3dB(A), and up to 7dB(A) through 120m of eucalypts (spacing >0.5m), relative to *CoRTN* predictions. After bushfire, it was found that excess attenuation can still be expected as a result of multiple scattering by tree trunks. The conclusion of the data analysis and literature review has shown that vegetation has the potential to inform urban design and compliment other forms of noise mitigation.

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(See . http://www.inceusa.org/links/Subj%20Class%20-%20Formatted.pdf .)

1. INTRODUCTION

The effects of vegetation on sound propagation have been the subject of much debate for a number of years. The common school of thought amongst acoustics practitioners is to suggest that trees and hedges are not effective noise barriers. However, there is increasing evidence that this is not always true and a significant noise reduction may be achieved through vegetation if present in sufficient density and depth. There are also other considerations in evaluating effectiveness such as the permanence of unprotected vegetation. Future changes in land use, land clearing and fire can prevent the long term objectives being met if relying on unprotected vegetation.

In the United Kingdom, the Transport and Road Research Laboratory (1) conducted a series of short-term 15-minute measurements and found an excess attenuation of 6dB(A) in L_{A10} due to traffic noise through 30m of dense spruce (average spacing of 1m and trunk diameter of 0.12m) compared with the same depth of grassland, and 8dB(A) compared with that predicted by the *Calculation of Road Traffic Noise* (*CoRTN*) prediction algorithm. Fang and Ling (2) have also shown in studies of 35 evergreen tree belts that strong attenuation of traffic noise is possible. More recently, numerical calculations by Van Renterghem et al. (3) indicated that tree belts could be effective in reducing road traffic noise, on condition that planting schemes are optimised and tree density is sufficiently high. Calculations showed that a 15m deep and 2.5m stem height tree belt planted at 1m average spacing with 0.11m diameter tree trunks was found to have a performance equivalent to a standard 1.5m high noise barrier.

Research by Albert (4) has shown that in heavily vegetated areas, low frequency propagation is principally influenced due to ground effect where increased attenuation is expected because of the acoustically softer ground. Multiple scattering between trunks will interrupt the direct line-of-sight between source and receiver, typically affecting the dominant octave band for A-weighted traffic noise, which is the 1kHz band. Absorption from vegetation itself was found to be negligible for traffic noise and leaves were found to have an influence at high frequencies (above 2kHz) only.

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There are now several road traffic noise assessment manuals from various global government bodies including Road Directorate of Danish Road Institute (5), Illinois Department of Transportation in the United States (6), United States Department of Agroforestry Centre (7), and Department of Transport and Main Roads in Queensland Australia (8), which refer to the use of vegetation to reduce noise levels, rather than just to soften the visual impact of noise walls (9). However, no details of potential reduction are given. While these documents discuss the use of vegetation for noise control, there is no mention of considering existing trees or proposed planting when evaluating noise impacts.

Many road traffic noise prediction methods neglect the effects of vegetation on sound propagation, including *CoRTN*, *STAMSON*, *NMPB-Routes-2008* and *FHWA*. It appears that only a few noise prediction algorithms consider the effects of vegetation on road traffic noise, but in different forms. The *ISO9613-2:1996* algorithm considers vegetation in the form of dense foliage and is incorporated into the *FHWA Traffic Noise Model* as an optional element, while the *Nord2000 Road* predicts the propagation effect of “scattering zones” or vegetation based on average tree density, the mean tree trunk diameter and a mean absorption coefficient.

The prescription of noise mitigation measures for roads and freeways depends on the outcome of a noise assessment, which is based on modelled noise levels. Although the *ISO9613-2:1996* and *Nord2000* algorithms consider vegetation, it is often discounted in noise assessments for conservatism as vegetation is regarded by many as non-permanent features. However, one might think that a catastrophic event such as a bushfire would render the effect of trees useless; it was found in this study that multiple rows of tree trunks still provided significant reduction. For this reason, noise assessments may over predict noise levels. Specifically incorporating attenuation from existing vegetation in the noise assessment procedures may reduce the cost associated with adopting unnecessary engineering solutions to reduce modelled noise levels.

This study considers experimental data as well as relevant literature including guidelines and research papers to identify additional noise propagation loss above that predicted by CoRTN. The analysis highlights that where permanence issues can be resolved there may be additional benefit from considering vegetation for a highway project.

2. ANALYSIS METHODS

2.1 Overall Methodology

Nine sites were used for measurements, including one at which measurements were repeated. They are listed in Table 1. Initial testing was conducted at two sites on the Pacific Highway, namely Nirvana Way (between Frederickton and Eungai – Site 1) and Kungala Road (between Woolgoolga and Glenugie – Site 4). These tests collected data for up to 7 days. Further testing for the purpose of this study was conducted at five sites between Woolgoolga and Glenugie (Sites 4, 5, 6, 7 and 8), with data being collected for a period of one night and a number of hourly measurements at Sites 7 and 8. Two control sites were also selected with similar road and traffic conditions but minimal vegetation (Sites 2 and 3). Site 9 is discussed separately below.

Table 1 – Measurement Sites

Site	Location	Type	Duration
1	Frederickton to Eungai	Vegetated	1 week
2	Woolgoolga to Glenugie	Control	1 night
3	Woolgoolga to Glenugie	Control	1 night
4	Woolgoolga to Glenugie	Vegetated	1 week, plus 1 night repeated measurement
5	Woolgoolga to Glenugie	Vegetated	1 night
6	Woolgoolga to Glenugie	Vegetated	1 night
7	Woolgoolga to Glenugie	Limited Vegetation	Hourly
8	Woolgoolga to Glenugie	Limited Vegetation	Hourly
9	Lake Munmorah Area	Burnt Vegetation	Hourly

2.2 Method for Determining L_{Aeq} Excess Attenuation

The attenuation due to vegetation is determined using a procedure requiring both *CoRTN* predicted levels and measured levels. The difference between the measured attenuation and that predicted by the *CoRTN* model (modified as described below) is defined as "excess attenuation" in this study, while "attenuation" is defined as the difference between the L_{Aeq} traffic noise level measured close to the road (typically within 10m) and that measured some distance away. The reason for using excess attenuation rather than measured attenuation due to vegetation is because it is difficult to locate ideal test sites where a control site and a vegetated site have the same ground conditions (ground cover and terrain), view of the road, and traffic conditions.

This procedure eliminates the effect of traffic parameters such as vehicle speed at each site, volume mix, road surface, etc., and provides a direct measure of the size of any correction required for the presence of vegetation, when using the *CoRTN* model. The two control sites provide an indication of the accuracy of the model in generally comparable conditions, in the absence of vegetation.

2.3 Experimental Setup

Noise monitoring was conducted concurrently with traffic counts at all sites. All noise monitoring was conducted using ARL NGARA environmental noise loggers. Note that the ARL NGARA environmental noise logger is capable of remotely monitoring and storing noise levels every one-tenth of a second and storing WAV files for aural analysis. Additionally, the NGARA noise logger is capable of producing spectral data for 1/3-octave band analysis.

2.4 Prediction Method

The following factors were considered in the modelling process:

- Concurrent traffic volume and percentage of heavy vehicles for daytime and night time;
- Vehicle speeds for daytime and night time;
- Road surface types and road gradient;
- Different noise emission levels and source heights;
- Location of the noise sources on the highway;
- Topographical information along and surrounding the entire project corridor;
- Shielding from mounds or barriers.

Expected noise levels were calculated using procedures based on the *CoRTN* prediction algorithms. The standard prediction procedures were modified in a number of ways, following normal practice for road traffic noise prediction in New South Wales (NSW).

- Noise source heights are set at 0.5m for cars (tyre and engine), 1.5m for heavy vehicle drivetrain (tyre and engine) and 3.6m for heavy vehicle exhausts, representative of typical values for Australian vehicles (10);
- Noise from a heavy vehicle exhaust is set at 8dB lower than the noise from the engine; and
- Hourly L_{Aeq} values are taken as 3 dB below *CoRTN* calculated hourly L_{A10} values, with no chart correction for low traffic volume; and
- Percentage of absorbent ground cover is set to 75% at all sites.

While a soft ground factor of 100% has been found to give better prediction of L_{A10} levels in the UK the calculated level has been found to under-predict L_{Aeq} levels measured over grassland, for typical conditions in NSW (11). This was indicated by Kean (11) to be due to differences between L_{10} and L_{eq} for increasing vehicle spacing expressed as cars per kilometre. Typically practitioners in NSW are required to adopt a standard soft ground factor of 75% to represent typical grassland conditions. (Note that in the *CoRTN* methodology, any soft ground cover ranging from 60% to 89% is treated as 75%). The model was implemented using SoundPLAN software (Version 7.1).

3. SITE SELECTION

3.1 Control and Vegetated Sites

The study sites were selected adjacent to the existing Pacific Highway from Frederickton to Eungai and Woolgoolga to Glenugie. The traffic on both of these sections of the Pacific Highway was of sufficient density and free-flowing for traffic noise to be dominant, and validated noise models for both of these sections of the Pacific Highway were available.

Altogether eight sites that are typical of topographical conditions adjacent to road corridors in rural

NSW have been considered in this study (see Table 1). At each site the ground was relatively flat, and covered by vegetation (bush or open grassland).

Three sites where tree stands are present are covered by mature and immature eucalypts in great depth (>100m) and of fairly consistent trunk diameter between 0.10m and 0.20m (see Figure 1 and Figure 2). The selected tree belts are of considerable width (angle of view of the road from receiver), and at locations furthest from the road, the vegetation obstructs greater than 160 degrees angle of view of the road. The average tree spacing at these sites was observed to be consistent with the scheme of one tree per 0.25m^2 recommended in the NSW Road Traffic Authority *Landscape guideline* (12). The two sites selected as "control" sites are covered with grass with a few isolated trees in the vicinity (see Figure 3), which were thought to have negligible effect on the noise measurements.

At two sites, limited depths of tree stands are present, comprising a combination of shrubs and eucalypts and pine trees planted very densely together (<0.25m^2 tree spacing) with trunk diameter typically around 0.10m (see Figure 4 and Figure 5).

At all sites, measurements were undertaken at a range of distances from the road, in addition to the monitor directly adjacent to the road which serves as the base value for attenuations.

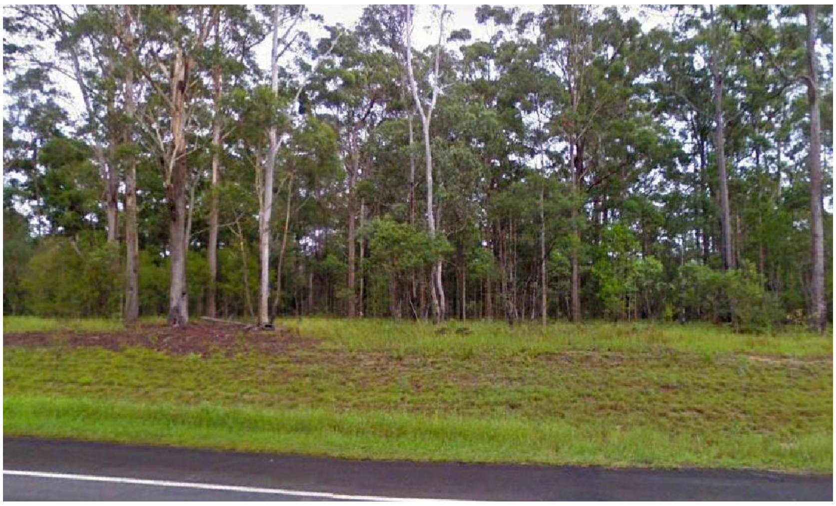

Figure 1 – Site 1 - Eucalypt forest (>100m depth)

Figure 2 – Site 4 - Eucalypt forest (up to 80m depth)

Figure 3 – Site 2 - Control site

Figure 4 – Site 7 - Pines and Eucalypts (20m depth)

Figure 5 – Site 8 - Eucalypts (<20m depth)

3.2 Bushfire Site

Although there is evidence that features such as trees and shrubs can reduce noise levels, the *CoRTN* procedure recommends that for regulations and planning purposes it is not appropriate to include such non-permanent features in a practical prediction procedure (13). One regular cause of such impermanence is bushfires. In the catastrophic event of a bushfire, ground condition will change temporarily and some trees will not regrow. Generally, however, most trees, especially eucalypts, are expected to regenerate in time. It would be expected that even when only multiple rows of tree trunks are present some noise reduction may still be achieved.

The literature survey discussed herein has found no studies concerning the effect of vegetation on road traffic noise immediately after a bushfire event. In 2013 there were a series of bushfires across the state of New South Wales during the month of October, which provided the rare opportunity to determine whether the standard noise assessment practice (where the effect of trees is disregarded for conservatism to account for catastrophic events) is indeed reasonable.

The study sites were selected adjacent to the existing Pacific Highway in the Lake Munmorah area. The traffic on this section of the Pacific Highway was of sufficient density and free-flowing (at 80km/hr) for tyre noise to be the dominant noise source. Figure 6 shows a view of bushland from the Pacific Highway before the bushfire and Figure 7 shows the same view after the bushfire. It can be seen in Figure 6 and Figure 7 that foliage and soft ground cover has been significantly reduced as a result of the bushfire. Typically, the tree spacing ranges up to 2m and the trunk diameter is between 0.05m and 0.15m. The measurement location is 53m setback from the nearest edge line of the road and the tree belt is approximately 39m in depth.

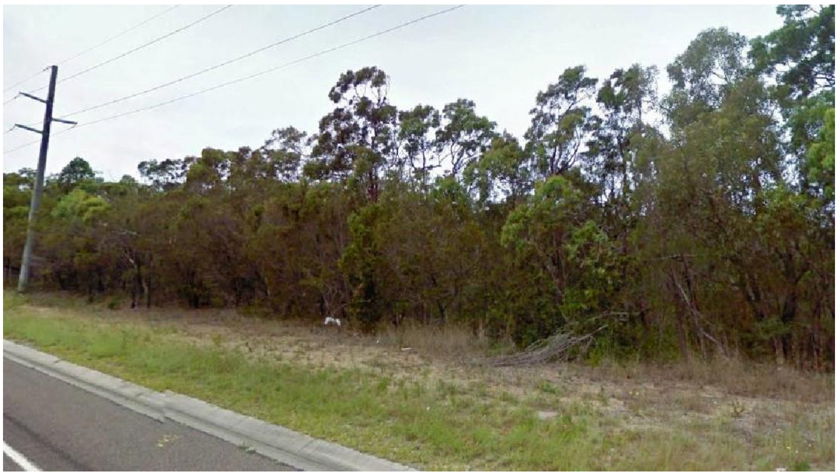

Figure 6 – Before bushfire Pacific Highway, south of Kangaroo Drive, Central Coast NSW

Figure 7 – After bushfire Pacific Highway, south of Kangaroo Drive, Central Coast NSW

4. RESULTS

4.1 L_{Aeq} Excess Attenuation of Control and Vegetated Sites

Measured excess attenuation values at vegetated sites, control sites and sites with limited vegetation are shown in Figure 8.

The results show that at the control sites, the excess attenuation appears to be between -1 and +1dB – that is, measured noise level differences align closely with those predicted by *CoRTN*. On the other hand, at all sites with vegetation the measured excess attenuation is clearly positive. Note that the tree belt at the vegetated sites typically starts at 5 to 10m away from the edge of the nearest carriageway. For sites with limited vegetation, the location at 50m away from the road is affected by approximately 19m of trees and the location at 31m is affected by approximately 10m of trees.

In this study, the noise level through 10 to 20m of vegetation was observed to be in the range of 2 to 3dB lower than predicted by *CoRTN* with no allowance for vegetation. Typically the excess attenuation is around 5dB through greater than 50m deep of trees. The highest excess attenuation of 7dB was achieved through approximately 120m of mid-north coast dense eucalyptus forests.

4.2 L_{Aeq} Excess Attenuation of Burnt Bushland

For burnt bushland, while changes to ground condition and foliage cover are significant as seen in Figure 6 and Figure 7, clearly notable positive effects can still be expected when multiple rows of burnt trees are present. This appears to be because the reduction in A-weighted equivalent traffic noise level is highly frequency dependent, predominantly dictated by octave bands around 1kHz. The excess attenuation through 39m of burnt bushland is approximately 4dB (see Figure 8). It is noted that multiple 15-minute samples of measurement indicated consistency in the results. However, it should be noted that measurements were only conducted at one location due to site availability. Additional measurements should be conducted at other sites to improve the credibility of excess attenuation due to burnt vegetation.

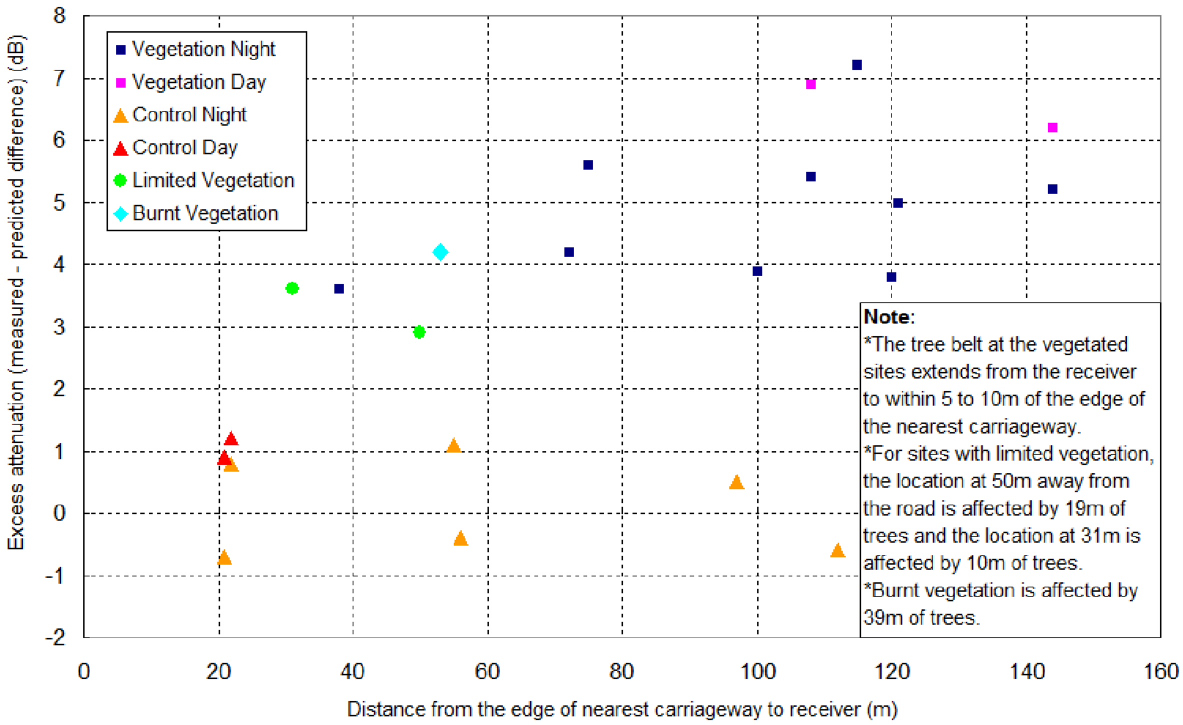

Figure 8 – Estimated excess attenuation

4.3 Repeatability of Measurement

Initial testing was conducted at Kungala Road in Halfway Creek for a period of up to 7 days. In order to demonstrate the repeatability of measurement, the tests made near Kungala Road were repeated for a period of up to 1 day after 7 months at the same location. The measurement results are presented in Table 2. It can be seen in Table 2 that although there is some difference in $L_{Aeq,9hr}$ measured during winter and the end of spring, it is in fact due to change in traffic conditions.

Table 3 shows the nightly average $L_{Aeq,15minute}$ difference at Kungala Road between a location close to the road and a location at a further setback (This excludes nights when weather conditions precluded accurate measurements). These values show the variability in the nightly average $L_{Aeq,15minute}$ difference is small (less than 0.5dB).

Table 2 – Measured $L_{Aeq,9hr}$ near Kungala Road, Halfway Creek in different seasons

Date	Total Vehicles	Heavy Vehicle Percentage	Average Speed (km/h)	$L_{Aeq,9hr}$ (dBA)
25-26 November 2012	1061	34%	98	51.3
16-17 June 2013	1105	19%	101	50.4

Table 3 – Nightly average $L_{Aeq,15minute}$ difference at Kungala Road, Halfway Creek

Date	Average Nightly $L_{Aeq,15minute}$ Difference (dB)
21/11/2012	15.8
25/11/2012	15.7
26/11/2012	15.8
27/11/2012	16.1

5. ROAD TRAFFIC NOISE ASSESSMENT WITH EXISTING VEGETATION

In the formulation of *CoRTN*, reference 13 indicates:

"Although there was evidence that other ground conditions (besides hard and grassland) and features such as thick hedges can reduce noise levels, it was recommended that the grassland prediction should be used for all non-hard ground surfaces as it is difficult to define different ground surfaces adequately. And it is likely that the various surface conditions may not be permanent, so it was considered hardly possible to include such 'non-permanent' features in a practical prediction procedure for regulations and planning purposes."

However, 'non-permanent' features such as thick hedges differ from dense forests, both acoustically and physically. For example, in a catastrophic event such as a bushfire, while other plants (such as hedges) may not survive being burnt, most of the eucalypts are expected to regenerate in time as they have evolved adaptations to survive bushfires. Densely spaced eucalypts affect sound propagation at frequencies of around 1kHz and below, whilst hedges usually do not.

Since the *CoRTN* model is designed to calculate noise levels over grassland, the use of *CoRTN* modelling output without considering the presence of dense vegetation in the assessment may result in over prediction.

Table 4 below shows the predicted worst case night time traffic noise levels for a typical highway over flood plain (for traffic at speed of 120km/h, with 40% heavy vehicles and on plain concrete pavement road surface) using NSW modified *CoRTN*. The Table shows setback distance from the centre line of the outermost traffic lane, and the significance of the identified noise levels.

Table 4 – Predicted night noise level $L_{Aeq,9hr}$ at different setback distances from the centreline of the road (NSW modified *CoRTN*)

Setback distance from the centre line of the road (m)	Predicted night noise level $L_{Aeq,9hr}$ (dBA)	Significance of the identified noise level
150	60	Acute
230	57	2dB over redeveloped road criterion
320	55	$L_{Aeq,9hr}$ redeveloped road criterion
500	52	2dB over new road criterion
700	50	$L_{Aeq,9hr}$ new road criterion

An examination of the information in Table 4 indicates that if the night time noise criteria are 55dBA and 50dBA for redeveloped and new road projects (typical of comparatively conservative criteria), respectively, many noise sensitive receivers within 320m and/or 700m from the centre line of the road may exceed the criteria, if predicted noise levels are taken as is. In reality, the actual noise level at some of these locations would be significantly lower than the predicted noise level because of hundreds of metres of vegetation between the source and receiver. For example, where there are multiple rows of tree belts planted sufficiently close together, conservatively adopting an excess attenuation of 2dB as a minimum for tree belts of 20m in depth (see Figure 8) would reduce the distance at which the “new road” criterion is met from 700m to 500m. For the “redeveloped road” criterion, the distance would be reduced from 320m to 230m. Note that along the sections of highway considered in this study, many receivers where predicted noise levels exceeds the base criteria were found to be obscured by considerable depth of existing vegetation belts, where 4 to 7dB of A-weighted traffic noise reduction can be expected. This suggest the setback distance of noise sensitive areas could be reduced further if a site specific excess attenuation is used rather than the minimum of 2dB as seen in Figure 8.

6. Discussion

The benefit of considering the attenuating effects of vegetation when calculating road traffic noise can be significant. This offers the opportunity to not only refine the noise assessment process but also to reduce the costs associated with implementing traffic noise reduction techniques by including existing and/or proposed vegetation as an alternative or to complement conventional noise control techniques where other permanence issues have been resolved.

The presence of vegetation can be identified together with other landscape factors during the preliminary identification of potential noise issues at a corridor/route level. This would provide approximate location, density, length and depth to allow the consultant to determine the effectiveness of vegetation in reducing traffic noise as early as possible in the project life cycle. For noise sensitive areas with limited depth of vegetation, the effectiveness of vegetation can be confirmed by conducting short-term measurements at night during the noise monitoring stage of the project.

In relation to proposed planting, in NSW the standard landscape and urban design principles (12, 14) require natural pattern be integrated into road design to protect ecological systems and biodiversity, and for visual screening purposes. In areas where dense planting is mandatory, this should be communicated to the relevant stakeholders and be considered in the noise assessment. For other areas, the use of vegetation as a form of noise control would ultimately depend on the opportunity of roadside planting and feasibility beyond the pavement. For example, visual screening can be dangerous in some rural settings where residents would prefer visibility over privacy to make hazard awareness more apparent. Conversely, residents adjacent to the subject road in urban and/or suburban areas may request densely populated planting be adopted alongside the road for privacy. Road planning and design must contribute to the accessibility and connectivity of communities and a general permeability of movement through areas. This suggests that the choice of noise mitigation (e.g. noise wall, vegetation, earth mound etc.) should ultimately be selected in consultation with the multi-disciplinary project team, other agencies, stakeholders, interest groups and the community.

7. CONCLUSIONS

The excess attenuation for different depth and categories of vegetation has been presented, namely, considerable depth, limited depth and burnt bushland. The effectiveness of vegetation in attenuating road traffic noise is greatest close to the road (over the first 10 to 20m), and the rate of attenuation decreases as the distance from the road increases. The field study also showed that significant positive effects can be expected even when only multiple rows of tree trunks are present. The conclusion of the data analysis and literature review is that vegetation has the potential to be included as an attenuation measure where all permanence issues have been resolved.

Important generalisations useful for evaluating proposed road projects with the presence of vegetation are presented together with opportunities to refine the current noise assessment procedure.

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