The variability of road traffic noise and implications for compliance with the noise conditions of roading designations

November 2011

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NZ Transport Agency research report 446

ISBN 978-0-478-38003-3 (print)
ISBN 978-0-478-38002-6 (electronic)
ISSN 1173-3756 (print)
ISSN 1173-3764 (electronic)

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VK Dravitzki, RJ Jackett and CWB Wood (2011) The variability of road traffic noise and implications for compliance with the noise conditions of roading designations. *NZ Transport Agency research report 446.* 66pp.

Keywords: designation conditions for noise, noise compliance, noise measurements, noise measurement errors, noise measurement and modelling, noise propagation, noise variability, road traffic noise

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Acknowledgements

The authors wish to thank Mr Keith Ballagh of Marshall Day Acoustics and Mr Rob Hannaby of the NZTA for their peer review; Dr Stephen Chiles of URS corporation, for his input into the final draft; and Vivienne Sutton of the Opus Information Centre for her extensive search of and obtaining the literature on their behalf.

Terms, abbreviations and acronyms

AADT	average annual daily traffic
CadnaA	a software package for computer-aided noise abatement that allows calculation, presentation, assessment and prediction of environmental noise
CONCAWE	Conservation of Clean Air and Water in Europe – established in 1963 by a small group of leading oil companies to carry out research on environmental issues relevant to the oil industry
CRTN	Calculation of Road Traffic Noise model
dB	decibel – sound is measured as sound pressure and expressed as a relative measure of the sound pressure of that sound compared to the sound pressure of the sound that is just detectable to most people with normal hearing. The unit of sound is the Bel. One Bel is a 10 times increase in sound pressure level, so for easy use the more common unit used is one tenth of a Bel, or a decibel. The quietest detectable sound (or reference sound pressure level) is a pressure of 20μPa. (Note: This definition is provided to assist the general reader. For a full scientific definition, refer to NZS 6801: 2008.)
dBA	sound when A-weighted – most sounds are composed of many frequencies and human hearing can detect some frequencies much better than others. The measured sound level can be adjusted, so that it better equates to what a person would hear, by reducing the very low and the very high frequencies. This is called A-weighting. (Note: This definition is provided to assist the general reader. For a full scientific definition, refer to NZS 6801: 2008.)
FHWA	Federal Highway Administration (agency within the US Department of Transport)
HGV	heavy goods vehicle
$L_{Aeq(24\ hour)}$	‘equivalent noise level’ – a form of the average noise level over a 24-hour period. It is the constant noise level that has the same energy as all the fluctuating noise levels that occur in this period. This form of average is, in effect, weighted so that it is close to the louder events that occur, rather than the arithmetic mean.
$L_{Aeq\ LT}$	the long-term (ie averaged over months or a year) continuous energy-equivalent sound pressure level, in A-weighted decibels
L_{dn}	the day–night noise level – an average daily noise level similar to LAeq(24 hour), but in which the noise of over certain hours at night is weighted to represent its increased impact
NZTA	NZ Transport Agency
SoundPLAN	a software package that specialises in computer simulations of noise and air pollution situations
SPL	sound pressure level
TNM	Traffic Noise Model, originally released by the FHWA in 1998 – a software package for predicting noise impacts in the vicinity of highways, developed as a means for aiding compliance with policies and procedures under FHWA regulations

Contents

Executive summary

This research, which was undertaken between 2006 and 2008, aimed to identify the variability of road traffic noise, and on the basis of that variability, to identify:

- a suitable method of establishing compliance with the noise conditions of designations for roading projects
- a method of establishing compliance for roading projects where it has been agreed that noise is to be managed within a certain limit.

There are instances when actual measurements of noise are essential. However, outside of these instances, practice has evolved whereby noise levels have increasingly been established by measurement rather than by modelling. This research was prompted by concerns that designation conditions for road traffic noise are often framed without a full regard to the variability inherent in noise measurement. We sought to quantify the variability in noise measurement and then in light of this identified variability, develop a recommended approach for establishing compliance.

Most of this research preceded the new traffic noise standard NZS 6806:2010. However, this discussion of the variability of road traffic noise is also relevant to that standard and to developing designation conditions under that standard.

The research explored:

- the uncertainty involved in road traffic noise measurement
- the conditions under which measurement is likely to yield the most consistent results
- the role of measurement and modelling as components of the noise assessment process.

From this information, a set of guidelines for establishing compliance was developed, as well as recommendations for managing uncertainty in noise assessment.

This report provides practical strategies for recognising and reacting to possible sources of bias, and provides useful estimates of the uncertainty of noise measurements in real-life conditions.

Two aspects of variability were considered:

1. variability of the noise source, including the volume of traffic, the number of heavy vehicles, traffic speed, the characteristic make up of both the light-vehicle fleet and the HGV fleet, road surface type, road surface condition and road gradient
2. variation in noise due to propagation effects, including meteorological conditions, the distance between source and receiver, atmospheric absorption, ground absorption and ground cover, atmospheric stability, and wind speed and direction.

Findings on variation of noise source

- Volume: For a measurement on a randomly selected day of the year, the uncertainty interval due to traffic volume was in the region of ±1dBA for most roads, although some rural roads had uncertainties much higher, perhaps in the region of ±3dBA. Restricting measurement to weekdays during non-holiday periods could reduce the uncertainty to about ±0.5dBA for most roads, but could introduce a similarly sized bias relative to the annual average, depending on the road type.
- Heavy goods vehicles (HGV): The high proportion of HGV on all road types over the working week caused the weekdays to be consistently noisier than the annual averaged %HGV level, but by only a

small amount, typically 0.2dBA. The much lower percentage of HGV at the weekend could result in some sites being 1dBA quieter than the annual average.

- Speed: The day-to-day uncertainty in noise emission due to speed was [-0.7, +0.6]dBA in open-road speed zones.
- Road surface: Variation in road surface types could give rise to a difference of 6–8dBA (but 2–4dBA was more typical). The effects of road deterioration led to an increase or decrease of 1–2dBA. Potholes and roughness had a large but unpredictable effect, but this was obvious and therefore not a source of error.

Findings on variation in noise due to propagation effects

- Noise propagation resulted in attenuation of road noise, and the amount of attenuation depended largely on the meteorological conditions and the distance between source and receiver. Atmospheric absorption, ground absorption, atmospheric stability, and wind speed and direction contributed to attenuation of road traffic noise, and changes in any of these phenomena between surveys could produce different sound-level measurements.
- The distance between source and receiver was critical in determining the amount of road noise attenuation. However, the distances from the road for which the separate phenomena of ground absorption, atmospheric absorption and meteorological effects occurred differed for each phenomenon.
- Ground absorption had a substantial but fairly predictable effect on the noise level at all distances from the road, but for any receiver, ground conditions could vary over time if the ground surface changed between measurements due to, for example, the moisture content of the ground, mild vegetation growth, or foliage change within a season.
- Temperature, pressure, and relative humidity had a fairly insignificant effect on sound propagation, unless the propagation distance was very long (greater than 200–300m). It is considered that measurement may reasonably take place over the range of conditions common in New Zealand, providing the instrumentation is within its operating range.
- Meteorological conditions of wind and temperature lapse rate had a strong effect on attenuation. Close to the road, atmospheric turbulence could scatter sound unpredictably, but it was considered that wind (at speeds appropriate to noise measurement) would not have a strong effect on received noise level. Further from the road, the effects of wind and temperature lapse completely dominated the overall variability in noise level, and consistency between measurements was much more difficult – the variation quickly became unacceptable beyond a few tens of metres from the road edge (calculated as the systematic error plus the combined random errors for upwind and downwind measurement). For measurements made far from the road, measurements limited to just downwind conditions were more consistent than measurements confined to just upwind conditions. However the measurements were not comparable, as there was a substantial difference between the downwind and upwind noise levels.

Summary of propagation effects

Phenomenon	Range of conditions	Typical range of uncertainty in dBA with distance from the road				
		<30m	60m	100m	200m	300m
Estimate of total variability	Variation of measurements in favourable conditions (downwind, inversion)	±2	±2	±2	±3	±7
	Variation of measurements in unfavourable conditions (upwind, no wind)	±3	±3	±4	±6	±9
	Variation of measurements in unspecified conditions (incl. bias from upwind v downwind)	±4	±5	±10	±13	±22

The following restrictions to conditions for measurement of noise improved the consistency of results:

1. Weekdays only: (Monday–Thursday): Restricting measurement to weekdays could improve consistency between measurements, while introducing only a very small amount of bias relative to the annual average level (less than 0.5dBA).
2. Downwind only: Downwind measurements could result in sound levels being somewhat higher than would be the case under other conditions, and this needed to be considered in the noise assessment. However, it was the condition in which the variability was the most predictable and adjustments to the measurements could be made with the most confidence.

Recommended method of establishing compliance with noise conditions

Establish the existing noise levels by a combination of site assessment, detailed modelling (using a model such as SoundPLAN or FHWA TNM) and noise measurement.

1. Through a site assessment, identify the extent to which traffic noise is the dominant source of ambient noise for the area, and note other aspects of the site to include in the modelling.
2. Undertake noise measurements at a sample of the locations to be modelled and follow the recommendations to make consistent noise measurements.
3. Use these noise measurements to establish a reliable model; ie, observe the match between modelled and measured noise levels, and where a significant difference occurs, investigate both the model inputs and the measurements to reconcile these differences.
4. During the measurements, record traffic counts, weather conditions and ground conditions so that the measurements made on the day can be adjusted to the model's prediction, which is based on average annual daily traffic (AADT) flows and neutral weather conditions.
5. Base future noise levels on modelled levels, with key inputs being terrain, traffic volumes (with speed and mix of heavy and light vehicles), road surface type, road and receiver positions, and positions of noise barriers or bunds if included.
6. Establish compliance with the noise conditions by means of the modelled levels and post-construction reviews of the model's inputs, and then if necessary, adjust the model and rerun it to verify the compliance. The review should include the following steps:
   - Establish that the model is an accurate depiction of the road as *finally* constructed.
   - Verify that the *inputs* into the model of terrain, buildings and positions are correct.

- Make detailed traffic counts to establish that the traffic volumes, mix of heavy and light vehicles, and traffic speeds contained in the model are correct.
- Ensure traffic parameters used in the model for the forecast year are realistic.
- Test the road surfaces used for their effect on traffic noise and adjust the model accordingly.
- Do on-site inspections to verify the positions of barriers in the model – measure their height and specifically test the effectiveness of the barrier in stopping noise.
- Where buildings are to be insulated, test the effect of the insulation by conducting simultaneous indoor and outdoor measurements both before and after treatment.
- As with establishing the model for existing noise levels, take post-construction noise measurements at a sample of the locations modelled. These noise measurements are not directly used to establish compliance, but to inform the post-construction noise model and improve its reliability. That is, observe the match between modelled and measured, and where a significant difference occurs, then investigate *both* the model inputs and the measurements to reconcile these differences. As for pre-construction, record the traffic counts, weather conditions and ground conditions during the measurements, so that the measurements made on the day can be adjusted to the model's prediction (which is based on AADT flows and neutral weather conditions).

7 Where compliance needs to be *demonstrated* over several years or more post-construction (eg 10 years after), then the measurement of traffic parameters, road surface noise effects, the effectiveness of barriers in reducing noise and the effectiveness of building insulation in reducing noise should be re-measured and input back into the model. The effect of other changes that are beyond the control of the roading authority, such as removal or changing of the intervening vegetation, or the establishment of new buildings or the removal of existing buildings, should also be accounted for by modelling the effect of having them present, and also with them absent.

Compliance with NZS 6806

The draft conditions of NZS 6806 have more of a methods approach and a focus on the 'Best practicable option'. This may include a certain level of mitigation from a particular road surface, and further mitigation from noise barriers. Noise assessments include houses 100m from the road edge in urban areas, and 200m from the road edge in rural areas.

The method recommended above is a good fit for showing compliance with NZS 6806. Elements of the 'best practicable option' can be tested for noise performance and, coupled with traffic information, can then be used in modelling to show the final noise levels at the protected premises and facilities of interest.

Abstract

Many road designations have conditions with respect to noise that require that when the road is completed, measurements will be undertaken to prove that the performance standards of those conditions have been fulfilled. However all measurements are subject to variability, and the designation conditions do not address either the expected nature of this variability, or how it should be accounted for in establishing compliance with the conditions.

This research was carried out in New Zealand between 2006 and 2008. It sought to quantify the variability in noise measurement, and then in light of this identified variability, develop a recommended approach to establishing compliance.

This report first discusses the evolution of current practice, and then examines in detail the expected variability that can occur both in noise generation and noise propagation. The impact on noise levels of factors such as traffic volume, HGV, traffic speed, road type, road deterioration, wind speed and direction, ground type and vegetation is examined. Recommendations to improve measurement consistency are made.

The recommended method of compliance that is advanced is based on noise modelling, supplemented by measurement, to validate the overall model, followed by testing the performance of noise mitigation elements that are incorporated in the modelling.

1 Introduction

This research, which was supported by the NZ Transport Agency's (NZTA) 'research for industry' fund, aimed to investigate the issue of variability of road traffic noise, and on the basis of that variability, to identify:

- a suitable method of establishing compliance with the noise conditions of designations for roading projects
- a method of establishing compliance for roading projects where it has been agreed that noise is to be managed within a certain limit.

Opus Central Laboratories conducted the research between 2006 and 2008, with assistance from Marshall Day Acoustics.

The research was prompted by concerns that designation conditions for road traffic noise are often framed without a full regard to the variability that is inherent in noise measurement.

Although the research had some input from other acoustic professionals, it must be noted that this is a research report, not a New Zealand or industry standard, so the report should not be construed as representing a consensus of the acoustic sector.

The result of the research is a recommended guideline, together with a report that frames the recommended guideline. It is up to others how they apply this research and recommended guideline. For example, it is expected that this report could be used directly to assist in a more rigorous drafting of designation conditions for noise, or for other roading projects where the noise limits have been agreed to.

The discussion on the variability of road traffic noise could also be used to assist in interpreting the measurements that are made.

Most of this research preceded the new traffic noise standard NZS 6806:2010. However this discussion of the variability of road traffic noise is also relevant to that standard and to developing designation conditions under that standard.

2 Current New Zealand practice (2009)

2.1 The origins of current practice

New Zealand roading projects that require a designation are usually approved subject to a set of conditions that are developed as part of the consenting process to minimise the project's effects. Noise is commonly one of the effects of roading projects to which designation conditions apply, to ensure these effects are managed and minimised. The effect being managed is the impact of noise on a community's amenity and public health, with 'noise level' as an indicator of that impact. Impacts are have historically been managed by either restricting the extent to which noise levels can change, or by setting a threshold that noise levels may not exceed. Once granted with its associated conditions, the designation then imposes a legal requirement on road controlling authorities to comply with those conditions.

This research discusses the significant issues in demonstrating that compliance is being achieved, and develops recommendations for demonstrating compliance with the noise conditions of designation consents, or compliance with other road traffic noise limits that have been agreed on.

The origins of New Zealand practice derive from the Calculation of Road Traffic Noise (CRTN) model and its usage in the UK, where noise control regulations meant that if it was shown that the level of road noise for houses adjacent to highways was 68.0dBA or above, compensation would be paid for noise impacts. The CRTN model was specifically developed for the purpose of determining noise levels at such houses.

The CRTN model was used to predict noise levels, according to the rules of the model, to within 0.1dBA. It was not necessary to undertake noise measurements to verify that this modelled noise level was correct, but obviously the modelling inputs used in the calculation could be reviewed. Although the CRTN model contained a measurement option for establishing the noise level, this option was limited to specific circumstances where the model could be unreliable – otherwise the prediction model, CRTN, had to be used.

In the late 1980s and early 1990s in New Zealand and parts of Australia, new procedures were added to the CRTN process. These were the New South Wales Road and Traffic Authority (RTA) Guidelines (Roads and Traffic Authority 1992) and the 'Transit New Zealand Noise Guidelines', now known as the 'NZTA Noise Guidelines' (Transit NZ 1999). These guidelines sought to control the degree of increase in noise compared with an area's pre-existing ambient noise level. The CRTN model was incorporated into these guidelines to help predict the future noise level of a project, and it could also be used as part of the assessment of existing noise levels.

Prior to this, validation studies of the CRTN model were undertaken in both Australia and New Zealand to establish the model's applicability to the situation in each country, and what, if any, adjustments should be made to it. The validation for uninterrupted traffic flow in New Zealand is described in Barnes and Ensor (1994). An adjustment (of minus 2dBA) to the model baseline for an asphaltic concrete road surface was proposed, and in addition, an adjustment for heavy goods vehicle (HGV) content of traffic flow. (Subsequent research reports, such as Dravitzki and Wood (1999), contain further validation of the model.)

In both New Zealand and Australia, it was accepted that the CRTN model, adjusted appropriately for each country, provided a correlation between measured level and predicted level of noise of ±2dBA within a 95% confidence interval. However, it should be noted that in both the New Zealand validation and the Australian study, it was the noise generation component and the near-field propagation components that were primarily being evaluated by the validation study. This focus on the noise generation component and near-field propagation component is common for many traffic noise model validations, as these are the components most likely to show local variation. The effects of barriers, bunds, and propagation over distance, such as those contained in the CRTN model, are often not validated further, as the basic physics of these effects is the same for most models.

It should also be noted that the measurement conditions are limited to those set out in the CRTN measurement option. Measurement conditions are limited to the following road conditions:

- the road is dry
- most of the wind is towards the receptor, rather than parallel to the road
- the average wind speed does not exceed 2m/sec in the direction of road to receiver
- the wind at the microphone does not exceed 10m/sec in any direction.

The NZTA Noise Guidelines describe the assessment point as the point at which noise levels are measured and/or assessed. The Guidelines do not prescribe that the prediction should be checked by on-site measurements, nor that the current ambient noise should be established by measurement – but this absence of a specific direction to either calculate or measure should not be interpreted as an implied preference for a specific approach.

There are instances when noise measurements are essential. For example, when the Guidelines are applied to low-noise environments, ambient noise levels need to be determined by measurement. This is because when traffic volumes are low or traffic is very distant, ambient noise usually cannot be reliably predicted by road traffic noise modelling the way it can for environments with a higher noise level. This is particularly true for new roads through farmland and well away from nearby major roads.

Apart from these areas where measurement is the only viable way to establish the noise level, practice has evolved whereby existing noise levels have increasingly been established by measurement rather than by modelling – perhaps because others involved in the designation process are more inclined to accept a noise level established by measurement than one established by modelling. In addition, for smaller-scale assessments, measurements may be a much more practicable way of establishing the noise level than via the more laborious process of modelling.

In the early 1990s in New Zealand, a noise assessment would involve a site visit to:

- verify the dominant sources of noise (especially to verify that traffic was the dominant noise)
- appraise the relevant site attributes for input into the noise modelling
- take some sample measurements, usually of a duration of 10–30 minutes – although short, these measurements could be used to estimate a '$L_{Aeq(24\text{-}hour)}$ level' often within an accuracy of 1 to 2dBA.

Developments then led to a requirement for full 24-hour measurements at several key locations on site. This change occurred because of a perception that for the public, and at designation hearings, the short-term measurements were insufficient, and measurement was a more credible means of establishing existing noise levels than modelling. This may have arisen in part because of misunderstandings about the ±2dBA difference between measured versus modelled levels, which is discussed later in this report.

This measurement approach has further evolved into continuous measurements being taken at one site for up to one week. Logging sound-level meters can now record data for several days, and specific meters can monitor and record for weeks or more. Meters are usually left unattended most of the time. It is important that the type of noise can be identified. Traffic noise has a distinctive pattern that is evident in the logged data as long as the logging interval is quite short (say about one minute).

It is claimed that by reviewing the logged data, anomalous data can be identified and removed. This is true for a number of situations, as long as the anomaly has a pattern that is clearly different from the pattern of road traffic noise. However, anomalous noise that has a similar pattern to road traffic noise cannot be readily extracted.

Removing anomalous data creates a gap in the data record that can be filled by an estimate of the true data, but then there is no record of the true data for this gap period. While taking measurements for several days can help to reduce any uncertainty, other significant parameters, such as actual traffic flows or weather, are usually not measured as intensively as noise unless a relevant traffic or weather station is nearby.

Since 2002, the growth in the use of digital noise models such as SoundPLAN or the FHWA’s Traffic Noise Model (TNM) has made it possible to model noise for many locations adjacent to a roadway. On-site measurements used in conjunction with these models are now starting to fulfil the same role as in the early 1990s; that is, they provide a number of reference points across the modelled area that can be collectively used to establish whether the modelled current situation has had the correct inputs. The new situation can then be fitted to the model, and the change in noise determined by comparing the modelled current situation with the modelled future situation.

When applying the NZTA Noise Guidelines, the allowed increase is often only 3dBA, and for a very high noise environment, this allowable increase might be only 2dBA, or 1dBA, or 0dBA. This allowed increase needs to be compared with the margin of error that would have to be allowed for the difference between two independent noise measurements made in different time periods with a Type I sound-level meter, and following the accepted methods of the New Zealand Standard for measurements of environmental sound, NZS 6801: 2008. With good best-practice techniques, this margin of error may be 1dBA or less, but with road traffic noise (which is a source that varies in time) and a noise reading extending over a 24-hour period (meaning that the propagation conditions vary), the margin of error is greater. The purpose of this research was to help identify this variability.

Although the NZTA Noise Guidelines do not prescribe that post-construction measurements be made, most designation conditions for noise require that post-construction noise levels should be measured to ‘prove’ that the noise mitigation has been properly implemented. An example of such a noise condition is shown in section 2.3.

A possible reason for favouring measurement may stem from the way modelling is portrayed. Modelling is usually stated to match measurements by ±2dBA at the 95% confidence interval. This implies that modelling results in a variable quantity and measured noise results in an absolute quantity.

However, both measurements and modelling are subject to variability, but of a different nature. Environmental noise measurements vary according to a range of traffic conditions, weather conditions, and other propagation conditions such as ground-cover condition. This report describes this variability in detail.

In theory, greatly increasing the number of measurements will mean that the true noise level is better identified, but there are economic limitations on the number of measurements that can be made.

Modelling also has some issues. Although the physics of noise propagation are well known, most models simplify many of these conditions in order to make the model more practical and requiring less of a burden of input data. These simplifications reduce the models’ ability to calculate the true noise level. However, if the detailed conditions that occurred during the period being investigated were measured and then input into the model (providing the model was adapted to accommodate this level of input detail), then the noise level measured and the noise level modelled would be a much closer match. Modelling also requires judgements on how to model particular physical situations. Different people using the same model type may vary in how they make these judgements, and this can be a further source of variation of modelled noise level compared with measured noise level.

It would be better to regard a model as representing a set of ideal or typical conditions in which the noise occurs. For example, modelling shows the noise level if:

- it is the annual average daily traffic (AADT) flow that is present
- there is no enhanced propagation due to weather
- the ground conditions remain constant.

Modelling the current situation, followed by modelling the new situation, would then be a much more precise method of determining the typical change in noise levels, and the typical noise level, as long as the physical change (or works) is properly represented in the model.

2.2 What is meant by the term ‘the noise level’?

Neither the NZTA Noise Guidelines nor New Zealand Standard for road-traffic noise from new and altered roads, NZS 6806: 2010, appear to contain a clear statement of what is meant by the term ‘the noise level’ with respect to the noise source being measured or assessed, and the meteorological conditions under which it should be measured or assessed. It is clear that the noise descriptor is $L_{Aeq(24\ hour)}$, but as the noise on any given day is affected by variations in generation and propagation, then further definition is needed.

An indication of what is meant by the noise source is given by the requirement that noise prediction is to be based on the AADT. Thus the noise source is partly defined with respect to traffic volume.

If prediction of future noise levels of a project are to be determined by the CRTN model, which does not include a weather component, then it seems reasonable to assume that ‘the noise level’ is not that which happens to occur by chance on any particular day, but is a more abstract (theoretical, calculated) noise level that would occur at a receiver when the site conditions include the AADT and in atmospheric conditions that are neutral with respect to propagation. If this is not the case, it would be unreasonable to base the design of a roading project and its associated noise mitigation features on the AADT and predicted noise levels based on a CRTN model that assumes neutral meteorological effects, when the project’s compliance could be required in any weather condition acceptable under NZS 6801: 2008. There needs to be a clear direction that the reading must be adjusted for meteorological effects.

The current requirement of NZS 6801: 2008 is only that measurements ‘should’ be adjusted to slightly positive conditions. It is understood that in effect, this is a neutral propagation condition and so aligns reasonably well with CRTN, which assumes only neutral conditions. However, given that inconsistent measurements can occur in neutral or upwind weather conditions, there is no effective way to reliably adjust these.

Also, the AADT is defined as the one-day average of the yearly traffic volume. This is a theoretical traffic volume that may never occur at that precise volume on any day that measurement is attempted. This then calls into question much of current practice in using measurement to establish ambient noise levels, both before and after construction of roading projects, as a means of reliably establishing that the requirement for only a small change in noise (1 to 3dBA) has been complied with. To enable noise measurements to be appropriately adjusted, hour-by-hour noise measurements would need to be matched with hour-by-hour traffic counts and hour-by-hour weather readings of wind, temperature, and cloud cover. All these parameters are seldom measured in the detail that would be required.

Key studies of the noise dose/response relationship (such as Shultz 1979) are based on the long-term noise level. Therefore the noise level to be measured could be the noise level for the AADT present in either the typical weather conditions or neutral weather conditions, but there is no direction or guidance about which approach to take.

Noise assessment reports prepared for roading projects appear to provide little indication of how meteorological conditions were taken into account, other than to highlight that conditions for measurement were suitable, or that a weather station was checked for records of weather conditions during measurements. They mainly seem to have excluded days when noise measurements could not be attempted because the weather was unsuitable.

It appears likely that the current method of addressing the variation that occurs in both the generation and propagation components of road traffic noise follows one of the following two forms:

- The day and weather conditions chosen for the measurement minimise the variation, so the variation, and need to correct for it, need not be considered.
- In the absence of an agreed method of addressing the variation that may occur in the measurement, practitioners adjust for it, or make allowance for it, according to their own perception of the best way to do this.

2.3 Typical noise conditions

Below is an extract from the conditions for a roading project in the Wellington region. These are typical for noise conditions for roading designations since about 1995. These conditions are of a performance style, with an upper-limit noise level set and compliance to be established by measurement. The post-construction noise measurements become a key element in showing that the specific noise-level requirements are met.

> ***Traffic Noise Mitigation***
>
> *22. Four zones are identified. Different requirements for the control of noise apply in each zone. They are:*
>
> *Zone A - all areas adjacent to the proposed road but excluding Zones B, C and D.*
>
> *(i) The Requiring Authority shall take measures to ensure that, in respect of dwellings and teaching areas in educational facilities which existed, and to those for which a building consent existed, at 24 December 1997 (being the date of the Notice of Requirement), exposure to traffic noise from the proposed road will not exceed the levels set out in the 'External Criteria' column of Table 1 below at any time within 10 years of the new route becoming operative. (Measures to be taken include as necessary the construction of fences, bunds or other acoustic barriers.)*
>
> ***Ambient Noise Survey***
>
> *24. No more than 6 months before commencing construction of the proposed road or any section thereof but before construction has commenced, the Requiring Authority shall, for the purposes of Table 1, carry out a noise survey at selected locations to determine current ambient sound levels. The locations shall be identified by the Requiring Authority and approved by the Council Officer or Consultant nominated by the Council's Chief Executive as having the requisite skill and experience.*

Operational Noise Survey

25. The Requiring Authority shall carry out, in accordance with the requirements of the equivalent Council Officer or Consultant, as appointed under Condition 24, an operational traffic noise survey within 6 to 9 months of opening the new road or a section thereof, to confirm compliance with the noise levels set out in Condition 22. If the noise levels in Condition 22 are shown not to be met, the Requiring Authority shall carry out all necessary mitigation measures to ensure compliance.

26. To ensure ongoing compliance the Requiring Authority shall carry out further traffic noise surveys:

(i) Between the 6th and 9th month after the opening of the new road or section thereof; and

(ii) between the 5th and 6th year after the opening of the new road or section thereof; and

(iii) in the case of the part of the road through the Waikanae Christian Holiday Park property, again immediately prior to the end of a 10 year period after the opening of the new road or section thereof.

In accordance with the requirements of the equivalent Council Officer or Consultant as appointed under Condition 24. If the noise levels in Condition 22 are shown not to be met, the Requiring Authority shall carry out mitigation measures to ensure compliance.

[Noise condition] Table 1 Average Noise Design Levels

Noise area	*Noise descriptor*	*Ambient noise level (dB(A))*	*Average noise design level (dB(A))*
Low	*L_{eq}(24 Hour)*	*Less than 43*	*55*
	"	*43–50*	*Ambient +12*
Medium	*"*	*50–59*	*62*
High	*"*	*59–67*	*Ambient +3*
	"	*67–70*	*70*
	"	*More than 70*	*Ambient*

Condition 24 shows that a pre-construction assessment was to be undertaken to establish current noise levels, and these were to be used to establish the design noise level (noise limits) for the individual residences/educational facilities that were impacted. As shown in the table, the allowed change in noise was small, often ranging from 'no more than +3dBA change' to 'no change'.

These conditions also required that once the road was constructed, noise levels were to be established by measurement as complying. For this particular road, the conditions required compliance tests to be made soon after construction, after five years, and after 10 years, to ensure compliance was ongoing over this period.

Several aspects of this condition need comment. The term 'at any time' is used, and the noise index to be used is the 24-hour average noise level, $L_{Aeq(24\ hour)}$. The term 'at any time' could be taken to mean on any day within that 10-year post-construction period. Most acoustic professionals would probably interpret the meaning as a normal (non-holiday) weekday. However, an interpretation based on the NZTA Noise

Guidelines is that this should be the AADT flow, measured in 'neutral' conditions; ie conditions that neither enhance nor decrease the measured noise level.

Designation conditions like this example imply that there is a high level of precision in noise measurement, and successive measurements made temporally well apart could reliably detect a change in noise level as small as 1dBA. However technical literature and information on sound-level meters (eg Bruel and Kjaer 1994) suggests that the variability of quality sound-level meters alone can be as much as this margin.

Designation conditions usually require measurement procedures to be in accord with NZS 6801, which defines how measurements should be made. At present there is no standard or agreed procedure for how compliance is to be established, including, for example, *when* measurements should be made, *how many* measurements should be made, or how one or two *measurements above the limit* should be regarded. In standards for other disciplines, it is common to require that compliance is shown by the mean value of a number of readings, and in addition, that no reading is to vary by more than a specified amount from the mean. For example, NZS 3661.1, a standard for slip-resistant flooring, states that five specimens are to be tested, and for compliance, the mean reading must be a coefficient of friction of 0.4 or greater, and no reading can be less than 0.35.

While the growth of traffic over time is included in the noise assessment, and the imposed noise limit expects this projected growth to have been accounted for, the requirement for measurements at five and 10 years time (as in this particular designation condition) are not included in every noise condition. Other designation conditions may require an assessment immediately post-construction, with this measurement adjusted according to the projected traffic growth and then checked for compliance with the noise limits.

A measurement in 10 years time is fraught with practical difficulties. The designation in the above example is for an area undergoing much residential development, and the whole area could be markedly changed in 10 years. Buildings or plantations that provided screening might be removed; ground levels might be altered by subdivision; land uses and vegetation between residences and the roading project might have changed. Any of these changes could greatly affect the noise levels in the area, and these changes should not be the responsibility of the roading authority. However, under the current system, roading authorities might be held responsible for these changes if they cannot explain the extent of the change in noise, beyond that which has been caused by them, that may have occurred since the road was opened. These measurements are usually required to be the average noise level over the 24-hour day. At present there is no commonly agreed methodology for addressing the day-to-day variability in these measurements.

2.4 NZS 6801:2008

The latest version of NZS 6801: 2008 was published in 2008, superseding the first version NZS 6801: 1999. NZS 6801: 2008 appears to have a greater expectation than the previous version that meteorological effects on the propagation of sound should be taken into account. Section 7.1.4 of NZS 6806: 2008 states that:

> *... in any condition of consent or rule seeking to define how noise is to be measured, it is sufficient to cite measurement of sound shall be in accordance with NZS 6801: 2008. This reference means that the meteorological influences of sound are to be taken into account as described in this section of the standard and its relevant appendices.*

However, the apparent certainty of this clause is weakened by the conditional terms in the preceding clauses, such as section 7.1.1 '... persons measuring sound levels should identify ...' and section 7.1.2

'... to demonstrate compliance measurements should include ...' and '... when predicting sound levels it is recommended that slightly enhanced propagation ...' and section 7.1.3 '... measurements may be conducted ...' Similarly, 'Appendix B: Prediction of sound' is informative.

NZS 6801: 2008 defines a meteorological window in which most measurements should be made. It appears to be more interested in the range of measurements that would occur owing to the range of conditions, rather than a single measurement. Measurements should either be adjusted to slightly positive propagation conditions or include measurements in these conditions. The intention appears to be that the sound level at the high end of the likely range should be included..

Clause 7.1.2 of NZS 6801: 2008 notes that to demonstrate compliance, the slightly positive propagation condition should be included in the measurements. Clause 7.1.3 states that non-compliance can be measured under any conditions in the meteorological window. These two clauses imply that for compliance, the whole range of possible noise readings – excluding those that are anomalously favourable to propagation – need to be less than the required value. However, given their placement in the standard and their prominence relative to other matters in the standard, it does not appear that these clauses are intended to be definitive for establishing compliance in all circumstances. Indeed, when considering road traffic noise expressed as a 24-hour average value (as $L_{Aeq(24\ hour)}$), there are two clear reasons why the interpretation of compliance implied by these clauses of NZS 6801: 2008 may be difficult to substantiate: ie the extent to which meteorological conditions that favour propagation coincide with high levels of traffic noise, and the basis of population response to road traffic noise.

1. **The extent to which meteorological conditions that favour propagation coincide with high levels of traffic noise:**
   The main contribution to traffic noise $L_{Aeq(24\ hour)}$ is the traffic flow occurring during and between the two daily peak traffic rates; ie approximately 7am–6pm. Slightly positive propagation conditions are described by NZS 6801: 2008 as meteorological category 5. Tables B1–B4 of appendix B of NZS 6801 show that daytime meteorological conditions are more likely to have stability categories of A, B or C. Meteorological condition stability category D, if it occurs, is likely to be short-lived in the daytime. In addition, winds of more than 6m/sec in New Zealand are likely to be turbulent, because of the topography. Meteorological category 5, if it does occur is therefore more likely to be in the night-time hours, which make only a minor contribution to the overall traffic noise $L_{Aeq(24\ hour)}$ level.

   In addition, while it is typical for most New Zealand locations to have one or two directions as the dominant source of strong winds or rain, almost all New Zealand sites have wind from multiple directions, so that the number of days when the noise is reinforced by the wind direction will be largely offset by the number of days with the wind blowing in the opposite direction. While NZS 6801 recommends adjusting to the slightly positive wind condition, because the research (eg by Shultz) on subjective response to noise is in relation to the long-term noise level, the neutral condition is more likely to be the *average* long-term level.

2. **Population reaction to noise:**
   Underpinning the NZTA Noise Guidelines on traffic noise is the relationship (as established by Schultz (1979) between the proportion of the population who are highly annoyed by traffic noise, and the noise level measured by the day-night noise index L_{dn}. Berglund and Lindvall (1995) note that many studies since Schultz's publication have tried to disprove his work and many others have sought to confirm it. Although the relationship does exist, it is not strong and there are many other factors that mediate people's reactions to noise. The Schultz relationship was based on the response to a long-term exposure to noise, in terms of months or years. The role of variations in noise level in this overall

'high annoyance' relationship, such as short periods of exposure to enhanced propagation, are not known.

Given these two factors, when using a 24-hour noise index such as $L_{Aeq(24\ hour)}$, we believe it is probably best to use conditions of neutral propagation.

2.5 NZS 6806: Road traffic noise

The New Zealand Standard *NZS 6806: 2010 Acoustics – road-traffic noise – new and altered roads* was published in April 2010. This standard is very similar to the NZTA Noise Guidelines with respect to the following issues that are relevant to this report:

- The standard uses the same noise indicator; ie $L_{Aeq(24\ hour)}$.
- It refers to ambient noise surveys as being part of a way of establishing existing noise levels.
- Although NZS 6806: 2010 sets limits in absolute noise level rather than limits to change of noise level as in the NZTA Noise Guidelines, one of the NZS 6806: 2010 criteria uses a 3dBA change in the ambient noise level as a threshold before the standard is invoked.
- NZS 6806: 2010 expects noise to be predicted for the new or altered road using the CRTN model and AADT traffic flows (as do the NZTA Noise Guidelines), but via a process likely to require the use of an area model such as SoundPLAN or FHWA TNM.
- While NZS 6806: 2010 contains no discussion on how compliance with the Standard is to be established, as of November 2010, draft conditions for projects were being framed under the Standard. These conditions were expected to have a more methods-based focus than conditions under the NZTA Noise Guidelines, but would still have the expectation of a particular acoustic outcome being achieved, perhaps within noise categories rather than specific noise levels.
- Particularly relevant to this research project, NZS 6806: 2010 requires noise levels to be assessed up to 100m from the road edge for roads in urban areas, and 200m from the edge of the road in rural areas. Within these distances from the road, a variety of factors could influence measurement variability.

2.6 Aims of this project

This research project began in 2006 and aimed to:

- determine the best estimates of the day-to-day variability applicable to noise assessments of road traffic noise, especially of state highways
- establish an agreed methodology for determining whether new roads or roading improvements have complied with the negotiated noise conditions required by the council or Environment Court hearing.

The uncertainty involved in road traffic noise measurement, and the conditions under which measurement is likely to yield the most consistent results, were investigated, and the role of measurement and modelling as components of the noise assessment process were reviewed and developed into a set of guidelines for establishing compliance. Recommendations for managing uncertainty in noise assessment were also developed.

This research is intended to help address such issues as:

- the over-designing of noise mitigation measures as a compensation for uncertainty

- the high risk of disputes over whether or not roading authorities have complied with the noise consents attached to their new construction projects.

This report provides practical solutions for recognising and reacting to possible sources of bias, and provides useful estimates of the uncertainty of noise measurements in real-life conditions.

2.7 Change in methodology

This project's methodology was originally framed with a view to gathering the evidence of the variability in road traffic noise measurement via measurement only. The project's budget was framed around establishing measurements adjacent to several different road types, and then measuring at a range of distances from these roads over several weeks. Simultaneous measurements of traffic flows and weather conditions would also be made. Subsequent analysis would then identify the variability of measurement.

However it soon became clear that a different approach was needed. We found that variability could be divided into two types – variability in noise generation and variability in noise propagation. We found that there had already been extensive research done on the variability of propagation, carried out over a much greater range of conditions and for longer periods than our current study could accommodate. Our current study, if carried out, would have only added a further dataset to this extensive literature. Therefore, it was decided that the variability of noise propagation could be better investigated by both a review of the literature on the effects on propagation, and via calculations using models applied to conditions identified in the standards as acceptable for noise measurement.

Using detailed analysis of extensive traffic flow measurements and the data gathered for previous research, we could draw on a much wider range of traffic flow situations, and on data over several years, as well as include factors that influenced variability in noise generation over the medium to longer term.

3 Understanding the theory of measurements and uncertainties

Noise conditions and noise assessments made in accordance with the NZTA Noise Guidelines and parts of NZS 6806: 2010 require measurement of the noise level both before and after the ‘road improvements’, with the difference being attributed to the influence of the improvements themselves.

3.1 Practical solutions to managing uncertainty

To determine how the improvements have affected the long-term noise level at a site, the degree of uncertainty regarding the measured noise level should be as low as possible. However, there are many factors that can cause uncertainty in noise measurements because the measured noise level on any particular day is influenced by a multitude of factors: some that can be recognised and accounted for, and others that are not readily recognised and must always be considered to be a source of error. The assessment should strive to detect and avoid the recognisable errors, while quantifying any remaining variability and incorporating this as an uncertainty regarding the long-term noise level.

3.2 Restrictions

To provide estimates of uncertainty that are of a specific magnitude, it is necessary to define the range of conditions within which the uncertainty applies. In determining the uncertainties, we assume that ‘reasonable’ conditions for noise measurement are present during all measurements. The intent is for the uncertainty to cover the variation in noise level due to factors that cannot reasonably be identified and accounted for by the practitioner. The environmental states and conditions that are obvious to the practitioner (such as wet road, road works or strong winds) are not accounted for in the uncertainty, because these are already covered by the current methodology – they would be reported, and measurements taken before and after the change would not normally be considered equivalent. For example, if a road was resurfaced between measurements, the change would be noted by the practitioner and the measured noise levels would not be considered equivalent, as they were effectively measuring two different situations. Similarly, if the weather fell outside of a certain range of conditions, no noise measurements would be made.

This philosophy would also exclude sets of measurements not taken within a reasonably short time frame, because gradual changes in the environment may not be obvious to the practitioner, but could have a significant impact on the measured noise level. For example, the progressive wearing of the road surface over several years, which can alter the noise by about 1dBA, can easily be missed by a returning practitioner, and would almost certainly be missed if a different practitioner made the second set of measurements. It is not reasonable to expect this pair of measurements to agree, and it is generally not feasible to incorporate this type of systematic error into the uncertainty analysis. Ideally, ‘before’ and ‘after’ measurements would be no more than a few weeks apart. However roadworks and any ‘settling-in’ of the road surface typically occur over a time period of months, which therefore has to be the basis of the time frames considered in this report.

3.3 Interpretation of findings

The uncertainty limits presented within this research can be considered to be the inherent uncertainty in road noise measurement when it is taken using current best practice. Their magnitude is largely a result of the fundamental variability of sound generation and transmission, and it is unlikely that they can be reduced much by improved practice or equipment (other than advised herein). However, errors of greater magnitude than the uncertainties specified here are quite possible if best practice is not followed or if freak conditions are encountered but not recognised.

3.4 Definition of terms

The following definitions of statistical terms are given in the context of noise measurement, and in particular, of estimating the long-term average noise level, $L_{Aeq\,LT,}$ at a specified location.

3.4.1 True noise level

The true noise level at any receiver can never be determined exactly, as every measurement involves some degree of uncertainty. Furthermore, the definition of true noise level itself is open to interpretation, as it involves simplifying the complicated interactions of air and ear, over space and time, typically into a single value in decibels. In this report, the quantity sought is assumed to be $L_{Aeq\,LT}$, the long-term continuous energy-equivalent sound pressure level, in A-weighted decibels (for simplicity, referred to as the ‘long-term average noise level’).

3.4.2 Assessed noise level

The assessed noise level is the best estimate of the true noise level, and includes consideration of the accuracy with which it predicts the true noise level, as well as a description of what it is considered to measure. The assessed noise level may be determined by measurement or prediction, and may be based on one or more measurements. Limits of uncertainty are necessary to estimate the range of values within which the true noise level lies.

3.4.3 Error

The term ‘error’ refers to the difference between the measurement itself and the long-term average noise level – the quantity we are attempting to estimate. Error in this context does not imply a mistake or failing of operator or equipment. Error may be broken down into two categories: random error, which can be thought of as ‘scatter’; and systematic error, commonly known as ‘bias’, which is a difference in mean values.

3.4.4 Random error (precision)

Random error quantifies the inherent imprecision of a measurement; the unpredictable component of a set of measurements.

There is a limit to the precision with which the long-term average noise level can be estimated, owing to the limitations of the measurement process and the variability of the noise level from day to day. Steps may be taken to account for the various factors that affect the noise level, but a certain level of uncertainty is inevitable. Over many measurements this uncertainty will tend towards zero, as the individual random errors ‘average out’ and the assessed noise level more closely reflects the true (long-term) noise level. If the inherent variation is small, then fewer measurements are needed to get a good estimate of the true value. If the inherent variation is large, then the uncertainty will also be large unless many measurements are taken to reduce it. Reduction of random error is usually achieved through increasing sample size, although selective sampling can also reduce random error.

Examples of random error are the day-to-day fluctuation of traffic volume and small-scale environmental effects.

3.4.5 Systematic error (bias)

Systematic error has the same size and sign in every measurement taken, and has the same recurring cause. This is commonly referred to as bias.

Systematic error occurs when there is a consistent difference (positive or negative) between a measurement and the actual value of the quantity. A systematic error cannot be detected by analysis of the survey data alone – some prior knowledge or observation is necessary for detection. To address systematic error, measurement can be avoided during conditions known to promote the error, in favour of those conditions that do not; or alternatively, a correction factor can be applied to measurements known to contain a bias. The bias cannot be reduced by increasing the number of measurements, as it always 'pushes' the result in the same direction. If a bias is correctly identified and quantified, it can be corrected by basic subtraction of the error from the measurement.

Examples of bias in noise measurement include:

- noise differences due to the seasonal fluctuation of traffic volume
- badly calibrated or drifting equipment
- how the particular environmental conditions on the day of measurement differ from the 'typical' conditions (upwind, downwind, inversion, etc).

3.4.6 Confidence interval

The confidence interval provides an estimate of the range of values within which the true noise level is likely to fall. The interval is usually constructed around the mean of a set of measurements (or single measurement), and the limits of the interval (confidence limits) are determined by the random error of the measurement. The random error is usually estimated from the sample variance, but it may also have been determined previously.

A percentage likelihood that the interval includes the true noise level, where the likelihood is usually 90%, 95%, or 99%, is commonly presented in one of two ways:

- as a conventional interval, eg 58 to 62dBA
- as a central value with uncertainty limit, eg 60±2dBA.

In noise measurement, the upper and lower limits of uncertainty could be asymmetrical about the mean, owing to the logarithmic scaling decibel, and therefore the conventional interval format is the more accurate representation, and will be used herein. However, there are indications from measurements of the distribution being reasonably normal about the mean, and the central value method is probably adequate.

3.5 Uncertainty and bias in noise measurement

Every measurement of a quantity involves some amount of uncertainty. The uncertainty is due to the limitations in precision with which the measurement is made, and to external factors influencing the quantity to be measured. In noise measurement, it is usually some kind of long-term average noise level that is sought. For this analysis, as mentioned earlier, the quantity that is sought is assumed to be $L_{Aeq\,LT}$, the long-term continuous energy-equivalent sound pressure level, in A-weighted decibels.

3.5.1 Random sampling

In most sciences, multiple random samples are taken to reduce uncertainty that is due to random error. It is also possible to estimate the magnitude of the random error by analysing a large set of samples. In noise assessments, and in part because it is a 24-hour average level being measured, economical and practical limitations often dictate that assessments be based on one sample (or a very small number of samples) of the noise environment[1]. The random error of measurement cannot be estimated from the distribution of many samples, so, instead, knowledge of the random error typical of noise measurements is required in advance. It has typically been up to the practitioner to estimate, through experience and guesswork, the limits of uncertainty for a particular noise measurement.

Providing estimates of the typical uncertainty of outdoor noise measurement is a primary aim of this study. There are a number of ways to express uncertainty, but the most useful, from a practical point of view, is the confidence interval.

Another way in which noise measurement may differ from other types of measurement is that sampling conditions are unlikely to be randomly selected. There are conditions under which measurement is avoided (eg in bad weather, or during a public holiday), and conversely, under which measurement is desirable (eg Monday to Friday evenings are popular for 24-hour measurements because they fit in with the practitioner's working week). While non-random selection will usually help to control the influence of external factors, it does have an influence on what we consider to be 'random error'. Clearly, limiting the survey to one measurement means there is zero chance that random error can be 'balanced out' by the other samples. A factor that is a source of random error over many samples will technically be a systematic error for a single sample – it 'pushes' in only one direction – although it is usually still useful to treat it as a random error in the analysis. This is dealt with in more detail later in this section.

The discussion in this report is based on a continuous 24-hour measurement taken to determine a single average noise level. We attempt to consider all factors affecting the noise measurement, as well as those that affect its use as an estimate of the long-term average noise level. In doing so, we advise on which effects may reasonably be considered as random errors of measurement and, wherever possible, provide a quantification of the uncertainty to be expected as a result. We also highlight potential sources of systematic error, provide estimates of their likely effect, and advise on whether measurement is reasonable given the presence of the systematic error, and whether a correction factor should be introduced.

3.5.2 Illustrated example of random and systematic error

Figure 3.1 demonstrates a hypothetical situation where a single noise measurement is made, and its uncertainty is estimated by some method (eg from a published table, previous noise measurements, etc). The random error is assumed to be randomly distributed. For this example, the uncertainty at the 95% confidence level has been arbitrarily set at ±2dBA (these limits and the associated normal curve are shown in the figure). In practical terms, the uncertainty limits define the range within which there is a 95% likelihood that the actual value lies. As can be seen from the figure, the measurement was 60dBA, and the ±2dBA uncertainty means that for a correctly defined uncertainty distribution, there is a 95% chance that the actual level lies within the interval 58dBA to 62dBA. In this example, the actual level is shown as 59dBA, which is indeed within the interval. The benefit of including a sensibly defined confidence interval

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[1] Sound is a continuous phenomenon, and modern sound-level meters actually take samples many times per second. However, the concept of a representative 'noise level' at a location is discrete and necessitates much longer-term measurements.

is clear: it is possible, with a measurement of 60±2dBA, to say with high certainty[2] that the actual noise level is greater than 58dBA.

Figure 3.1 Demonstration of random error in noise measurement

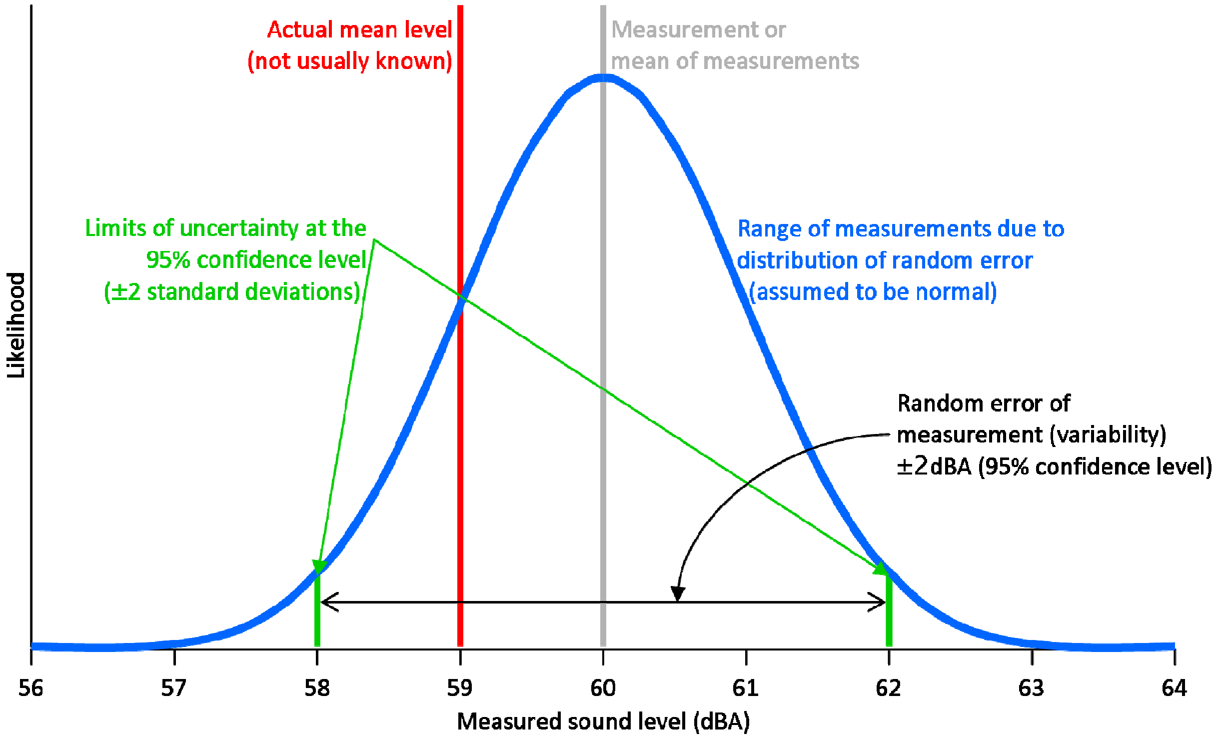

Figure 3.2 shows the same situation, except that there is a systematic error (bias) of +1.5dBA introduced into the measurement. This could be due, hypothetically, to the noise meter having drifted off calibration, or abnormal weather conditions interfering with sound propagation, or a combination of several factors. Whatever the cause, the measured level will always be 1.5dBA higher that it should be. This is different from the random error accounted for by the error distribution curve (as in figure 3.1) because this error is always biasing the measurement in one direction, whereas a purely random error is random about (above or below) a true mean. If the bias is not accounted for, the practitioner is likely to come to the wrong conclusion. For example, if the bias of +1.5dBA shown in figure 3.2 is not corrected by subtracting 1.5dBA from the measured value, the practitioner may come to the conclusion that there is a 95% likelihood that the actual noise level lies between 59.5dBA and 63.5dBA, which is false.

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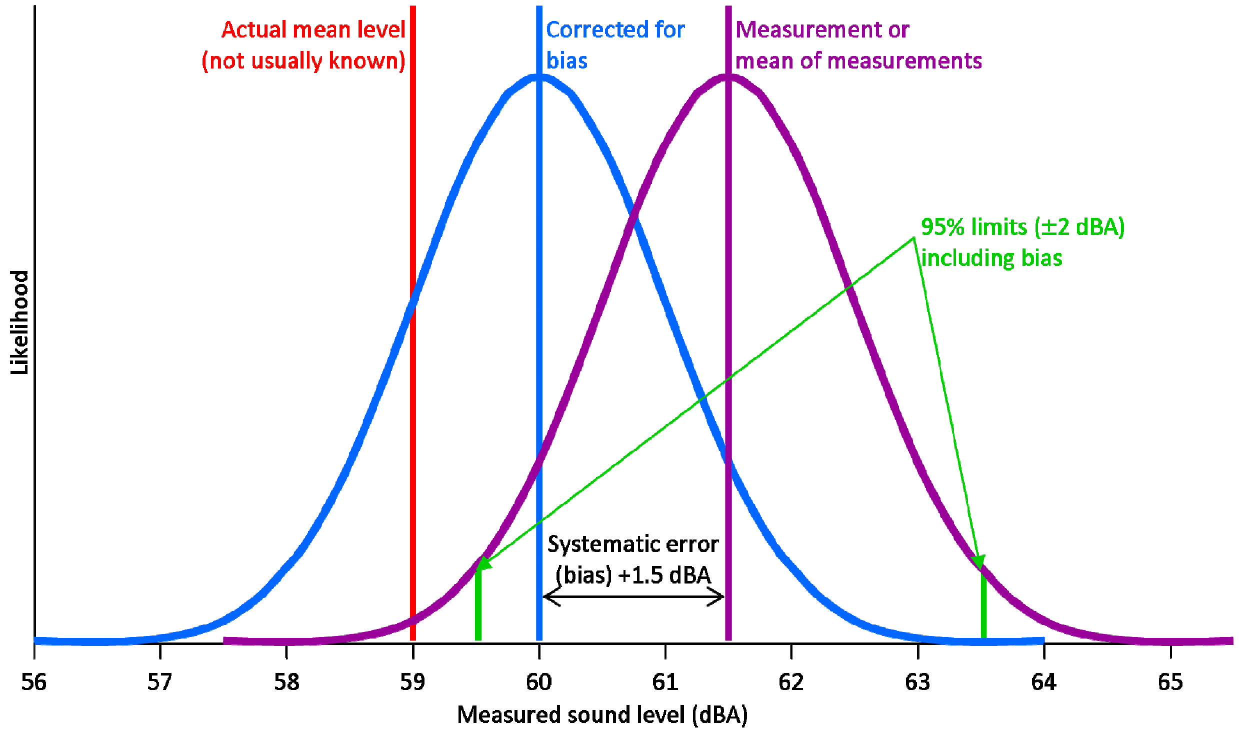
[2] High certainty being 97.5% in this case, as long as the estimate of random error is a good one.

Figure 3.2 Demonstration of systematic error in noise measurement



Though often a difficult task, if the bias can be identified and if the magnitude and direction of the bias can be determined, then the measurement can be corrected by subtraction of the bias. Once the bias has been removed then the measurement result in figure 3.2 (in purple) becomes the same as discussed for figure 3.1.

3.5.3 Determining the bias

If many samples are taken, phenomena affecting the measured quantity in a random manner (symmetrical variations about a mean) will average out over the course of a survey, and can reasonably be neglected as a bias. For example, the day-to-day changes in traffic volume will not have a substantial effect over an average of 20 days worth of noise measurements. However, if very few samples are taken, these effects will not average out, and then they become potentially significant errors. At the extreme of only a single noise measurement, it could be considered that there is no random error other than instrument precision, and that every factor affecting the measurement is acting as a bias. In practice it is more constructive to consider the measurement uncertainty to be composed of two parts: random error about a mean, and systematic error (bias) displacing the mean. In this interpretation, the random error incorporates all the variables that will not, or cannot, be completely accounted for by other methods, and the systematic error is limited to factors that are substantial in effect and can be realistically identified and corrected. Note that a correction to a systematic error contains its own uncertainty.

Given the unique nature of small non-random samples as discussed above, it is possible, to some extent, to choose which type of error a certain factor will fall under. The already non-random sampling may be further focused on particular traffic or weather conditions, perhaps increasing systematic error, but reducing random error because the samples are being drawn from a more uniform population. If significant gains can be made that outweigh the negative impact of the introduced bias, limitations to measurement conditions may be favourable. For example, the practitioner may chose to measure only in downwind conditions, to minimise variation between samples. This will introduce a bias, but the gain due to increased consistency (reduction of random error) may be deemed to be worth it. It may then be possible to use a correcting factor to reduce the effect of the bias and achieve a net gain to accuracy.

Conversely, if further focusing the sample on a particular condition reduces the random error only slightly, the added restriction of measurement conditions and additional complication of properly correcting for the bias may not be worthwhile. In some cases the uncertainty introduced in applying the bias correction may completely negate the consistency improvement. Naturally there is a 'grey area' between the two extremes, and each factor must be investigated individually to determine whether it would benefit from restriction of measurement conditions.

Given that systematic error is always present at a fixed value, and the random error may take any positive or negative value up to and beyond its confidence limits, the magnitudes of the errors are not directly comparable.

A further complication is the fact that noise levels add logarithmically when calculating average values. Despite the added complexity, this may work to the benefit of the practitioner because it means that higher noise levels dominate the average. For example, if it is observed that half the time the wind is blowing downwind, and downwind measurements are typically 5dBA louder than upwind measurements in that location, then the resulting averaged noise level and its uncertainty are almost totally dependent on the downwind measurement. The bias due to measuring during downwind conditions is therefore minimal, and because downwind measurements have much lower random error than measurements taken upwind of the source, the uncertainty limits are also relatively narrow.

4 The noise source

The noise source considered in this report is road traffic noise. Factors affecting the noise source are:

- the volume of traffic
- the number of HGV
- traffic speed
- the characteristic make up of both the light-vehicle fleet and the HGV fleet
- road surface type
- road surface condition
- road gradient.

The extent to which these factors vary, and the period over which they vary, can differ for the individual factors. The first three factors can change on a daily, weekly, seasonal and long-term basis.

The following table shows the data sources used in this project to identify the variability in the factors that influence noise emissions from roads.

Table 4.1 Data sources used in this project for determining variability in factors affecting noise emission from roads

Factor	Size of dataset used	Source of data used
Traffic volume	365 days of data at 8 sites	NZTA state highway traffic data collection system
Percentage HGV	365 days of data at 4 sites	NZTA state highway traffic data collection system
Traffic speed	2–3 days of data at 8 sites	Dravitzki and Wood (1999)
Road surface type	Approximately 40 sites	Dravitzki and Kvatch (2007)
Road surface condition – surface wetness	2 sites	Dravitzki and Kvatch (2007)
Road surface condition – aging	Approximately 20 sites	Dravitzki, Walton and Wood (2006); Dravitzki and Kvatch, (2007)

Note that 'percentage HGV' is used in preference to 'number of HGV', as this is how the majority of HGV data is made available, and corresponds with how some noise-prediction models accept input data.

4.1 Noise effects of variation in traffic volume and number of HGV

To assist in the analysis of variability of the noise source, a conceptual model of the different road types was formulated and is shown in figure 4.1. The figure depicts characteristics of the traffic flows of some distinct highway types, expressed in the context of a highway linking two major cities.

State highways tend to have the following two main roles:

1 As a major link between cities for both cars and HGV carrying freight, which make the full journey from one major city to another major city, so their number is reasonably constant as assessed anywhere along the route. For the links between major cities (including, for example, Auckland,

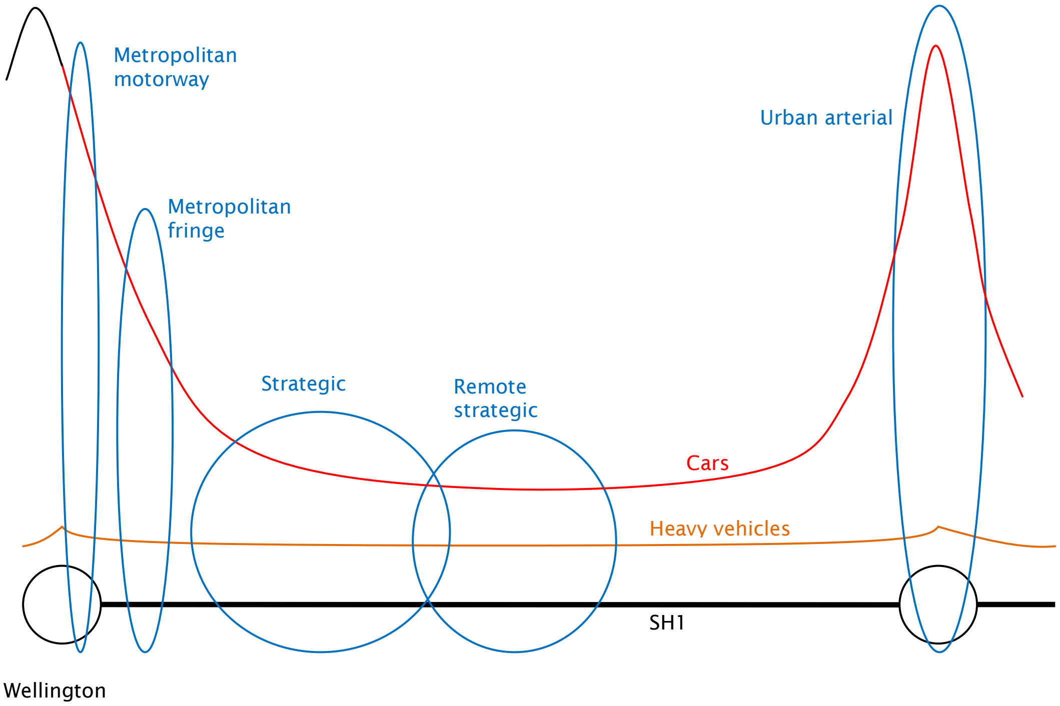
Wellington and Christchurch), we have called this a ‘strategic’ role, and where this role dominates with respect to the traffic flows evident, we have termed the highway a ‘strategic highway’.

2 As a major local road near main towns and cities, with local traffic entering the state highway for that much shorter local journey so that close to these towns and cities, traffic volumes, especially cars, increase markedly.

Figure 4.1 (not to scale) illustrates the relative volumes of light vehicles and HGV during the daytime over this hypothetical section of the state highway network, and shows how car volumes show a strong ‘city-proximity’ effect, while HGV volumes are fairly consistent over the entire route.

Roads linking provincial cities are usually similar to those in the figure, but on a smaller scale. We have termed these roads ‘rural highways’, to distinguish them from the links between major centres as described above.

Figure 4.1 Illustration of the city-proximity effect on traffic volumes on strategic highways (daytime)



These different road types have different traffic properties, and hence different noise emission properties.

The metropolitan motorway has very high traffic volumes and a near-continuous flow, with peaks. The number of HGV is high, but appears low as a percentage of traffic flow (perhaps 5%) because the number of cars is so high.

At the metropolitan fringe, the traffic flow is dominated by cars, though not to the same extent as for the motorway. Further from the cities, as depicted in figure 4.1, the total number of HGV remains reasonably constant, but the percentage HGV will rise (typically 8–12%) because the number of cars is decreasing.

In remote locations between the cities, the daytime percentage of HGV may be quite high, perhaps 15% or higher. Strategic highways link major cities, but their rural sections are well removed from the influence of major cities and intervening provincial cities, and are characterised by drastically reduced numbers of cars at night. However, the HGV flow between the two major cities provides fairly constant numbers of HGV over the entire 24 hours, and as a consequence, night-time HGV percentages can be 40–50%.

Rural (non-strategic) highways (not depicted in figure 4.1) link towns and cities within a province, and generally have fewer HGV than strategic routes. These also experience a strong drop-off in both light- and heavy-vehicle volumes at night.

In this study, only urban arterial roads that were also state highways were examined, because of data availability. Urban arterial roads are characterised by low proportions of HGV (below 5%) because of high car volumes, but they can vary in other characteristics, depending on the location and primary function of the route.

For this study, traffic data from a variety of highways chosen to represent these different road types was analysed for day-to-day variability of traffic and the consequent impact on noise generation. The aim was to gain an appreciation of the extent of this variability over a broad range of classifications, rather than to define a noise profile for each road classification. For this purpose, the single sample of each road type, specifically selected to highlight a situation illustrated by figure 4.1, was sufficient. The roads for which data was examined, and their classifications, are presented in table 4.2. (For further information on road classifications, refer to Traffic Design Group 2001).

Table 4.2 Roads included in analysis

Road type	Highway (chainage) name – description	Data origin	Traffic volume	%HGV
Metropolitan motorway	SH1N (1068) NGAURANGA SB – overpass	Telemetry	Yes	Yes
	SH1N (1068) NGAURANGA NB – overpass	Telemetry	Yes	No
Strategic highway at metropolitan fringe	SH1N (1040) PUKERUA BAY	Telemetry	Yes	Yes
Strategic highway	SH1N (988) OHAU – Ohau over-bridge	Telemetry	Yes	No
Strategic highway well away from urban influence	SH1N (827) HIHITAHI – near Deacons Rd	Telemetry	Yes	Yes
Rural highway with urban influence	SH2 (895) CLAREVILLE – north of Whites Line	Telemetry	Yes	No
Rural highway	SH2 (937) RIMUTAKA – north of Pukuratahi Br.	Telemetry	Yes	Yes
Urban arterial	SH1N (1076) Patterson St – south of Basin Reserve	Survey	Yes	No
	SH1S (343) Russley Rd, Chch – north of Ryans Rd	Survey	Yes	No
Provincial urban arterial	SH3 (241) Coronation Ave, New Plymouth	Survey	Yes	No
	SH45 (1) Powderham St, New Plymouth	Survey	Yes	No

The NZTA supplied traffic volume data for the 12 sites identified. For 7 of the sites, telemetry data was available for the full 2005 year, and for the remaining 5 sites, only survey data was available.

The data was analysed for day-to-day variation, and two factors were identified that could possibly contribute to measurable bias in noise measurement if not accounted for: the holiday season, and the day of the week.

4.1.1 Variation in traffic volume by time of the year

By graphical observation of the data for each site, it was noted that public holidays and the summer holiday season had noticeably different daily traffic volumes from the rest of the year (this tested significant at *p*<001). Analysis revealed that flows were generally disturbed (relative to the majority of the year) for much of December and January. Public holidays also resulted in disturbed flows and affected the weekend nearest to the holiday. Therefore this analysis grouped the days of the year into three sets: 'all year', 'holidays', and 'non-holidays' (see table 4.3).

Table 4.3 Groupings of days of the year into holidays and non-holidays

Set name	Size of set	Description
All year	365 days/annum	Every day of the year
Holidays	50 days/annum	First 4 weeks of January, last 2 weeks of December, public holiday weekends
Non-holidays	315 days/annum	All days that do not fall within the 'holidays' set

Where there was sufficient available data for each road classification, the daily traffic volume data was divided into the sets 'holidays' and 'non-holidays' (as defined above), and analysed for day-to-day variability and for any systematic error (compared with 'all-year' data). Note that this analysis excluded the effect of the shorter end-of-term school and university holidays, as these are not holidays for the majority of the driving public and there is also some variability between the institutions as to when they occur.

A 95% confidence interval in decibels was constructed for traffic volume for each site and time grouping. The 2.5th and 97.5th percentile traffic volumes were used to calculate sound pressure levels (SPL) using the CRTN method, holding all other factors constant (%HGV speed, surface, etc). The width of the interval derived in this manner was therefore accurate, but would not be symmetrical about the mean value because of the logarithmic scaling. We adopted a $[-\Delta L_{low}, +\Delta L_{high}]$ notation instead. Table 4.4 presents the uncertainty for each road classification in dBA at the 95% confidence level. This was interpreted as the range within which the actual noise level would be contained 95% of the time (eg in 19 out of 20 measurements). The variation for measurements taken randomly throughout the entire year ranged from approximately ±1dBA to ±3dBA, depending on road classification. Limiting measurement to non-holiday periods had relatively little effect on the day-to-day variability of noise emission due to traffic volume.

Table 4.4 Day-to-day variation of traffic volume over the year, in terms of SPL

Road classification	All year (365 days pa) ±dBA @ 95%	Non-holidays (315 days pa) ±dBA @ 95%	Holidays (50 days pa) ±dBA @ 95%
Metropolitan motorway	-1.2, +1.0	-1.0, +0.8	-1.8, +1.2
Strategic highway at metropolitan fringe	-0.8, +0.6	-0.8, +0.6	-1.2, +1.0
Strategic highway	-1.1, +0.9	-1.1, +0.9	-0.8, +0.6
Strategic highway well away from urban influence	-3.6, +2.0	-3.0, +1.8	-2.3, +1.5
Rural highway with urban influence	-1.2, +1.0	-1.1, +0.9	+1.4, -1.0
Rural highway	-2.6, +1.6	-2.3, +1.5	+1.8, -1.2
Urban arterial	*[a]	-0.5, +0.5	*[a]
Provincial urban arterial	*[a]	-1.6, +1.2	*[a]

a) Not enough data was available for a reasonable analysis.

The actual long-term noise level, $L_{Aeq\ LT}$, is a function of the long-term (annual) traffic volume, and therefore the AADT is considered to afford the mean noise-emission level for the year. If noise measurements are made over some small portion of the year, then a bias may be introduced due to the fact that traffic flow changes over the year. As explained, examination of the data reveals that particularly atypical traffic volumes arise over the summer holiday period, and for the few days surrounding public holidays. Therefore the data for this research was analysed to determine whether measurement during the holidays introduced a bias relative to the annual average level, based on the AADT. Likewise, avoiding holidays may introduce a bias, and the size of this bias was also determined.

Table 4.5 presents the average bias between the 'holiday' and the 'all-year' noise emission, and between the 'non-holiday' and the 'all-year' noise emission. This was a systematic error, a positive number indicating that the time grouping was, on average, noisier than the 'all-year' noise level, and a negative number indicating that it was quieter than the annual average level ($p < .01$).

Table 4.5 Systematic error (bias) due to holidays

Road classification	Average bias: non-holiday minus AADT dBA	Average bias: holiday minus AADT dBA
Metropolitan motorway	-0.2	0.8
Strategic highway at metropolitan fringe	0.1	-0.5
Strategic highway	-0.1	0.1
Strategic highway well away from urban influence	-0.1	0.5
Rural highway with urban influence	-0.2	1.4
Rural highway	0.0	0.0

From table 4.4 it is clear that restricting measurement to either non-holidays or holidays reduced the day-to-day variability by some small amount. However a more important result was the difference in the average noise level between holiday and non-holiday periods, the systematic error shown above in table 4.5. Roads may have fundamentally different noise emissions during the holiday period – some may increase, while others may decrease, relative to the rest of the year. This data shows a difference between holiday and non-holiday periods ranging from -0.6dBA through to +1.6dBA, and it is likely that more extreme examples could be found within other New Zealand sites. This is compounded by the fact that it is relatively hard to predict what the holiday bias will be for a particular site, unless detailed traffic data throughout the year is available.

Standard practice when making traffic noise measurements (following the requirement for noise levels to be 'representative' under NZS 6801) is to avoid holiday periods because of the atypical flows that may occur. This practice is supported by the data, given the range observed within this small sample of roads. Clearly, limiting measurement to non-holiday periods also introduced a systematic error, but this appeared to be fairly insignificant, on the scale of a few tenths of a decibel. Note that holiday traffic (as defined here) made up less than 15% of the days in the year. However, as is discussed in the next section, traffic flows also varied between weekend and weekday, so that the proportions of the year that might be called 'representative' conditions, and the proportion that might be called 'non-representative conditions', were almost equal.

An alternate means of accounting for systematic error is to apply a correction factor to the measurement to cancel out the bias. There is currently no table of correction factors available, and it is highly unlikely that this could be economically produced and validated. A preferred approach is to adjust the measurement to the AADT, if reliable traffic counts are available (ie from an automatic counter, not a short sample count).

4.1.2 Variations in traffic volume by season

To varying degrees, most roads have a seasonal pattern of increased traffic during summer and decreased traffic during the winter months (significant at $p<0.01$), and this is a potential source of systematic error. However, at its extremes, as shown in table 4.5 above, the seasonal effect (excluding the effects from the summer holiday period) had an impact on noise emission of less than half a decibel. Because of the low magnitude of the cycle relative to the inherent variability of traffic volumes, it was absorbed into the day-to-day variability for each road type, rather than accounted for separately.

4.1.3 Variations in traffic volume by day of the week (non-holiday traffic flow only)

Day of the week was also identified as a factor that strongly influenced traffic volume. Although the nature of the influence depended on the type of road, a pattern common to all the sites was the relatively stable distribution of traffic from Monday through to Thursday. The Friday to Sunday traffic pattern was highly dependent on road classification, and in all cases differed to the weekday pattern (significant at $p<.01$). These findings were in line with Traffic Design Group (2001), which also notes that the traffic properties of Friday are often different from the other weekdays. In this analysis, Friday was therefore grouped within ‘weekend’.

Table 4.6 Groupings of days of the week

Set name	Size of set	Description
All week	7 days/week	Every day of the week
Weekdays	4 days/week	Monday, Tuesday, Wednesday and Thursday
Weekend	3 days/week	Friday, Saturday and Sunday

A 95% confidence interval was constructed for traffic volume for each site and time grouping. Traffic volumes were converted into sound pressure levels (SPL) using the CRTN method, holding all other factors (%HGV, speed, etc) constant. A confidence interval for SPL in each time grouping was then produced for each road type.

In general, each road classification’s weekly pattern was quite consistent over the whole year. However, to reduce confounding factors, and recognising the holiday effect identified earlier, the day-of-the-week analysis was performed only on the non-holiday data for each site.

Table 4.7 shows the day-to-day variation for each of the different intervals within the week. Limiting measurement to only weekdays resulted in a reduction in the uncertainty for most road classifications, sometimes by a factor of 2. Weekend measurements were generally no more consistent than random measurements made at any time during the week (the ‘all week’ group).

Table 4.7 Day-to-day variation due to traffic volume within the week, in terms of SPL

Road classification	All week (Mon–Sun) ±dBA @ 95%	Weekdays (Mon–Thu) ±dBA @ 95%	Weekend (Fri–Sun) ±dBA @ 95%
Metropolitan motorway	-1.0, +0.8	-0.3, +0.3	-1.0, +0.8
Strategic highway at metropolitan fringe	-0.8, +0.6	-0.7, +0.6	-0.7, +0.6
Strategic highway	-1.1, +0.9	-0.7, +0.6	-0.9, +0.8
Strategic highway well away from urban influence	-3.0, +1.8	-2.1, +1.4	-2.2, +1.5
Rural highway with urban influence	-1.1, +0.9	-0.5, +0.5	-1.4, +1.1
Rural highway	-2.4, +1.5	-0.9, +0.8	-1.2, +1.0
Urban arterial	-0.5, +0.5	-0.5, +0.5	-0.5, -0.5
Provincial urban arterial	-1.7, +1.2	-0.9, +0.8	*[a]

a) Not enough data was available for a reasonable analysis.

When compared with the expected annual average, table 4.8 shows that measuring only on either weekdays or on weekends introduced a bias. Because of the fairly balanced split between the size of the time groupings (four weekdays versus three weekend days) the systematic errors were also quite symmetrical. Using the medium state highway as an example, weekdays were consistently 0.5dBA quieter than the average, and weekends were about 0.5dBA noisier than the average; or, equivalently, weekends were about 1dBA noisier than weekdays for this road type. For most of the locations studied, the weekends were noisier than the weekdays.

Table 4.8 Systematic error (bias) due to day of the week, in terms of SPL

Road classification	Average bias: weekdays dBA	Average bias: weekend dBA
Metropolitan motorway	+0.2	- 0.2
Strategic highway at metropolitan fringe	-0.6	+0.7
Strategic highway	-0.1	+0.2
Strategic highway well away from urban influence	-0.2	+0.4
Rural highway with urban influence	-0.5	+0.5
Rural highway	0.0	-0.1
Urban arterial	0.0	+0.1

4.1.4 Summary of day-to-day variability due to traffic volume

4.1.4.1 Road classification

Day-to-day variability in noise emission depended largely on the road classification: metropolitan, urban, and associated arterial highways had much lower internal variability (random error) than more remote and rural highways.

Routes accommodating significant commuter traffic (metropolitan motorway, urban fringe) typically had stable weekday flows, and may have had reduced flows over holiday periods or weekends. These roads were generally quite consistent from day to day, and even when including weekends and holidays, the random error appeared to be in the region of ±1dBA. Excluding weekends and holidays could reduce this to less than ±0.5dBA.

4.1.4.2 Holiday periods (excluding school term holidays)

By avoiding measurement during the summer holiday period and for several days before and after public holidays, bias due to the sometimes substantially different traffic volumes during those times could be avoided. Based on the data to hand, this bias was in the range -1dBA to +2dBA, depending largely on road classification.

4.1.4.3 Seasonal cycle

There was a statistically significant seasonal variation in traffic volume (excluding the holiday period), with higher volumes in the summer than in the winter. The rate of change of noise level was very slow, and the amplitude of the variation was below 0.5dBA for all of the sites analysed. For practical reasons, it was recommended that the seasonal effect on noise emissions should be ignored as a bias (remembering that holidays are already excluded). This effect was accounted for within the day-to-day variation, as the data contributing to the estimates of random error had not been adjusted for the seasonal cycle.

4.1.4.4 Weekdays/weekends

By avoiding measurement on Fridays, Saturdays and Sundays, the day-to-day uncertainty due to traffic volume could be reduced by around 50% for most road classifications (that is, reduced by approximately 0.5 to 1dBA). This may be desirable if the only goal is consistency of measurement. However as discussed earlier there is considerable ambiguity as to what is meant by the term ‘the noise level’, especially with respect to the traffic conditions that generate it and the environmental conditions in which it is measured. Many roads had higher noise levels during the weekends (often by >1dBA), and this may also be a time when communities are the most sensitive to noise – therefore, the weekend may be the most appropriate time to make the noise measurement.

The choice of measurement day should be decided on a case-by-case basis, taking into account repeatability, practical considerations, and with a clear understanding regarding the noise issue that is to be established; ie typical weekday, worst case, etc. Where possible, the follow-up measurement should fall within the same period (ie Monday–Thursday, Friday–Sunday) to reduce the likelihood of systematic error.

4.1.4.5 Typical uncertainty due to traffic volume

For a measurement on a randomly selected day, it appeared that the uncertainty interval due to traffic volume was in the region of ±1dBA for most roads, although some rural roads could have much higher uncertainties, perhaps in the region of ±3dBA. Restricting measurement to weekdays during non-holiday periods could reduce the uncertainty to about ±0.5dBA for most roads, but could introduce a similarly sized bias relative to the annual average, depending on the road type. For some remote or rural roads, restricting measurements to non-holiday weekdays could reduce overall uncertainty by 1dBA or more, and introduce very little bias.

Taking multiple noise measurements over several days was recommended, particularly in the case of rural and remote highways, where large day-to-day variations in noise level were more common.

4.1.5 Noise effects of variation in the characteristics of the vehicle fleet

The vehicle fleet will change only on a long-term basis. Motor registration data administered by the Ministry of Transport shows that the New Zealand vehicle fleet is effectively replaced over a 15–20 year interval. Therefore, during a period of, for example, 5 to 10 years, the fleet characteristics can change to include more modern, quieter trucks and cars that comply with overseas standards, and new vehicle types such as SUVs or electric vehicles. For example, over about the last 30 years, vehicles have become quieter with respect to the engine and mechanical component of their noise, and tyres have become larger – thus, tyre road-noise effects are the dominant noise source, even at urban speeds. Tyres on vehicles have also changed. Up until about 1990, most tyres were manufactured in New Zealand and designed for noise reduction for our road types. Few tyres are now designed for New Zealand road types, and so may be noisier. Designation conditions that require actual measurement 10 years post-construction therefore need to incorporate the effects of these longer-term trends that would have not been anticipated in the prediction modelling. There is also a need to ensure that the key parameters of models, found reliable in the past, are revalidated perhaps at 15–20-year intervals, to ensure they are relevant to the current vehicle fleet.

4.2 Noise effects of variation in heavy vehicles over the week

HGV data was obtained from the NZTA, showing the quarter-hourly percentage of HGV at four sites for one year. As with the volume data, the HGV data was grouped by day into holidays and non-holidays, and then into weekdays and weekends. The holiday data was excluded from the analysis because this time period was found to be unsuitable for measurement (as in the previous section on traffic volume). In any case, HGV volumes remained remarkably constant throughout the year (but not over the week), and the change in *percentage* of HGV over the year was largely due to the change in the denominator, the total traffic volume.

In this case weekdays were defined as Monday to Friday, as there was a clear difference between the five weekdays and the two-day weekend. This interpretation of weekday differs from that taken for the traffic volumes, but was necessary as the character of the Friday traffic was nearly identical to that of the Monday–Thursday traffic, and contrasted sharply with that of the Saturday and Sunday traffic. Once this analysis of the effects of percentage HGV and of traffic volume was completed, the data was regrouped with a common definition of weekday as being Monday to Friday.

A 95% confidence interval was constructed for percentage HGV for each site and time grouping. The limits of the interval were converted into SPL using the CRTN method, holding all other factors (traffic volume, speed, etc) constant. A confidence interval for random error in daily average SPL in decibels was then produced for each road classification.

Table 4.9 shows the day-to-day variation due to %HGV for the different intervals within the week. The uncertainties listed here were, in general, slightly lower than those due to traffic volume. Limiting measurement to ‘weekdays only’ or ‘weekend only’ resulted in a reduction in variability for these road classifications by as much as 50%, but in absolute terms the reduction was small.

Table 4.9 Day-to-day variation of %HGV by day of the week, in terms of SPL

Road classification	All week ±dBA @ 95%	Weekdays only ±dBA @ 95%	Weekends only ±dBA @ 95%
Metropolitan motorway	-0.3, +0.3	-0.3, +0.3	-0.2, +0.2
Strategic highway at metropolitan fringe	-0.6, +0.5	-0.2, +0.2	-0.2, +0.2
Strategic highway well away from urban influence	-1.5, +1.1	-1.0, +0.8	-0.7, +0.6
Rural highway	-0.4, +0.4	-0.2, +0.2	-0.2, +0.2

Table 4.10 shows the bias introduced by measuring only on weekdays or only on weekends, respectively. The bias was relatively small in the case of weekday measurements, mainly because those days accounted for 5/7 of the yearly average. The high proportion of HGV on all road types over the working week caused the weekdays to be consistently noisier than the annual averaged %HGV level ($p<.01$), but by only a small

amount, typically 0.2dBA. As table 4.10 shows, the much lower percentage of HGV over the weekend could lead to noise levels at some sites being 1dBA quieter than the annual average, perhaps more.

Table 4.10 Systematic error (bias) in %HGV by day of the week, in terms of SPL

Road classification	Average bias: weekday dBA	Average bias: weekend dBA
Metropolitan motorway	0.1	0.0
Strategic highway at metropolitan fringe	0.2	-0.4
Strategic highway well away from urban influence	0.3	-0.9
Rural highway	0.1	-0.4

In summary, the non-holiday day-to-day variation of percentage HGV appeared to be somewhat less acoustically important than variation in traffic volume. Grouping into weekdays and weekends had a significant *relative* effect in reducing the day-to-day variation, but the *absolute* effect was very small, a few tenths of a decibel at most. There seemed to be no useful improvement in consistency to be gained from restricting measurement to specific periods within the week. Measurement on any single day of the week did not appear to introduce appreciable bias relative to the annual average, with the caveat that using weekend measurements on roads with a high proportion of HGV (say 15 to 20%) could lead to underestimating the long-term noise level.

Comparing the systematic errors due to traffic volume only (table 4.8) and percentage HGV only (table 4.10), it can be seen that very often they were in opposition to one another. For example, the strategic highway at metropolitan fringe had a +0.7dBA contribution from increased traffic volume over the weekend, and a -0.4dBA contribution from decreased percentage HGV, resulting in a relatively small overall bias of +0.3dBA relative to the annual averaged level.

An indicative figure for day-to-day variation of noise emission due to percentage HGV is approximately ±0.5dBA. At some sites with a high proportion of HGV (perhaps 15% or greater), there could be a greater effect on noise variability.

4.3 Noise effects of variation in traffic speed

No NZTA data was available on the variation of average daily traffic speed. Central Laboratories holds some relevant speed data that was gathered for past projects where the number of HGV and traffic speeds had been measured at 20 sites (each over 24 hours and grouped into 15-minute intervals) for the purpose of validating noise models (Dravitzki and Wood 1999).

Data from 8 sites from different New Zealand locations (all at open-road speeds) was analysed, and with opposing lanes being analysed separately, this effectively resulted in 16 different sites. Each site typically had about 3 days of data, and in total there were 38 differences (of speed between days) to be considered. A single dataset of day-to-day speed differences for all sites was formed from the differences between all entries (days) within a site.

Generation of the 95% confidence interval was achieved by taking the 95th percentile (or second-highest) difference in this dataset as the interval for speed variation. The maximum typical day-to-day variation in speed was correspondingly found to be 5.0km/h, and therefore an indicative uncertainty for daily average traffic speed is ±2.5km/h. Using the CRTN tables for traffic speed, this translates to a 95% confidence interval of day-to-day uncertainty in noise emission due to speed of [-0.7, +0.6]dBA in open-road speed zones.

4.4 Noise effects of variation in road surface

The road surface type makes a significant difference to the amount of road traffic noise (Dravitzki, Walton and Wood 2006; Dravitzki and Kvatch 2007). The effect on noise levels that can be attributed to the road surface is different for cars than for trucks, but for typical vehicle streams, the range is about 6–9dBA, from the quietest surface to the noisiest surface (assuming that each is in good condition). The road surface is usually new on opening a project, may be resurfaced during the first 1 or 2 years; it is unlikely to be replaced before 8–15 years. The surface will, however, deteriorate over time and its noise characteristics will change. Road surface wear and bedding in of the surface can alter the noise effect characteristics by up to 1dBA. Roughness from seal joins and patches from maintenance could have a larger but localised effect.

The effect of the road gradient will be constant over time, unless it is changed as part of works.

There is evidence to suggest that the surface of the road can contribute to changing noise emission levels on time scales of hours to days. Dravitzki and Kvatch (2007) showed that weather conditions could have a significant effect on road-surface noise emission. Open-graded road surfaces, while appearing mostly dry to the eye, were still affected by the moisture held within voids, and consequently generated significantly more noise. Although data for that research was limited, it was found that for at least some surface types, there was about a 2dBA difference between measurements made, respectively, 4 hours and 50 hours after the cessation of rain. It is probable that surface type and weather conditions would have an effect on both the magnitude of the noise change and on the drying time.

Until further research has been completed on this phenomenon, it is recommended that for porous surfaces, measurement should be avoided for 50 hours after a rain event, especially as a visual inspection of dampness may not be sufficient to determine whether the road-surface noise emission is affected by moisture.

4.5 Combined effects of variations in traffic volume, proportion of HGV, and vehicle speed

Table 4.11 presents indicative figures for the variation of road noise emission due to the combined effects of volume, speed, and percentage HGV. The ‘any day’ column is the range that should be applied to noise measurements where the absolute level of noise is being estimated, and re-measurement may occur on any day of the week – this will be the usual case. The ‘weekday only’ column is applicable where the primary aim of the study is to determine the *change* in noise level between successive measurements *and* current and future measurements are able to be restricted to the days Monday–Thursday. The latter provides a slightly more consistent noise measurement, in most cases.

Table 4.11 Indicative uncertainty for road traffic noise emission due to combined effects of volume, speed and percentage HGV

Road type	Uncertainty any day ±dBA @ 95%	Uncertainty weekday only ±dBA @ 95%
Metropolitan motorway or urban arterial	±1	±1
Strategic highway well away from urban influence	±3	±2
Rural highway or provincial urban arterial	±2	±1

Each road has unique characteristics that contribute to its variability in noise emission from day to day. The information gathered from our sample of roads was used to define three rough classifications based on noise variability, which also showed something of a correlation with the purpose and location of the road. The general observation was that roads in the more built-up city environment appeared to be the least variable; rural roads and town arterials were moderately variable; and roads with a high proportion of HGV and/or weekend recreational traffic appeared to be the most variable.

5 Variation in noise because of propagation effects

Noise propagation results in attenuation of road noise, and the amount of attenuation depends largely on the meteorological conditions and the distance between noise source and receiver. Atmospheric absorption, ground absorption, atmospheric stability, and wind speed and direction contribute to attenuation of road traffic noise, and changes in any of these phenomena between surveys will produce different sound-level measurements.

The distance between source and receiver is critical in determining the amount of road noise attenuation. Clearly, as the propagation distance approaches zero, attenuation will also approach zero. However, the distances from the road for which the separate phenomena of ground absorption, atmospheric absorption and meteorological effects occur differ for each phenomenon.

Ground absorption has a substantial but fairly predictable effect on the noise level at all distance from the road, but for any receiver, ground conditions can vary over time if the ground surface changes between measurements due to, for example, the moisture content of the ground, mild vegetation growth, and foliage change within a season. Substantial observable changes can result in higher variations than those listed here (eg an area being paved, a lake being drained or tall grass being mowed flat).

Temperature, pressure and relative humidity have a fairly insignificant effect on sound propagation, unless the propagation distance is very long (greater than 200–300m). It is considered that measurement can reasonably take place over the range of conditions common in New Zealand, providing the instrumentation is within its operating range.

Meteorological conditions of wind and temperature lapse rate have a strong effect on attenuation. Close to the road, atmospheric turbulence may scatter sound unpredictably, but it is considered that wind (at speeds appropriate to noise measurement) will not have a strong effect on received noise level. Further from the road, the effects of wind and temperature lapse completely dominate the overall variability in noise level, and consistency between measurements becomes much more difficult. If measurement is made regardless of the wind direction, then beyond a few tens of metres from the road edge, the variation quickly becomes unacceptable (calculated as the systematic error plus the combined random errors for upwind and downwind measurement). For measurements made far from the road, measurements limited to just downwind conditions are more consistent than measurements confined to just upwind conditions. However the measurements are not comparable, as there is a substantial difference between the downwind and upwind noise levels.

5.1 Ground absorption/effect

One of the mechanisms of attenuation of sound as it propagates over distance is that of ground attenuation. Noise prediction models such as CRTN include ground attenuation in the calculation, considering such factors as:

- distance from edge of carriageway
- height of propagation
- proportion of absorbent ground.

The primary mechanism for ground attenuation depends on the direct wave and the reflective wave with a phase shift. For traffic noise, the greatest ground attenuation occurs because of the reflected wave’s 180°

phase shift on reflection resulting in destructive interference between the direct and reflected waves. Consequently, several factors additional to those considered by most models can affect this over time. These include:

- ground cover
- meteorological effects
- barriers.

In this report, barriers are not discussed as a source of variability other than to note that barriers interact with the ground cover by changing the effective height of the noise source and thereby reducing the effects of the ground cover.

5.1.1 Ground cover

Ground attenuation is a function both of the structure and the covering of the ground. While the structure of the ground is unlikely to change between successive measurement periods, it is possible for the ground cover to change – eg an intervening hay paddock or lawn can be mown, grass can grow, etc.

Studies by Wassilieff (1995) showed that over distances of 15–50m, with a microphone height of 1.2m, traffic noise-level variations in the order of 1dBA will occur depending upon whether grass is long or short. The type of grass cover affects the composition of the A1 soil horizon (underlying soil). Naturally long grass (eg paddock grass) appears to make the underlying soil more porous than closely cropped domestic lawn. The overall effect is small but measurable. Over greater distances, the difference in ground effect between long versus short grass will be greater, but the phase randomisation of the direct and reflected sound rays due to turbulence in the atmosphere will limit the measured level difference to only around 1dBA.

5.1.2 Trees

The attenuation of traffic noise by planting trees and shrubs is often overestimated. However, ground attenuation in planted and wooded areas can be enhanced because of the greater porosity of the ground due to fallen leaves, tree roots, etc.

Studies reported by Beranek (1971) showed that depending on their character, forests can provide 5–12dBA attenuation per 100m. However, for bare trees the attenuation is reduced to 0–5dBA/100m.

Consequently, the time of year should be an important consideration for measurements made in areas where deciduous forests may have an effect on the received traffic noise levels.

More recent studies by Lacorzana and Arusta (2004) of sound propagation through forests showed that sound propagation through pine forests was well described by a simple ground impedance used in the NORD 2000 sound propagation model. This is likely due to the effect of pine needles choking off any normal undergrowth, resulting in consistent ground conditions. There did not appear to be any obvious noise-screening or scattering effect from the tree trunks.

Larcoranza and Arusta (2004) also found that sound propagation through deciduous forests exhibited different behaviour that was not all that well described by a simple ground impedance model (possibly because of the effect of undergrowth), but there was a clear effect from sound scattering off leaves. Over distances of 40m, there was a difference of 1dBA between sound propagation through a beech forest with and without leaves (as it would be in summer versus winter). The difference was greater over greater distances, but measurements were only made up to distances of 80m from the test source.

5.1.3 Ground/meteorological interaction effects

Ground attenuation can vary in time because of atmospheric turbulence, particularly over acoustically soft ground. This turbulence generally has the effect of reducing the ground attenuation, largely due to the ‘randomisation’ of the phase between the direct and reflected waves. If such turbulence is ignored, it is likely that the effect of the ground attenuation will be overestimated, again particularly for acoustically soft ground. At this stage there appears to be no practical information regarding the extent of this effect. However, if the turbulence is sufficient to completely cancel out the ground attenuation, this could theoretically lead to significant variability over distance.

5.1.4 Ground cover and barrier interactions

Barriers have the effect of elevating a noise source to the height of the top of the barrier, which has the result of reducing the ground attenuation. This is because the path length difference between the direct and reflected waves is increased. For a barrier placed in the middle of an area of acoustically soft ground, the destructive interference of the ground reflection with the direct wave can be inhibited (mostly between 300–600Hz), which may actually increase the sound level at these frequencies compared with a situation with the barrier absent.

5.2 Atmospheric absorption

Atmospheric absorption is dependent on the weather conditions and can change from hour to hour, as well as within longer time scales of days or weeks. Atmospheric absorption is determined in terms of decibels per unit propagation distance for a given set of meteorological conditions, and is therefore dependent on the distance between road and receiver.

Absorption is also dependent on acoustic frequency, with higher frequencies being absorbed to a greater extent than low frequencies. It is unlikely that there is sufficient variation in traffic source spectrum to make this characteristic relevant to day-to-day variation, and the variation of the traffic spectrum has not been investigated.

The effect of atmospheric absorption on noise level is relatively well understood, and is documented within ISO 9613-2:1996 in the form of a table providing atmospheric absorption coefficients by octave band. We have applied this to the road traffic source spectrum to produce a single A-weighted value for traffic noise for each condition, and this is given in table 5.1.

Table 5.1 Atmospheric absorption coefficients by temperature and relative humidity

Ambient temp. (C)	Relative humidity (%)	Atmospheric absorption coefficient (dBA/km)						
		Octave band mid-frequency in Hz						Road traffic (dBA/km)
		125	250	500	1000	2000	4000	
10	70	0.4	1.0	1.9	3.7	9.7	32.8	3.8
20	70	0.3	1.1	2.8	5.0	9.0	22.9	4.5
30	70	0.3	1.0	3.1	7.4	12.7	23.1	5.6
15	20	0.6	1.2	2.7	8.2	28.2	88.8	6.0
15	50	0.5	1.2	2.2	4.2	10.8	36.2	4.2
15	80	0.3	1.1	2.4	4.1	8.3	23.7	4.0

It can be seen that the change in atmospheric absorption resulting from a 20°C change in temperature would be less than 2dBA/km of propagation. Likewise, a sizeable change in relative humidity from 20% to 80% would result in a 2dBA/km change in atmospheric absorption.

Evidently even a sizable change in the factors contributing to atmospheric absorption (ambient temperature and relative humidity) are unlikely to have any significant effect on the received noise level for source-receiver distances of less than about 200m.

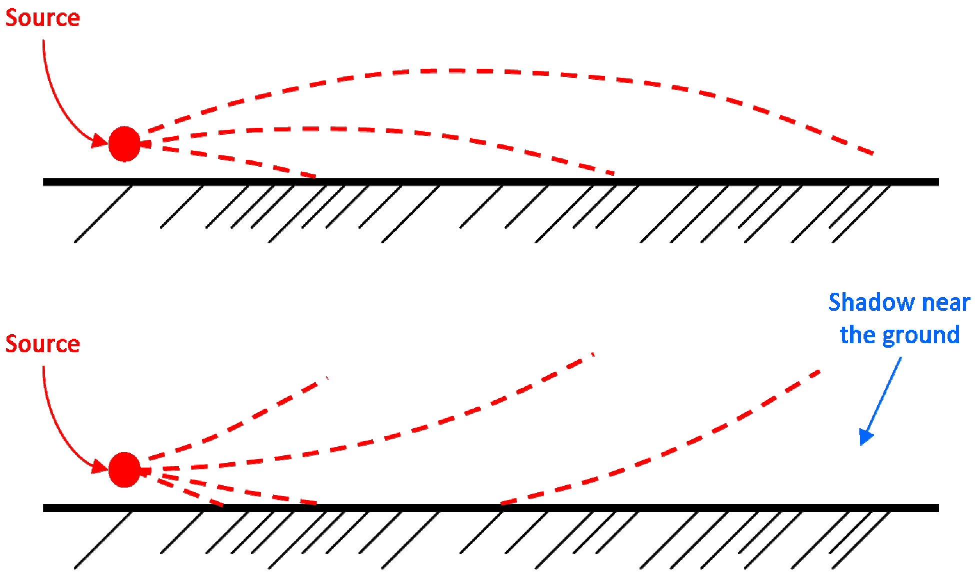
5.3 Wind and atmospheric stability

Air is the medium through which sound travels, and its velocity and temperature can have a significant effect on sound propagation. Scattering, refraction and absorption are the processes relevant to noise propagation.

Though quite different phenomena, wind and atmospheric stability primarily influence sound propagation by the same mechanism: refraction. They are often considered under the same heading of ‘meteorological conditions’ or ‘atmospheric conditions’, often with the exclusion of other phenomena such as atmospheric and ground absorption. To this end, most of the data on wind and atmospheric stability involves some combination of the two phenomena, and it is reasonable to consider them collectively in this analysis.

Refraction due to wind may occur when wind speed increases beyond a light breeze (above about 2m/s). In this case, gradients of wind speed with height may form due to friction between the air and the ground surface. The increasing wind speed with height causes sound rays to be refracted (bent) by the different speed layers of the medium. Sound rays travelling with the wind (downwind) are refracted back towards the ground, resulting in an increase in sound propagation that is often referred to as ‘enhanced propagation’, and a higher noise reading downwind. Rays travelling against the wind (upwind) are refracted away from the ground, resulting in reduced sound propagation, and sometimes even ‘shadow zones’ where no measurable sound reaches. These phenomena are shown in figure 5.1.

Figure 5.1 Showing enhanced propagation due to downwards refraction, and reduced propagation and shadow zone due to upwards refraction (ANSI S12.18: 1994)



Atmospheric stability affects sound propagation in much the same way. The atmosphere can assume a vertical temperature profile that is either favourable or unfavourable to propagation. On sunny, calm days the ground heats up, in turn warming the air immediately above it, and a temperature lapse can develop. In a temperature lapse, the air temperature decreases with height above the ground, causing sound rays to refract upwards, away from the surface, and hence resulting in unfavourable propagation conditions. On calm, clear nights when the ground surface is cold, the opposite condition sometimes develops: a temperature inversion. In a temperature inversion the air temperature increases with height, facilitating refraction downwards towards the surface, and the result is enhanced sound propagation. Light winds may produce a favoured direction for the increased or reduced sound propagation due to temperature gradient. Anything above a light breeze will cause vertical mixing and largely destroy the temperature gradient.

Craven and Kerry (2001) state that in practice, the wind vector has an influence an order of magnitude greater than temperature, although no research is cited to support this. In fact the magnitude of the meteorological effect is evidently not well known, or at least not widely published. In spite of this, citation of the CONCAWE report (Manning 1981) appears to be a popular diversion by many standards. The CONCAWE report is not actually an easy source of attenuation factors – to the extent that quotation of actual sound levels (in decibels) is confined to the appendices – but its popularity as a reference may come from the fact that it is written with prediction in mind. More recent studies have tended to focus on investigation of the meteorological effect rather than with the aim of generating correction factors.

5.3.1 Moerkerken and van Wijk

Moerkerken and van Wijk (1979) conducted research into the effect of wind direction and speed on the propagation of traffic noise over distances of 200m and 600m. Their 170 days of measurements showed that low wind speeds (0–2ms^{-1}, measured at 2m above the ground) in any direction caused relatively high attenuation in general, but that this was highly variable from sample to sample. However, for downwind speeds above 2ms^{-1}, attenuation was low and variability declined markedly (see table 5.2, where the numbers have been estimated from graphs supplied with their research paper).

Table 5.2 Effect of wind speed and direction on noise propagation at 208m from the road, relative to the level calculated for geometrical spreading only – estimation based on Moerkerken & van Wijk (1979)

Wind direction	Wind speed (m/s)	Attenuation at 208m (dBA)	Variation 95% level (±dBA)	Trend
Downwind	0–2	10	3	Relatively high attenuation below 2m/s, then stepping to low attenuation at 2m/s, and further reducing with increasing wind speed (-0.7dBA per m/s wind speed)
	2–6	4	2	
Upwind	0–8	15	4	Attenuation increases very slightly with increasing wind speed (+0.2dBA per m/s wind speed)
No wind	0	7–23	8	High range of attenuation probably due to atmospheric stability
Crosswind	0–6	17–5	6	Attenuation reduces sharply as wind speed increases (-2dBA per m/s windspeed)

They also found that day-to-day variability close to the road (10m and 15m) was about ±2dBA (95% CI), but it appears that this was not corrected for variations in traffic properties. Moerkerken and van Wijk (1979) concluded that for reproducibility, ‘a meteo-window should be centred around downwind and exclude crosswind as much as possible’. This is because downwind conditions provide the most consistent measurements and the bias introduced as a result can be corrected for. They also considered that daytime wind speeds below 1m/s in winter and 2m/s in summer should be excluded, as these conditions caused highly variable noise measurements.

5.3.2 Delanne et al

Delanne et al (1983) conducted a survey of noise levels at several distances on either side of busy rural roads in an attempt to isolate the effect of wind direction on traffic noise propagation. Their results indicated that even as close as 30m from the road, downwind propagation could result in levels being approximately 1dBA higher than if it were upwind propagation (combined data from wind speeds ranging from 2m/s to 6m/s). At a distance of 120m from the road, the difference between downwind and upwind propagation increased to perhaps 8dBA over the same range of wind speeds. These figures must be treated with some degree of caution, as the presentation of information within the paper is somewhat ambiguous.

5.3.3 Wayson and Bowlby

Wayson and Bowlby (1988) conducted a statistical study of measurements taken near a 6-lane motorway under a variety of meteorological conditions, to determine the relative influences of meteorological parameters on traffic noise propagation. Using statistical methods to account for the various factors, they found evidence that meteorology influenced measurements taken just 38m from the road's centre line (approximately 16m from the nearest lane edge). The report provided an estimate of error with distance from the source.

The findings should be used with some caution, as there are some issues of concern regarding the regression analysis – eg factors are not independent; all six significant factors have been included in the regression; and the sample size is inadequate for the number of factors.

Table 5.3 presents the measured variability for each distance surveyed, as well as the modelled regression errors. From the correlation tables contained within their report, it appears that wind velocity, wind direction (upwind or downwind) and temperature lapse rate had the strongest influence on noise level.

Table 5.3 Variability in road traffic noise, based on information contained within Wayson and Bowlby (1988)

Distance to road edge (m)	Measured variability, 95% confidence level (±dB)	Estimates of error from regression equations, 95% confidence level	
		Downwind (±dB)	Upwind (±dB)
16	3.3	1.1	1.4
40	1.5	1.8	2.3
100	3.7	3.7	4.6
180	--	6.0	7.6

Wayson and Bowlby also found that while temperature lapse rates did not exert significant influence on sound level within 40m of the road, they became important as the distance increased to 100m.

Elsewhere, the scattering mechanism is generally regarded as being much less significant than refraction, although atmospheric turbulence may scatter sound into regions that would otherwise be acoustic shadows. However, Wayson and Bowlby found that turbulence could have an effect comparable to that of combined wind and temperature parameters at distances of less than 100m from the roadway.

5.3.4 ISO 9613-2: 1996

International Standard ISO 9613-2:1996 *Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation* provides a method of accounting for the effect of meteorological conditions on noise measurement (refer to clause 8 of that document). The equations given are specifically for point sources, but several point sources can be combined to simulate a line source as necessary. Geometrical divergence, atmospheric absorption, ground effects, screening, reflections and 'meteorological correction' are covered by the document, as well as a discussion on accuracy and limitations.

This method is based on propagation conditions as specified in ISO 1996-2: 2007 (downwind within an angle of ±45° of the source, and wind speed between 1m/s and 5m/s). The literature shows that this environmental condition gives the most consistent noise reading, but is also the situation that that gives the highest noise level. This 'may be the appropriate condition for meeting a specific community noise limit' if the purpose is to establish that the noise limit is seldom exceeded. This measurement condition also facilitates the estimation of long-term noise levels because the extent of the bias is the most predictable.

The meteorological correction is applied to the assessed (short-term) downwind noise level to estimate a long-term (months or more) noise level, accounting for the variety of meteorological conditions that are likely to occur over that period, both favourable and unfavourable to propagation.

For typical road traffic measurements at about 1.5m above the ground:

$$C_{met} = C_0\left[1 - 20 / d\right] \qquad \text{(Equation 5.1)}$$

where

C_{met} is the meteorological correction in decibels, applied to the assessed short-term downwind noise level to estimate the long-term noise level

C_0 is a correction factor in decibels, which depends on local meteorological statistics for wind speed and direction, and temperature gradients[3]

d is the distance (in metres) between source and receiver, and is greater than 20m.

The correction factor, C_0, is determined by analysis of the local meteorological statistics. For example, if the meteorological conditions favourable to propagation occur for half of the year (on average), and the attenuation during the remaining half of the year is higher by, say, 10dB, then C_0 will be the logarithmic weighted average of 0dB and -10dB, which is -2.6dB. The meteorological correction is then calculated from (1) and added to the assessed downwind noise level, and the result is the estimated long-term noise level.

In practice, values of C_0 are limited to the range 0dB to -5dB, with values below -2dB being exceptional, and thus according to the standard, only elementary statistics of the local meteorology are needed for a ±1dB accuracy in C_0.

Clause 9 of ISO 9613-2: 1996 also provides a discussion on the accuracy and limitations of the method. It considers that 'restricting attention to moderate downwind conditions of propagation limits the effect of variable meteorological conditions on attenuation to reasonable values'. It provides a figure of estimated

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[3] Note that the method as presented here differs slightly from the method given in ISO 9613-2: 1996, in that attenuation is represented by a negative C_o, and hence C_{met}, rather than the positive terms defined in the standard. This makes intuitive sense, more closely follows convention where corrections are added rather than subtracted, and can be calculated by a simple logarithmic average (no calculation method is explicitly stated in the standard).

accuracy of calculation of ±3dB for distances out to 1000m from the source, which includes consideration of atmospheric absorption, ground effect, and downwind sound propagation. Note that this figure does not represent a *measurement uncertainty* under either stable or changing conditions for any one measurement.

5.4 ISO 1996-2: 1987/BS 7445-2: 1991

ISO 1996-2: *Description and measurement of environmental noise – Part 2: Acquisition of data pertinent to land use* (also a British Standard, BS 7445-2: 1991) provides guidance on noise measurement outdoors, necessarily including meteorological conditions.

From section 5.4.3.3:

> *To facilitate the comparison of results, it may be convenient to carry out measurements under selected meteorological conditions which are reproducible and correspond to quite stable sound propagation conditions. In particular, when there is one dominant source, it may be convenient to choose meteorological conditions which correspond to enhanced propagation from the source to the receiver and/or to the specified area and to adopt measurement time intervals corresponding to the following conditions:*
>
> - *wind direction within an angle of ± 45° of the direction connecting the centre of the dominant sound source and the centre of the specified area, with the wind blowing from the source to the receiver;*
> - *wind speed between 1 and 5 m/s, measured at a height of 3 to 11 m above the ground;*
> - *no strong temperature inversions near the ground;*
> - *no heavy precipitation.*

Therefore this standard prefers measurement to take place downwind from the source to facilitate reproducible measurements. It also requests that, if possible, an estimate of the variability of measurements is reported, based on analysis of the measurements taken over the sampling period.

Note that far more detailed coverage of the effects of meteorological conditions on noise measurement is contained in ISO 9613: 1996.

5.5 ANSI S12.18: 1994

The US Standard ANSI S12.18: 1994 *Outdoor measurement of sound pressure level* considers that in order to obtain accurate, reproducible noise measurements, it is imperative to consider the influence of environmental variables.

The standard provides a ‘general method’ and a ‘precision method’ for outdoor sound measurement.

- The **general method** for routine measurement specifies that average wind speed must always be below 5m/s, and no attempt should be made to adjust measured noise levels based on wind data. For distances of less than 30m, it considers that propagation is essentially independent of meteorological conditions (excluding ground effect) and measurement may take place whatever the wind direction. For distances in excess of 30m, the measurement can only be made downwind within ±45° of the source, and when there is no strong temperature lapse. Alternatively, measurement at any distance is allowable if there is a well-developed ground-based temperature inversion.

- The **precision method** for accurate measurements specifies that measurements can only be made downwind within ±45° of the source, with wind speed between 1 and 3m/s, and when there is no strong temperature lapse. Alternatively, measurement is allowable if there is a well-developed ground-based temperature inversion. The standard states that precise measurements can be made under favourable propagation conditions that are stable and suitable for reproducible measurement.

The standard does not prescribe the use of a particular prediction method to compute the attenuation due to environmental factors, and notes that using predictions decreases the precision of the measured results. When prediction methods are used, the standard requires that the method considers all environmental effects, and that documentation exists validating the method and stating the quantitative error of the predictions.

In an informative annex, ANSI S12.18: 1994 states that shadow zones due to upwards refraction typically reach attenuations of 20dBA or more, and that sound measurements are not reproducible under these conditions. Downwards refraction conditions are favourable to propagation, generating a minimum of attenuation due to environmental effects, and the standard considers that measuring in the downwind position may be the preferred situation when making noise measurements.

5.6 AS 1055.1: 1997

The Australian Standard AS 1055.1: 1997 *Acoustics – Description and measurement of environmental noise – general procedures* defines the basic quantities to be used for the description of noise in community environments and describes basic procedures for the determination of these quantities. The AS 1055.1: 1997 guidance on measurement of environmental noise is fairly vague about the effects of meteorological conditions, other than to say that microphone wind shields may induce noise.

It specifies that meteorological conditions may influence the measured noise level, and that noise limits should be complied with, whether on average over all relevant meteorological conditions, or under specified meteorological conditions only. In the latter case, AS 1055.1: 1997 suggests that, where appropriate, conditions should be those for which the sound pressure levels at the receiver location are the highest. This implies that assessment should be made under downwind or inversion conditions.

5.7 The CONCAWE meteorological model

CONCAWE was established in 1963 by a small group of leading oil companies to carry out research on environmental issues relevant to the oil industry. CONCAWE is an acronym from Conservation of Clean Air and Water in Europe. CONCAWE's Special Task Force on Noise Propagation published *The propagation of noise from petroleum and petrochemical complexes to neighbouring communities* (Manning 1981). As the title suggests, the report is based on industrial noise, but it provides results in octave bands, which are to some extent translatable to road traffic noise.

BS EN 1793-3: 1998 provides the European normalised traffic noise spectrum for an average motor vehicle. Sandberg and Ejsmont (2002) provide this spectrum in dBA. Thus it is possible to determine approximate octave band source spectra for road traffic. The CONCAWE report (Manning 1981), in appendix II, provides equations for the 'attenuation due to meteorological factors' in terms of octave band centre frequency, distance between source and receiver, and meteorological category (which follows from the body of the report). It follows that it is possible to calculate the excess attenuation of road traffic noise at some specified distance from the source under the given meteorological condition.

The meteorological category can be determined by fairly simple measurements and observations at the site. The process is reproduced in appendix D of NZS 6801: 2008 and can be summarised as follows:

- Determine the incoming solar radiation:
  - Consider the amount of cloud cover and the altitude of the sun.
  - Estimate the altitude from time of day and year.
  - Find the solar radiation estimate from tables.
- Use the measured surface wind to determine the Pasquill Stability Category[4]:
  - Measure surface wind speed.
  - Use wind speed, solar radiation and time of day to determine the Pasquill Stability Category from a table.
- Use the surface wind and the Pasquill Stability Category to determine the meteorological category:
  - Use wind speed, wind direction, and Pasquill Stability Category to determine the meteorological category (see table 5.4 below).

For meteorological categories 1, 2 and 3, which result in reduced propagation from source to receiver, the correction is positive and the corrected noise level is higher than the measured noise level. For categories 5 and 6, which result in increased propagation, the correction is negative and the corrected noise level is lower than the measured noise level (table 5.5).

Mean differences (by octave band) between the predictions of the model and observed values for two surveys at industrial plants are included in the report. We have applied a standard vehicle spectrum to the octave band levels to produce a single A-weighted sound level for traffic noise. Table 5.4 presents the mean differences, which provide some indication of the accuracy of the prediction model in terms of road traffic noise. The mean differences are positive where the model under-predicts, and negative where it over-predicts, but the magnitudes appear to be very reasonable (less than 1dBA for all but category 2 conditions). However see the note following table 5.4 for further discussion on this.

The CONCAWE report (Manning 1981) also provides uncertainties for the model based on a comparison of 1145 predicted and observed values at two industrial sites. This is presented as 95% confidence limits for each meteorological category and octave band. Using the A-weighted vehicle spectrum, the uncertainty limits in table 5.4 have been reduced to a single limit in dBA for each meteorological category.

The CONCAWE data in Manning (1981) was based on measurement and prediction of noise from industrial noise sources, rather than road noise sources. However it is unlikely that the industrial sources would be more inherently variable than a typical road. Unfortunately, the report does not specify the uncertainty in terms of distance from the road; the listed uncertainties result from analysis of all the data for each meteorological category.

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[4] The Pasquill Stability Category is a measure of atmospheric stability, and is described in more detail in appendix A of NZS6801:2008.

Table 5.4 Mean differences between measurement and predictions under the CONCAWE model, and indicative uncertainty limits in terms of road traffic noise

Met. category	Description	Mean difference obs./pred. dBA	95% uncertainty limits ±dBA
2	Strongly decreased propagation	1.6	9.0
3	Decreased propagation	0.8	8.9
4	Neutral propagation	0.3	7.4
5	Enhanced propagation	-0.1	6.4
6	Strongly enhanced propagation	0.0	6.5

The uncertainty limits quoted in the model are particularly large. The fact that the mean differences are so much lower than the uncertainty limits may indicate that the model was further tuned using the validation data. Another possibility is that the model is accurate but not precise, having a broad, but well-centred, error distribution (low systematic error, high random error).

CONCAWE meteorological category 4 represents conditions that are theoretically neutral to propagation – the reference conditions – and thus its meteorological attenuation factor is zero. However, the uncertainty limit shows that there is a fair degree of variability in measured level within this category: the 95% confidence interval covers a range of 15dBA.

Also of note is that uncertainty decreases with increasing meteorological category, demonstrating that the measurements are more stable in downwind and temperature inversion conditions than in upwind conditions.

The CONCAWE model was developed for receivers located 100–2000m away from a point or area noise source, and therefore cannot be used to make predictions for locations closer than 100m to the dominant noise-emitting road. The effect of meteorological category on the measured road traffic noise level at distances from 100m out to 500m from the road is provided in table 5.5. No adjustments were made to account for the line source nature of busy roads. This table was populated by filtering the octave band equations given in CONCAWE appendix II-1 (attenuation by distance and category) by the A-weighted traffic noise spectrum, to produce a single attenuation level for each meteorological category and distance from the road.

Table 5.5 The CONCAWE model, filtered for A-weighted road traffic noise

Met. category	95% uncertainty limits ±dBA	Correction to measured sound level in dBA at distance from the road				
		100m	200m	300m	400m	500m
2	9.0	+3.1	+6.6	+7.6	+8.0	+8.2
3	8.9	+1.2	+4.0	+4.7	+5.0	+5.1
4	7.4	0	0	0	0	0
5	6.4	-0.9	-3.1	-3.9	-4.3	-4.5
6	6.5	-1.6	-4.7	-6.2	-7.3	-8.3

For the distances most likely to be encountered in traffic noise measurements – up to about 200m or 300m from the road – the effect of meteorological conditions is lower under favourable propagation conditions (CONCAWE meteorological categories 5 and 6) than unfavourable ones (CONCAWE meteorological categories 2 and 3), and the uncertainty for these conditions is also much lower.

5.8 Summary of propagation effects

Table 5.6 provides indicative confidence limits for the environmental effects on propagated road traffic noise. These should be interpreted as being the best available estimates (based on the information in the previous sections) of the amount with which the noise level may vary because of subtle changes in the conditions between measurements (ie changes that remain within the broad range of conditions that a practitioner would consider equivalent).

Table 5.6 Summary of propagation effects

Phenomenon	**Range of conditions**	**Typical range of uncertainty (in dBA) with distance from the road**				
		<30m	**60m**	**100m**	**200m**	**300m**
Atmospheric absorption	Variation over the range of typical New Zealand weather conditions	±0.1	±0.2	±0.2	±0.4	±0.6
Ground absorption	Variation between short and long grass, ground cover, and foliage within a season	<±0.5	<±0.5	±0.5	±1	±1
Wind velocity, turbulence & atmospheric stability	Variation of measurements in enhanced propagation conditions (downwind)	±2	±2	±2	±3	±7
	Variation of measurements in reduced propagation conditions (upwind, no wind)	±3	±3	±4	±6	±9
	Variation of measurements in unspecified conditions (incl. bias from upwind v downwind)	±4	±5	±10	±13	±22
Estimate of total variability	Variation of measurements in favourable conditions (downwind, inversion)	±2	±2	±2	±3	±7
	Variation of measurements in unfavourable conditions (upwind, no wind)	±3	±3	±4	±6	±9
	Variation of measurements in unspecified conditions (incl. bias from upwind v downwind)	±4	±5	±10	±13	±22

Failing to account for the wind direction during a measurement produces a drastically wider confidence interval than if the only information was as to whether the wind was upwind or downwind, owing to the fundamental difference in received sound under these two propagation conditions. Therefore, failure to specify the basic meteorological conditions can clearly render any measurement meaningless for road–receiver distances of greater than about 30m.

5.9 The receiver/sound-level meter

The final part of the propagation pathway is the sound-level meter. There are several sources of variability attributable to the sound-level meter and its use.

5.9.1 Location

Consistency in noise measurement can be compromised if the location of the microphone is not accurately maintained. This means ensuring that the microphone is consistently located in terms of position in three dimensions, as well as in orientation in two angular dimensions (pitch and yaw).

Before the final choice of measurement location is determined, it should be verified that a small change in position does not lead to a significant change in the sound level measured. The location should then be recorded in detail and supplemented by diagrams or photographs (or both). The layout of the area immediately surrounding the microphone should also be noted, so that any changes to adjacent reflecting or screening surfaces can be identified during subsequent measurements.

5.9.2 Instrumentation

Any instrument and processing chain has a limited degree of precision, and hence an associated uncertainty. NZS 6801:2008 demands at least a Type 2 sound-level meter, and preferably Type 1. The type of microphone in use (eg free-field or random incidence) must also be compatible (and correctly set up) with the sound-level meter for the measurement chain's stated precision to be valid.

Brüel and Kjær have published some typical uncertainties for sound-level meters (cited in Craven and Kerry 2001) and these are shown in table 5.7 following.

Table 5.7 Typical uncertainty range of sound-level meters

Component of uncertainty	**Type 0 (±dB)**	**Type 1 (±dB)**	**Type 2 (±dB)**
Application	Lab. & field use	General field use	Noise surveys
Absolute accuracy (ref. conditions)	0.4	0.7	1.0
Directional effects	0.5	1.0	2.0
Frequency weighting	0.7	1.0	1.5
Time weighting	0.5	0.5	1.0
Calibrator	0.2	0.2	0.2
Typical uncertainty (normal conditions)	1.1	1.7	2.9

At reference conditions of 20°C, 65% relative humidity, 1013mb, and plane sound waves, a typical uncertainty for a Type 1 meter is ±1.7dB. A Type 2 meter, the specification required by NZS 6801: 2008, has an uncertainty of approximately ±3dB.

These uncertainties apply to the assessed noise level, and define the confidence interval within which the actual noise level is expected to lie. Relative accuracy, that is, accuracy between repeated measures, may be much better than the absolute accuracy presented in the table. In addition to this, the time-weighting and frequency-weighting errors are unlikely to have a substantial effect on the overall measurement of uncertainty, as road traffic has fairly consistent temporal and spectral characteristics.

With care, it appears that it is possible to operate Type 0 and Type 1 noise-level meters within ±1dB relative uncertainty for repeated measurements. A Type 2 meter should be capable of operating with a relative uncertainty within ±2dB for repeated measurements.

5.9.3 The effect of weather on instrumentation

Wind passing the microphone creates turbulence that generates noise at the microphone. The use of a wind shield is necessary to reduce this effect for most conditions suitable for noise measurement.

Temperature, pressure and humidity all affect the performance of the microphone to some extent (see table 5.8 below), but significant changes to microphone response are unlikely in the relatively mild New Zealand conditions [±0.5dB is possible as conditions approach any of the extremes of temperature (-10˚C, 50˚C), pressure (850mb, 1150mb), and humidity (20%, 100%)]. A more likely risk of inconsistency arises where the instrument has not been given the appropriate amount of time to reach a stable operating temperature, or where water has condensed inside the instrument, causing it to malfunction.

The effect of temperature on batteries varies across different battery types and different battery/meter combinations. The practitioner should be wary of leaving batteries exposed to cold temperatures, particularly overnight, and particularly in a situation where the meter continues to operate but under- or over-reads because of the low temperatures. Meter and battery specifications can be checked to ensure that the cold-weather battery performance will be sufficient.

Table 5.8 Uncertainty in sound-level meter under extreme weather conditions

Component of uncertainty	Type 0 (±dB)	Type 1 (±dB)	Type 2 (±dB)
Uncertainty under normal conditions	1.1	1.7	2.9
Atmospheric pressure (+/-10%)	0.3	0.3	0.5
Temperature (-10˚C to +50˚C)	0.5	0.5	0.5
Humidity (30–90%)	0.5	0.5	0.5
Uncertainty under extreme conditions	1.3	1.8	3.0

6 Recommendations for improving the consistency of noise measurement

6.1 Summary of the overall uncertainty of noise measurement

The uncertainties arising from variations in source, propagation and measurement can be combined by a root sum of squares to provide an indicative 95% confidence interval for the noise level at a specified receiver.

6.1.1 Influence of road

The road type has a strong influence on the day-to-day variability of road noise emission. Whilst bearing in mind that this uncertainty cited in this report was derived from a small sample of roads, roads in the more built-up city environment appear to be the least variable, rural roads and town arterials moderately variable, and roads with a high proportion of HGV and/or weekend recreational traffic appear to be the most variable. All the roads are more consistent in noise emission when considering only the weekdays Monday to Thursday, rather than the entire week.

6.1.2 Measurements close to the road

For measurements close to the road (<30m) the uncertainties due to each of the three phases of noise transmission are all fairly similar in magnitude. Surveys to measure the absolute noise level at a location need to consider the absolute precision of the noise meter and the random error due to traffic variation over the entire week. Surveys to determine a change in noise level between two equivalent surveys can reduce the uncertainty of the change by measuring only on weekdays and taking advantage of the *consistency* of the sound-level meter. This will usually reduce the confidence limits by about 1dBA for each measurement (table 6.1).

Table 6.1 Uncertainty in noise measurement close to the road

Road type	Absolute (Type 0/1/2 meter on any day)	Relative (Type 0/1 meter Mon–Thurs only)
Metropolitan motorway	±3	±2
Rural highway	±4	±2
Strategic highway well away from urban influence	±4	±2

6.1.3 Measurements at distance from the road

Surveys further from the road experience a higher degree of variability due to propagation effects, mostly as a result of variations in wind direction and strength. This variability is likely to dominate the uncertainty analysis for receivers further than a few tens of metres from the road. Vastly improved consistency will result if measurements are limited to one specific meteorological condition, such as only upwind measurement or only downwind measurement. For the most consistent measurements possible, the measurement conditions should be restricted to be downwind from the road (within an angle of ±45°) and in wind speeds between about 2m/s and 6m/s.

Measurements at locations far from the road are more strongly influenced by propagation effects, and hence weather conditions. The road type and sound-level meter type rating are less important to the variability. Baseline uncertainties for distances greater than about 50m from the road are provided in table 6.2.

These apply to general noise measurements under the following conditions:

1 measurement made on any day of the week (ie no restriction)

2 measurement taken with a Type 2 noise-level meter

3 primary noise source is a typical motorway, or highway (not a remote highway or other highway with high variability in noise emission).

Table 6.2 Guideline uncertainty levels for noise measurement at distance from the road

Wind direction from source to receiver	Uncertainty in dBA at distance from road edge			
	60m	100m	200m	300m
Downwind only	±3	±3	±4	±7
Upwind only	±4	±5	±5	±9
Upwind or downwind[a]	±5	±10	±13	±22

Note: Upwind or downwind here relates to the variability that occurs if no regard is paid to the wind direction, so that on one occasion measurements might be made upwind, and on the other occasion they might be made downwind.

6.1.4 Adjusting for sound-level meter type and restricted conditions

To correct for different road type, meter type, or survey type, make adjustments to the uncertainty limits as shown in table 6.3.

Table 6.3 Characteristic adjustments to uncertainty levels for noise measurements

	Noise measurement situation	Adjustment
Road type	Highways well away from urban influence or highways with atypical flows	+1
Sound-level meter	Type 1 in downwind propagation conditions	-1
	Type 0 in downwind propagation conditions	-1
Relative assessment (only when close to road)	Only weekdays and only downwind conditions	-1
	Only weekdays and only upwind conditions	-1

6.2 Restricting the conditions in which noise measurements are made

The measurement consistency can be improved by restricting the conditions under which measurements are to be made, and other issues, as listed below. However, restricting the conditions under which measurements are to be made may increase the amount of time needed to make a number of measurements.

1 **Weekdays only.**
Weekdays (Monday–Thursday) are more consistent in traffic flow and percentage HGV, and this is reflected in a more consistent noise emission level. Restricting measurement to weekdays only may

improve consistency between measurements, while introducing only a very small amount of bias relative to the annual average level (less than 0.5dBA).

2 **Consider whether the measurement should be of the absolute noise level, or the relative noise level.**
If the aim of the survey is to determine the absolute noise level at a certain location, then an 'absolute' measurement is necessary and will have to account for all the sources of variability associated with traffic noise measurement. If the measurement is part of a repeated measures survey, then some sources of variability may be cancelled out between the two measurements by repeating the measurements in similar conditions, and hence the uncertainty regarding the change in noise level may be somewhat lower. These factors include the variability due to the day of week (if limited to weekdays, as discussed above), and the error associated with the algorithms within the sound-level meter.

3 **Restrict to a single wind direction.**
In the case of measurements far from the road, wind direction has a very significant effect on both the level and variability of the noise level at the receiver. Restricting measurement to a single wind direction will result in much better repeatability. Upwind measurements are very likely to result in sound levels being somewhat lower than would be the case under other conditions, and this must be considered when assessing the noise level under these conditions.

4 **Restrict to downwind only.**
Downwind measurements in wind speeds of between 2m/s and 5m/s appear to be the most stable in terms of measured noise level. Downwind measurements may result in sound levels being somewhat higher than would be the case under other conditions, and this must be considered in the noise assessment. However, it is the condition in which the variability is the most predictable and adjustments to the measurements can be made with the most confidence.

6.3 Conditions when measurement should not be made

Some environmental conditions are not suited to noise measurement because they create very high levels of variability in received noise levels. To encourage consistency in measurement, the practitioner should not measure, or attempt to compare measurements, when the following conditions are present during one or both of the measurements:

1 **Very low wind speeds, crosswinds or high wind speeds** – At distances of more than about 30m from the road, propagation under these conditions is highly variable and unpredictable.

2 **If the road surface is porous** (eg open graded porous asphalt, known as OGPA) and rain has fallen within the last 48 hours, even if the road surface looks dry.

3 **When other noise sources, which may interfere with the road traffic noise measurement, are present, *where these may vary significantly between measurements.*** For example:

- other transport sources (eg trains and aeroplanes)
- human activity (eg schools, sports fields, gatherings, etc)
- amplified sound (eg from pubs, clubs, music events and sporting events)
- weather effects (eg rustling leaves, thunder, wind noise, noise from banging gates, noise from streams and rivers, etc).

4 **During public holiday weekends and the days either side of those and during the summer holiday period (the last two weeks of December and the first four weeks of January)** – Atypical traffic volumes can introduce a bias of the order of 2dBA relative to the typical noise level (depending on road type). An alternative is to adjust the readings to align with the AADT flow, but in order to make this adjustment, detailed traffic measurements from a traffic counter are required.

5 **If barriers or reflectors that would affect the measured sound level have been introduced or removed between measurements** – If this occurs, the practitioner should assess the impact this may have had on the noise level, and if necessary, discard the measurement. During each survey, comprehensive diagrams and photos of the both the measurement site and the intervening land to the noise source should be made, so that these sorts of changes can be identified.

6 **When snow covers the ground** –The amount of ground absorption may rise to levels that are not representative of the usual conditions.

7 Recommended method for proving compliance with noise conditions

7.1 Factors to consider

The previous sections of this report have set out a number of the issues regarding noise conditions for designation consents. Section 2 identified a trend for these conditions to be framed in a performance style with a noise limit that is not to be exceeded, and an expectation of using measurements to show compliance.

Section 2 also highlighted the ambiguity as to the meaning of 'the noise level', primarily with regard to whether this was an average noise level and long-term level, or a worst-case level. Sections 4 and 5 then identified the variations in noise that could occur, first through changes in the noise source, and then in the propagation of this noise. Section 6 set out recommended methods to improve measurement consistency, and the situations in which measurement should be avoided.

The intention of this research was to provide recommendations on methodologies to show compliance with designation conditions, with the implicit assumption that these were being framed with respect to the NZTA Noise Guidelines. Although the road traffic noise standard NZS 6806 has now come into effect, roads being built at present and in the near future are still likely to be expected to comply with their existing designation conditions, which will be based on the NZTA Noise Guidelines.

At the time of writing, draft conditions under NZS 6806 were being formulated, and so some discussion on showing compliance to this style of condition is included later in this section, in the expectation that this draft condition will become the norm.

In developing the recommended method of establishing compliance with resource consents, clarity as to what is meant by the term 'the noise level' is needed. The absence of this clarity has already been discussed, but for this research we believe that 'the noise level' is that which would occur if the AADT traffic was present and propagation conditions were neutral. The basis for this view has already been outlined in sections 2.2 and 2.3.

It is important that the inherent variability of noise measurement is recognised, and that a measurement over one day does not necessarily identify the longer-term daily average in the neutral propagation conditions that we are seeking to identify. The previous sections have shown the extent of this variability in detail.

Establishing compliance with the NZTA Noise Guidelines inherently requires the comparison of a situation that existed before a road was built, with the situation after it was built. There is usually at least two years between these assessments, and some conditions are framed so that the gap could be as much as 12 or 13 years. During that time, the ground will obviously change in the immediate road corridor and there can be further changes in the intervening ground. There will be short-term changes, such as the seasonal cycles that can occur over 6 to 12 months, during which grass and other vegetation will grow, and will have different noise propagation effects when dry compared with when wet; fields may be ploughed for crops, or alternatively, tall crops such as maize may be grown. These conditions can be significantly different when noise measurements are made a year or two later. More significant changes could occur in the longer term: for example, tree plantations could change greatly in height or be removed; or subdivision development could result in the presence of numerous houses and changes in traffic on local roads that would significantly alter noise levels measured at a receiver.

7.2 Choice between modelling and measurement

What is at issue is the best pathway to establish compliance with a designation or resource consent condition that has set a limit for road traffic noise, either as an absolute number or as a permitted increase.

Modelling is an effective method for predicting a long-term noise level with a standard ground effect on propagation and for neutral atmospheric conditions. Modelling software packages such as SoundPLAN and FHWA TNM and CadnaA are commonly used. Once this model is established it is easy to calculate noise for every receiver of interest, rather than just at a few locations that act as indicators of noise impacts, which used to be the previous practice. Both existing and future levels can be readily calculated for a large number of locations. However, with modelling there may be doubt as to reliability, as was discussed in section 2.1.

At first, measuring the noise can seem to be a simple and reliable method of determining the noise level. However, it is the long-term average noise level in neutral atmospheric conditions that is to be determined. Therefore, both traffic and atmospheric conditions should be measured, so that the measured noise level can be adjusted by a series of factors that will account for the effect of the non-standard conditions. However, to make the adjusted measurement reliable, a large amount of other data would need to be collected to make these adjustments, and as we have seen in this report, the precise relationship between the conditions that cause variability in noise level is often not well known. Consequently, adjusted noise measurements will offer little improvement in accuracy compared with modelling, and may on occasions be less reliable. Additionally, many measurements would need to be made to ensure that all locations of interest have been assessed for compliance.

NZS 6806: 2010 provides further complications because it requires assessment of noise levels 100m and 200m from the road edge. As discussed in section 6.1.3, at this distance atmospheric effects can have a pronounced, but not easily predicted, influence on the propagation of road traffic noise.

7.3 Recommended method

The recommended approach is therefore to establish the existing noise levels by a combination of site assessment, detailed modelling and noise measurement.

1. Through a site assessment, identify the extent to which traffic noise is the dominant source of ambient noise for the area, and note other aspects of the site to include in the modelling.
2. Undertake noise measurements at a sample of the locations to be modelled and follow the recommendations of section 6 to make consistent noise measurements.
3. Use these noise measurements to establish a reliable model; ie, observe the match between modelled and measured noise levels, and where a significant difference occurs, investigate both the model inputs and the measurements, to reconcile these differences.
4. During the measurements, record traffic counts, weather conditions and ground conditions so that the measurements made on the day can be adjusted to the model's prediction, which is based on AADT flows and neutral weather conditions.
5. Base future noise levels on modelled levels, with key inputs being terrain, traffic volumes (with speed and mix of heavy and light vehicles), road surface type, road and receiver positions, and positions of noise barriers or bunds if included.

6 Establish compliance with the noise conditions by means of the modelled levels and post-construction reviews of the model's inputs, and then if necessary, adjust the model and rerun it to verify the compliance. The review should include the following steps:

  - Establish that the model is an accurate depiction of the road as *finally* constructed.
  - Verify that the *inputs* into the model of terrain, buildings and positions are correct.
  - Make detailed traffic counts to establish that the traffic volumes, mix of heavy and light vehicles, and traffic speeds contained in the model are correct.
  - Ensure traffic parameters used in the model for the forecast year are realistic.
  - Test the road surfaces used for their effect on traffic noise and adjust the model accordingly.
  - Do on-site inspections to verify the positions of barriers in the model – measure their height and specifically test the effectiveness of the barrier in stopping noise.
  - Where buildings are to be insulated, test the effect of the insulation by conducting simultaneous indoor and outdoor measurements both before and after the treatment.
  - As with establishing the model for existing noise levels, take post-construction noise measurements at a sample of the locations modelled. These noise measurements are not directly used to establish compliance, but to inform the post-construction noise model and improve its reliability. That is, observe the match between modelled and measured, and where a significant difference occurs, then investigate *both* the model inputs and the measurements to reconcile these differences. As for pre-construction, record the traffic counts, weather conditions and ground conditions present during the measurements, so that the measurements made on the day can be adjusted to the model's prediction (which is based on AADT flows and neutral weather conditions).

7 Where compliance needs to be *demonstrated* over several years or more post-construction (eg 10 years later), then the measurement of traffic parameters, road surface noise effects, the effectiveness of barriers in reducing noise and the effectiveness of building insulation in reducing noise should be re-measured and input back into the model. The effect of other changes that are beyond the control of the roading authority, such as removal or changing of the intervening vegetation, or the establishment of new buildings or the removal of existing buildings, should also be accounted for by modelling the effect of having them present, and also with them absent.

7.4 Compliance with NZS 6806: 2010

Compliance and conditions under NZS 6806: 2010 have more of a methods approach and a focus on the 'best practicable option'. This 'best practicable option' may include a certain level of mitigation from a particular road surface, and further mitigation from noise barriers. To retain flexibility in the design stage, it is allowed that the 'best practicable option' may change, but there is the expectation that in general, houses will remain in the same noise category. Noise assessments include houses 100m from the road edge in urban areas, and 200m from the road edge in rural areas.

The method recommended above for establishing compliance with the NZTA Noise Guidelines is therefore an excellent fit for showing compliance with NZS 6806. Elements of the 'best practicable option' can be tested for noise performance and, coupled with traffic information, can then be used in modelling to show the final noise levels at the protected premises and facilities of interest.

Within NZS 6806: 2010 there is less emphasis on the existing noise level, so the extent of establishing the existing noise level and modelling of the existing noise can be adjusted to fit the context of the project.

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