Road Traffic Noise : Determining the Influence of New Zealand Road Surfaces on Noise Levels and Community Annoyance

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An Important Note for the Reader

This report is the final stage of a project commissioned by Transfund New Zealand before 2004, and is published by Land Transport New Zealand.

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Abbreviations and Acronyms

AC	Asphaltic Concrete
A-train	Semi-trailer towing a trailer
A-weighted	A way to adjust acoustical measurements to compensate for human ear sensitivity.
B-train	Two semi-trailers connected together
CaBx	Calcined Bauxite
CRTN	Calculation of Road Traffic Noise
Chipseal	A layer of sprayed bitumen into which is embedded a layer of aggregate
dB	Decibel, a unit used to measure the intensity of sound
dBA	Abbreviation for decibels, indicating that it is on an A-weighted value
HA	Highly Annoyed
HV	Heavy Vehicle, truck
Hz	Hertz, a standard measure of frequency, cycles per second
ISO	International Organisation of Standardisation
kHz	Kilohertz, 1,000 Hz or 1,000 cycles per second
km/h	Kilometres per hour
Leq	Equivalent Noise Level, the 'energy' average noise level over a given sample period, e.g. Leq_{24}
LV	Light Vehicle, car
mm	Millimetre
MPO	Mean Profile Depth, road texture measurement
n	Sample size
Nordic model	*'Road Traffic Noise – Nordic Prediction Method'* (Nordic Council of Ministers 1996)
OGPA	Open Graded Porous Asphalt
Sand circle	Use of sand to determine the average texture depth of a paved surface
SH1	State Highway 1
SLM	Sound Level Meter
Std	Standard
SUV	Sport Utility Vehicle
TNZ	Transfund New Zealand (Land Transport New Zealand)

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Executive summary

Introduction

Road traffic noise is a major cause of environmental concern in New Zealand. The effect that the road surface has on noise is the one major influence that the roading authority can control.

International literature and road noise models to date have considered that, for speeds below 60 km/h, tyre/surface noise does not have a significant effect (1–2 dBA) on road noise. Current thought is that a 3 dBA noise level change is just noticeable to most people, which makes the widely observed increases in community annoyance from road resealing hard to explain.

This research investigates the effect that road surface type has on road traffic noise at urban driving speeds (50 km/h) and the consequent effect on community annoyance. It then offers guidance on road surface selection, with regards to noise.

Methodology

The methodology utilised the reseal programmes of the Wellington and Lower Hutt roading authorities in 2002 to determine:

1. How the most common road surface types used in New Zealand affect noise level and tonality. This was achieved through controlled sound measurements of test vehicle 'cruise-bys' over 13 different surface types. The measurements were taken before, and then after, resealing at 21 sites.

2. The influence of a change in noise level on community annoyance. A 'repeated measures' survey of 138 participants was undertaken, living adjacent to one of 12 roads being resurfaced. Each completed a 4-page survey sheet before and after a surface reseal to determine any change in annoyance or behavioural disturbance.

Noise Measurement Results and Conclusions

The variation in noise from different road surfaces at 50 km/h was significant: for light vehicles in the fleet, a range of 7 dBA between the quietest bituminous seal and the loudest chip seal: similarly, heavy vehicles (HV) had a range of 4 dBA (see table 1).

The effect of a changed surface on the physical noise level is greater than previously thought. The road noise models used in New Zealand are seriously deficient regarding this effect, and need to be revised or replaced.

The noise effects of the different road surfaces at 50 km/h are the same at 70 km/h and 100 km/h. This is true for both trucks and cars.

Table 1 Effects of different surfaces at 50 km/h for light vehicle and heavy vehicle.

Vehicle Type	Average Noise Level (dBA)												
	Bituminous Mixes				Chipseal over Bitumen layer								
	AC (dBA)	Slurry (dBA)	OGPA (dBA)	Cape Seal (dBA)	7 mm (dBA)	10 mm (dBA)	12/7 mm (dBA)	12 mm (dBA)	16/7 mm (dBA)	16/10 mm (dBA)	19/12 mm (dBA)	16 mm (dBA)	19 mm (dBA)
Control LV	68	69	69	68	71	71	74	72	75	74	74	73	75
Typical fleet LV	69	70	69	68	72	72	74	72	75	74	73	73	75
Difference relative to AC: LV	N/A	+1	0	-1	+3	+3	+5	+3	+6	+5	+4	+4	+6
Control HV	79	76	77	76	77	79	79	77	80	80	-	80	-
Difference relative to AC: HV	N/A	-3	-2	-3	-2	0	0	-2	+1	+1	-	+1	-

Note:

- AC: asphaltic concrete
- Slurry: slurry seal (or micro surfacing)
- OGPA: open graded porous asphalt
- Cape Seal: slurry seal over a chipseal. Results are for type 2 over grade 3 chip
- 7 mm: nominal chip sizes, single coat
- 12/7 mm: nominal chip sizes; two coat seal

Newer chipseal generated louder low frequency components and quieter high frequency components compared to older chipseal. This was found to be consistent for all the chipseals studied.

The Mean Profile Depth, often used as a predictor of surface generated noise, did not sufficiently describe the noise generating potential of a surface.

There is no significant difference between dense asphalt and open graded porous asphalt at 50 km/h for cars, in marked contrast to expectations and Transit Guidelines.

The effect of speed as contained in both the CRTN and Nordic models may need to be revisited. The CRTN and Nordic models appear to seriously under-predict the effect of a speed increase on noise level for cars, and over-predict slightly for heavy vehicles.

Community Annoyance Study Results and Conclusions

Moderate to strong correlations are found between the level of physical change of noise, measured in dBA, and the change in annoyance.

Small changes in traffic noise level are matched with changes in behavioural disturbance, even if the change is less than 3 dBA. Behavioural change in the form of closing windows, raising one's voice or altering one's scheduled activities as a consequence of traffic noise is a natural adaptive response to a negative stimulus.

Results suggest that behavioural adjustment and annoyance interact in a complex way to produce a reaction to changes in the noise environment. It is apparent that behavioural disturbance is a more sensitive measure than mean annoyance, as it has a higher correlation to noise volume changes.

Results are contrary to the expectation that people become annoyed at factors tangentially associated with resealing, rather than noise per se. The survey responses suggest that people can identify the source of the noise that accounts for their change in annoyance and alteration of behaviour.

The tonal characteristics of the change due to reseal suggest that an 800 – 1000 Hz range is responsible for the change in noise annoyance.

Long term monitoring showed some evidence of noise habituation with respect to noise annoyance, but changes in behavioural disturbance appear to be more permanent.

Guidelines for Road Surface Noise

To produce guidelines for best use of lower noise surfaces, the effect of the road surface on the total traffic stream needs to be identified, together with identifying the environments where the improvement in noise environment will be effective. For any given street, the roading engineer can use Table 2 to assess the effect (or benefit) of choosing one surface type over another.

Table 2 Surface effect on noise

Ratio of light vehicles to heavy vehicles	Surface effect on noise (combined light and heavy vehicles) dBA				
	Dense Asphalt	OGPA	Fine chip #4,5,6	Medium chip#3	Coarse chip#2 and two coat seals
100:3	0.0	0.7	2.5	3.6	4.5
100:5	0.0	0.5	2.3	3.5	4.4
100:10	0.0	0.1	1.8	3.1	4.0
100:15	0.0	-0.1	1.4	2.8	3.7
100:20	0.0	-0.3	1.0	2.6	3.3
100:30	0.0	-0.6	0.6	2.4	2.9
100:50	0.0	-1.0	0.0	2.0	2.5
100:80	0.0	-1.3	-0.6	1.7	2.0
100:100	0.0	-1.4	-0.8	1.4	1.9

For the purposes of producing initial guidelines we have defined a new disturbance measure of *acutely affected* and devised a framework to describe acceptable and unacceptable change. Table 3 is based on the change in percentage of population that is exposed above the *acute level* of behavioural disturbance.

Table 3 Extent that the noise environment is improved for the adjacent community by selecting a quieter or noisier road surface.

<table>
<tr><th colspan="2">Change in noise level from road surface change</th><th>Less than 60 dBA Leq_{24}</th><th>Between 60 to 69 dBA Leq_{24}</th><th>Above 70 dBA Leq_{24}</th></tr>
<tr><td rowspan="3">Reduction</td><td>More than 3.6</td><td rowspan="2">Small Improvement</td><td>Improvement</td><td>Big Improvement</td></tr>
<tr><td>–3.5 to –1.1</td><td>Small Improvement</td><td>Improvement</td></tr>
<tr><td>–1 to 0</td><td>Little Change</td><td>Little Change</td><td>Small Improvement</td></tr>
<tr><td>No Change</td><td>0</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td rowspan="3">Increase</td><td>0 to 1</td><td>Little Change</td><td>Little Change</td><td>A Little Worse</td></tr>
<tr><td>1.1 to 3.5</td><td rowspan="2">A Little Worse</td><td>A Little Worse</td><td>Worse</td></tr>
<tr><td>3.6 and greater</td><td>Worse</td><td>Much Worse</td></tr>
</table>

Recommendations for Further Research

1 Determine the effects of a range of bituminous road surfaces on road traffic noise.
2 Revise noise models to better account for road surface effects relevant to NZ.
3 Investigate the interaction between annoyance and behavioural disturbance.
4 Acute behavioural disturbance needs to be better defined and guidelines revised.

Abstract

International literature published to date has considered that tyre/surface noise does not have a significant effect on road noise for speeds below 60 km/h, and that a 3 dBA noise level change is just noticeable to most people. This makes the widely observed increases in community annoyance from road resealing hard to explain. The first part of this research investigates the effect that road surface type has on road traffic noise at urban driving speeds (50 km/h), and finds that the road surface does have a significant effect, with the surface contribution varying by up to 7 dBA between common New Zealand surface types. The effects of each surface differed for heavy and light vehicles, but were consistent over all tested driving speeds. The second part of the research investigates the consequent effect on community annoyance, and finds that small changes in traffic noise level of as little as 1 dBA are matched with changes in Behavioural Disturbance. The Behavioural Disturbance Index was found to be a more sensitive measure of noise annoyance than traditionally offered techniques. Finally, guidance on including noise considerations in road surface selection is offered.

1. Introduction

Road traffic noise is a major cause of environmental concern in New Zealand. Evidence for this concern includes the following:

- The Ministry for the Environment 'Indicators of the Environmental Effects of Transport' identifies noise as the most significant of the 10 most significant environmental effects.
- About half of all objections to new roading projects cite noise as one of the primary concerns.
- Surveys (e.g. Transfund Project 'Noise Guidelines For Low Noise Areas') show that even at noise levels considered by roading authorities as the minimum noise practical for busy roads (55 dBA), about 10% of adjacent populations are highly annoyed and a further 20% are annoyed or are dissatisfied.
- Many local authorities, e.g. Wellington, Lower Hutt, Hastings, Auckland and Waitakere Cities, have received strong complaints and even petitions as a result of noise increases after suburban streets have been resealed.

The effect that the road surface has on noise is the one major influence that the roading authority can control. Road position relative to houses is usually fixed, and vehicle speeds are largely regulated by the road's type as an urban road or highway. The roading authority does not control vehicle types and tyre types, and traffic volumes can only be controlled by indirect means.

This research investigates the effect that road surface type has on road traffic noise at urban driving speeds (50 km/ph) and the consequent effect on community annoyance.

Significant effects on noise caused by road surface type have already been identified at highway speeds (100 km/ph) in the international literature but these effects were thought to be insignificant at urban driving speeds.

1.1 The effects of road surface type on overall traffic noise

The noise generated by traffic can be largely predicted from the following four factors:

- traffic flow rate,
- the speed of vehicles,
- the proportion of heavy vehicles, and
- the nature of the road surface.

Road contact noise is considered to exceed engine noise at speeds greater than 60 km/h (Berglund and Lindvall 1995). In more general terms the cross-over from engine noise to tyre/surface noise is regarded as occurring in the speed region of 40-70 km/ph.

In New Zealand the effects of the road surface are represented by the equations in the Calculation of Road Traffic Noise (CRTN) model (see Arana, 2001) which was originally developed in the United Kingdom. Corrections for surface involve an adjustment of –3.5 dBA for pervious surfaces at all speeds; and for impervious bituminous and concrete surfaces a correction of –1 dBA for speeds below 75 km/h. For speeds above 75 km/h a correction based on texture depth (usually 2-4 dBA) is required.

A New Zealand correlation of the CRTN Model was undertaken and a surface correction derived of 5.57 x C (0.71 - log S/V) where C = 1 for chipseal, S = sand circle diameter and V = vehicle speed. Sand circle diameters range from 120 mm for coarse chip to about 180 mm for finer chip and 280 mm for asphalt. Using this formula a difference of about only 1 dBA should exist between the different chipseal surfaces at 50 km/h and 2 dBA, between chipseal and asphalt.

A further equation is provided in Transit NZ Research Report PR3-0051 where interior car noise was found to increase as 1.69 TD where TD is the mean texture depth as determined by the sand circle test as TD = $57{,}300/D^2$ where D is the sand circle diameter in millimetres.

The Nordic noise model shows the following noise level corrections relative to asphaltic concrete for several road surfaces, for speeds of up to 60 km/h.

Surface	**Correction (After 1 year) dBA**	***Correction (Newly Laid)* dBA**
(Coarse) chipseal 16-20 mm	+1	+2
(Medium) chipseal 10-12 mm	0	0
(Fine) chipseal 6-9 mm	0	-1

Current knowledge therefore is that the surface effects at 50 km/h are small and of the order of about 1-2 dBA.

1.2 Community annoyance and road resealing

Increases in community annoyance when roads were resealed have been difficult to explain from the existing knowledge of road surface effects. This indicates that any effect at urban driving speeds will probably be less than 1 dBA and rarely more than 2 dBA. Current thought as expressed in the Transit New Zealand Noise Guidelines is that a change of 3 dBA is just noticeable to most people.

The implication is that, if the minimum change required to cause annoyance is a 3 dBA increase, changed surface types in urban areas will have no appreciable effect on annoyance levels (Raw and Griffiths, 1985). Consequently the community complaints are inexplicable, as there should not be enough increase in noise to cause annoyance, given the traffic speeds and surface types selected. If the noise changed by 6-7 dBA as a result of surface changes, then this extent of change may initiate complaints from noise level alone. However, if the change in noise level is only 1-2 dBA, the increase should not be noticed by most people and protest action unexpected. It may be that the tonal differences, rather than the increase in noise level itself, inflate the annoyance.

1.3 Project objectives and requirements

1.3.1 Objectives

The purpose of this project is to produce guidelines for use by roading authorities to aid them in selection of road surfaces, particularly in urban areas, so as to reduce road traffic noise and associated annoyance. The guidelines needed two main factors to be identified.

- First, identification of the extent that road surfaces type influences noise at urban driving speeds and for different vehicle categories,
- Second, identification of the nature and degree of increased annoyance that can occur when a street is resealed with a noisier surface, and, conversely, the increased satisfaction, if a quieter surface is used.

1.3.2 Requirements

The research was required to determine:

- The difference in noise between the most common road surface types used in New Zealand both in terms of noise level and tonal difference for urban and open road driving speeds, and
- The influence these noise differences have on community annoyance.

The project utilised the reseal programmes of the Wellington and Lower Hutt roading authorities. This enabled the measurement of the acoustic properties of road surfaces that were both near new, and at the end of their lives.

Simultaneously, because it involved populations that were exposed to a change in noise levels that also included tonal changes, assessments were undertaken of the populations' increased annoyance or increased satisfaction.

2. Noise Measurements

2.1 Road surface types

Thirteen common surface types intended to be resealed were selected. These included dense and open graded asphalt, coarse, medium and fine chipseals, and several two-coat seals. Texture measurements were made at 12 sites selected for the community effects surveys. These were measured with a non-contact laser profilometer and the mean profile depth (MPD) was calculated according to ISO 13473-1 (1997). Traffic noise levels at the sites were measured before and after resealing.

Specifically, the selection of road surfaces included:

- Dense graded asphaltic concrete (asphalt), similar to those used in other countries.
- OGPA (open graded porous asphalt), which is used primarily for higher speed skid resistance. It has relatively low voids compared to specialised acoustic surfaces (15-20%) and is laid only in relatively thin layers (30 mm thick).
- Chipseal surfaces (known in other countries also as spray seals, surface dressing) which consist of a layer of sprayed bitumen into which is embedded a layer of aggregate of specific size. The nominal aggregate sizes are:

  - 19 mm (Grade 2)
  - 16 mm (Grade 3)
  - 12 mm (Grade 4)
  - 10 mm (Grade 5) and
  - 7 mm (Grade 6).

The New Zealand classification is shown in parenthesis. The aggregates are of a roughly uniform size, within about 65-100% of the maximum size for the grade, and shaped so that the longest dimension is about 100% greater than the smallest dimension. As in other countries, two coat seals, where a smaller chip is fitted into the matrix of a larger chip, are used to increase mechanical properties, to stabilise developing failure or to increase skid resistance. They are also used in the belief that two coat seals are quieter. Common combinations are 19/12 mm, 16/10 mm, 16/7 mm and 12/7 mm.

2.2 Noise level measurements

The noise levels generated by control vehicles were measured on the open road in addition to all the test sites. This enabled identification of any relationship between the noise effects of the different road surface types at urban speed and open road speed. These control vehicles were then related to typical fleet vehicles at a selection of sites by comparing the noise effect of each control vehicle to a sample of those passing.

The noise level and spectral distributions (tonal content) were determined using a control vehicle in the 'cruise by' technique.

The control vehicles were:

- Light vehicle (LV) – 1999 Daewoo Nubira car.
- Heavy vehicle (HV) – 6x4 Scania tractor unit (tare weight 8020 kg).

Note that only the tractor unit of the heavy vehicle was used, as much of the work had to be undertaken in suburban streets unsuitable for a long truck to turn to make the repeat runs. (The additional tyres of trailer units will increase the tyre surface effect. Increased load will increase both tyre noise and acoustic noise.)

It had been intended to also include a medium vehicle, a 4WD SUV, but this was discontinued after initial tests showed the noise effects were similar to that of the car, i.e. within about 1 dBA.

For most sites, each control vehicle made 5 passes and then an average spectrum and noise level was then determined for each site.

The literature shows that, although the noise from different cars is influenced by a number of factors, the tyre type contributes very significant to the road surface noise generated. However, it was reasoned that, for each road surface type, taking a sample of 10-20 vehicles within the categories of either car or truck and averaging their individual noise would give a good representation of the noise generated by typical urban traffic streams. At 40% of the sites the noise and spectral distribution of approximately 20 passing cars, 10 to 20 medium vehicles, and around 10 trucks were measured. The differences between the fleet vehicles and control vehicles were subsequently used to modify the measurements made at the remaining sites, where only the control vehicles had been used.

The noise levels and the spectral content were determined using a sound level meter (SLM) placed at a position of 5 metres from the nearside wheel track. The SLM was connected to a computer, which analysed a 1 second sample of noise for both 1/3-octave band spectra and total noise level, utilising a high-speed A-D card which converts analogue signals into digital format.

2.3 Effects of traffic speed

Additional open road sites were selected where traffic travelled at 70 or 100 km/h. More is known internationally about the effects of road surfaces on traffic noise at 80-100 km/h. The road surface effects from the additional sites were then used to relate the road surface effects at typical urban driving speeds to those at open road speeds.

The open road sites also enabled a study of the effects of several road surfaces that are typical for open roads, but are not as common on urban roads. These different surfaces included coarse chipseals (grade 2 and 2/4), specialised fine chip (calcined bauxite) and open graded porous asphalt.

2.4 Consistency of the test method

The consistency of the method was verified as part of the test procedure. This included:

- Consistency shown among the multiple runs by both control vehicles. This was verified over smooth, medium and coarse textured road surface types.
- The variation in noise among the sample of fleet vehicles, and the consistency of the mean of these samples.
- The match of the control vehicles to the mean of the fleet vehicles.

3. Results of Noise Measurements

3.1 Consistency of the method

3.1.1 Control vehicles

The range of measured overall noise levels for the cruise-by control vehicle was studied. Table 1 lists the averages and standard deviations for the individual noise levels for the control vehicle.

Table 1 Noise levels for individual cruise-by runs: control vehicles.

Surface Type	Light Vehicle (LV)			Heavy Vehicle (HV)		
	Average Noise Level (dBA)	Std Deviation (dBA)	Sample Size (*n*) runs	Average Noise Level (dBA)	Std Deviation (dBA)	Sample Size (*n*) runs
Coarse (Grade 3)	74.5	0.52	9	80.1	0.51	6
Finer (4/6)	73.6	0.40	5	80.5	0.23	5
Dense Graded AC	68.9	0.40	5	78.6	0.52	5
OGPA	67.7	0.75	4	76.5*	0.60*	4

* *Test site differs from that of the light vehicle.*

The table shows a good agreement between the runs, with the standard deviation being generally less than 0.5 dBA. In addition, the spectra in Figures 1 to 4 show that the individual runs at each site are consistent, particularly in the range between 100 Hz to 8 kHz.

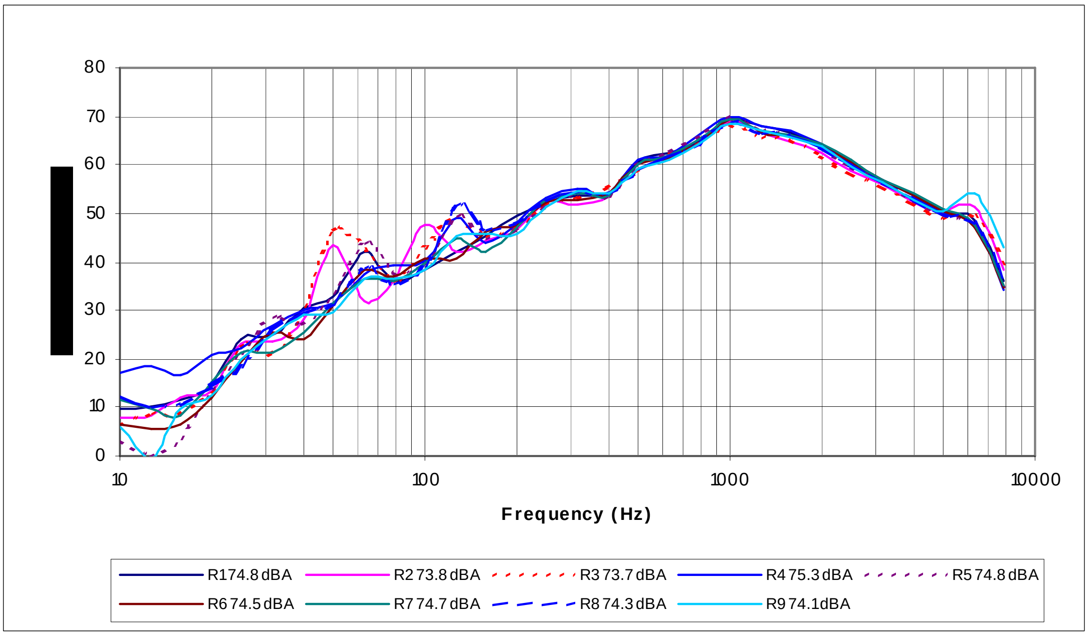

Figure 1 Control - light vehicle cruise–by noise levels : coarse (Grade 3) chipseal

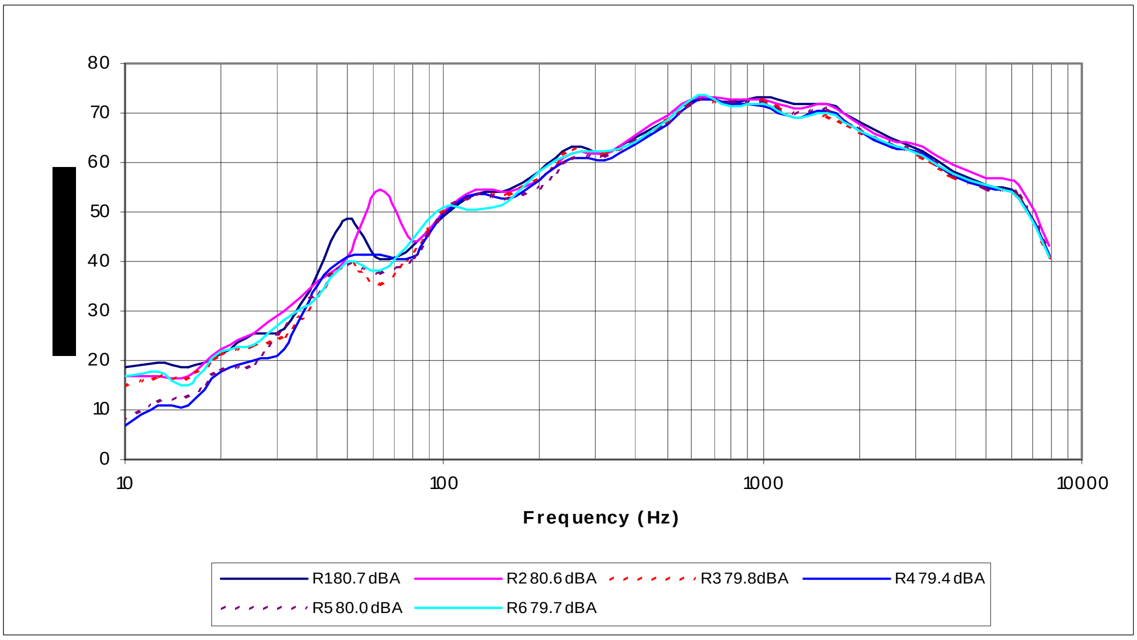

Figure 2 **Control - heavy vehicle cruise–by noise levels: coarse (Grade 3) chipseal.**

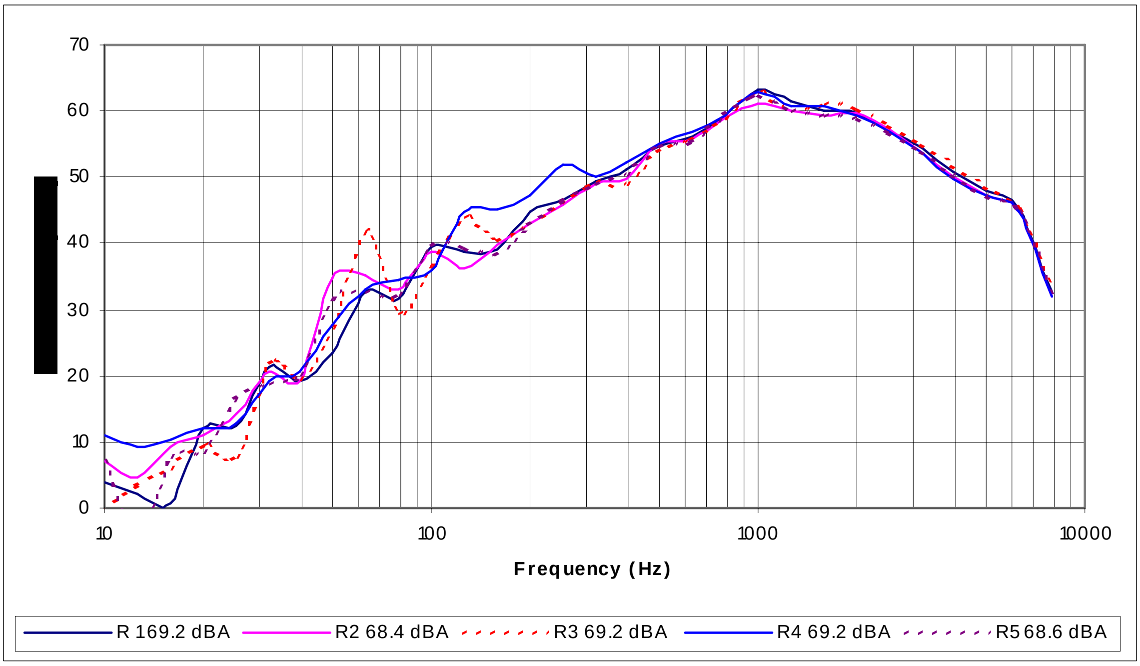

Figure 3 **Control - light vehicle cruise–by noise levels: dense graded AC**

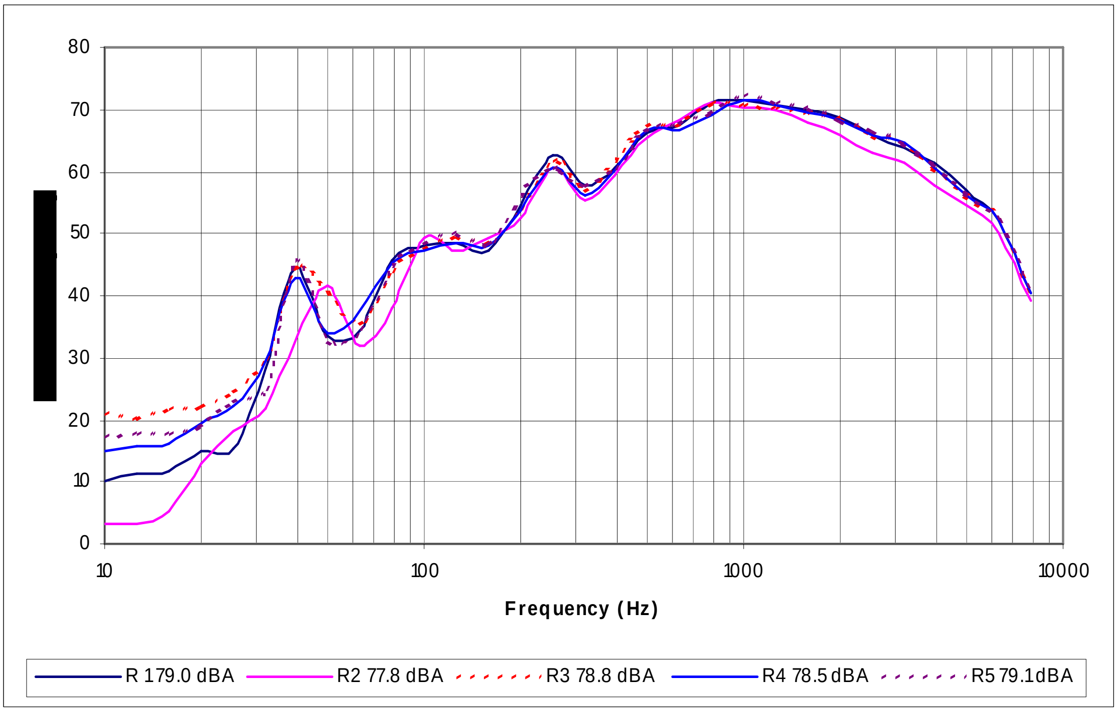

Figure 4 Control - heavy vehicle cruise-by noise levels: dense graded AC.

3.1.2 Fleet vehicles

In a similar manner, a study was carried out of the range of overall noise levels for the cruise-by fleet vehicles. Table 2 lists the sample averages and the standard deviations for the noise levels of the individual fleet vehicle passes.

For the fleet vehicle measurements the average noise level was calculated by the logarithmic combination of the noise spectrum for the individual vehicles. This method of determining mean noise levels was used throughout this work for both control and fleet vehicles.

Table 2 Noise levels for individual cruise–by runs : fleet vehicles.

Surface Type	Light Vehicle (LV)			Heavy Vehicle (HV)		
	Average Noise Level (dBA)	Std Deviation (dBA)	Sample Size (*n*) runs	Average Noise Level (dBA)	Std Deviation (dBA)	Sample Size (*n*) runs
Coarse (Grade 3)	76.2	2.30	27	82.6	2.06	8
Finer (4/6)	74.0	2.30	22	80.0	2.08	5
Dense Graded AC	69.9	2.56	22	78.9	2.21	12
OGPA	68.9	1.13	14	80.6	3.57	3

Table 2 shows that, compared to the control vehicles, the cruise-by noise levels of individual vehicles within the fleet vary considerably. This is understandable considering the variation in the makes and sizes of the vehicle types available. However, the sample was large enough to have adequately captured the mean noise level.

This was verified by a process illustrated in Tables 3 to 6, where the mean noise levels of smaller sample sizes from within each surface-type group were compared with the mean noise level produced from the total sample. In these tables 'run number' refers to single vehicles in the sample. For example in Table 3 there are 27 light vehicles in the 'coarse chipseal' sample; 1-5 are the first 5 vehicles, 6-10 the second 5 vehicles and so on. As shown in Tables 3 to 6, the mean is fairly stable (within about 1.5 dBA) for about 5 vehicles and is stable (i.e. generally less than 1 dBA) for any combination of 10 vehicles. This gives confidence that the method is robust and that the sample sizes for each site were sufficient to be representative of the fleet.

Tables 4 and 6 omit the evaluation of heavy vehicles as the overall sample size was too small for such a comparison (see the *n* value of Table 2).

Table 3 Comparison of smaller samples within surface-type group : coarse (grade 3 or 16 mm) chipseal.

Run Number	1-27	1-5	6-10	11-15	16-20	20-27
Light Vehicle Noise Level (dBA)	76.2	77.4	74.6	74.4	76.9	75.6
Variation from Mean of Large Sample (dBA)	0	+1.2	-1.6	-2.2	+0.7	-0.6

Run Number	1-8	1-4	5-8
Heavy Vehicle Noise Level (dBA)	82.6	81.3	83.5
Variation from Mean of Large Sample (dBA)	0	-1.3	+0.9

Table 4 Comparison of smaller samples within surface-type group : finer (grade 4/6 or 12/7 mm) chipseal.

Run Number	1-22	1-5	6-10	11-15	16-22
Light Vehicle Noise Level (dBA)	74.0	74.2	74.6	73.8	73.5
Variation from Mean of Large Sample (dBA)	0	+0.2	+0.6	-0.2	-0.5

Table 5 Comparison of smaller samples within surface-type group : dense graded AC.

Run Number	1-20	1-5	6-10	11-15	16-20
Light Vehicle Noise Level (dBA)	69.9	69.4	71.4	68.7	69.6
Variation from Mean of Large Sample (dBA)	0	-0.5	+1.5	-1.2	-0.3

Run Number	1-10	1-5	6 – 10
Heavy Vehicle Noise Level (dBA)	78.9	77.9	79.8
Variation from Mean of Large Sample (dBA)	0	-1.0	+0.9

Table 6 Comparison of smaller samples within surface-type group : OGPA.

Run Number	1-14	1-5	6-10	11-14
Light Vehicle Noise Level (dBA)	68.9	68.2	68.9	69.6
Variation from Mean of Large Sample (dBA)	0	-0.7	0	+0.7

3.1.3 Control vehicles compared with fleet vehicles – urban speeds

Table 7 shows the A-weighted sound level comparison between the average noise level for the fleet vehicles and the average cruise-by noise level for the control vehicles.

Table 7 Control vehicle noise vs. fleet noise at 50 km/h.

Road Surface	Average Noise Level (dBA)					
	Light Vehicle			Heavy Vehicle		
	Control Vehicle	Fleet	Difference Control Vehicle Fleet	Control Vehicle	Fleet	Difference Control Vehicle Fleet
Coarse (grade 3)	74.5	76.2	-1.7	80.1	82.6	-2.5
Finer (4/6)	73.6	74.0	-0.6	80.5	80.0	+0.5
Dense graded AC	68.9	69.9	-1.0	78.6	78.9	-0.3
OGPA	67.7	68.9	-1.2	NA*	NA*	NA*

* *OGPA results for the heavy control vehicle were obtained from two different sites, one of new OGPA and one of 'Old' OGPA. Consequently a straight comparison may not be valid.*

Table 7 shows that for light vehicles, the average fleet vehicle noise is around 1 dBA greater than for the test vehicle. Similar comparison for the heavy vehicles is not so clear. The heavy vehicles samples were smaller, due to the limited number of heavy vehicles available for sampling on suburban streets, and so the data is more variable.

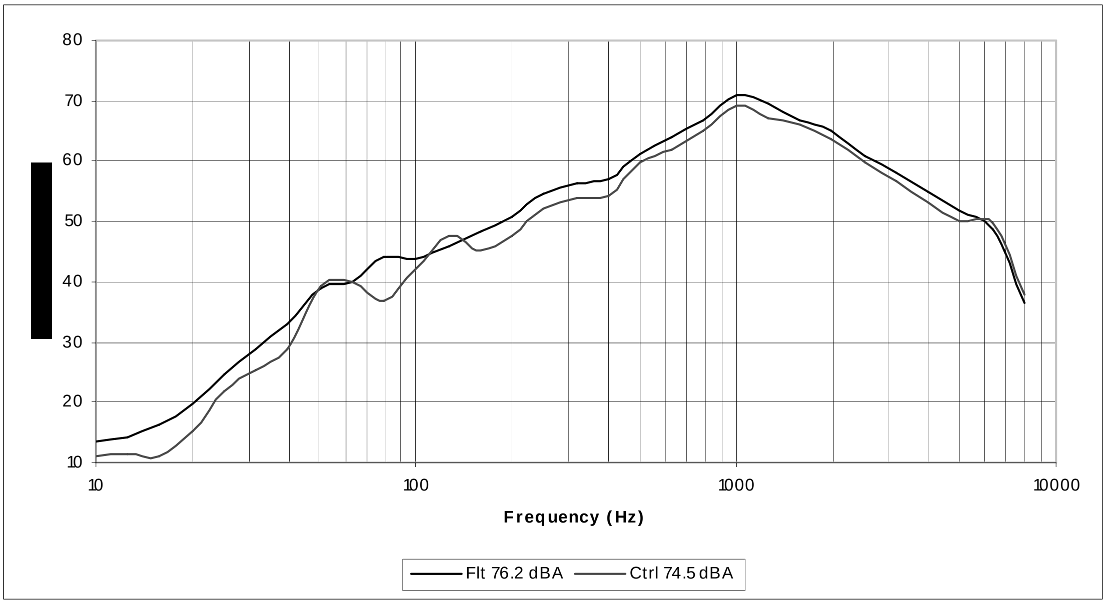

Figure 5 Fleet vs. control - light vehicle cruise-by noise levels: coarse (grade 3) chipseal.

A further way to assess consistency is to compare how the 1/3 octave band spectra of the test vehicle compares with the average spectra for the fleet. Figure 5 above and figures 6 and 7 below show the 1/3 octave band spectra for both the control and the fleet vehicles at two sites. These show the difference between the average fleet vehicle noise and that of the control vehicle for the light vehicle on both chip and AC and for the heavy vehicle on AC only. It can be clearly seen, especially for the car, that there is a close correlation between the two. The heavy vehicle gives a good match in the tyre noise part of the spectra. The disparities elsewhere can be expected given that the test heavy vehicle is only the tractor unit.

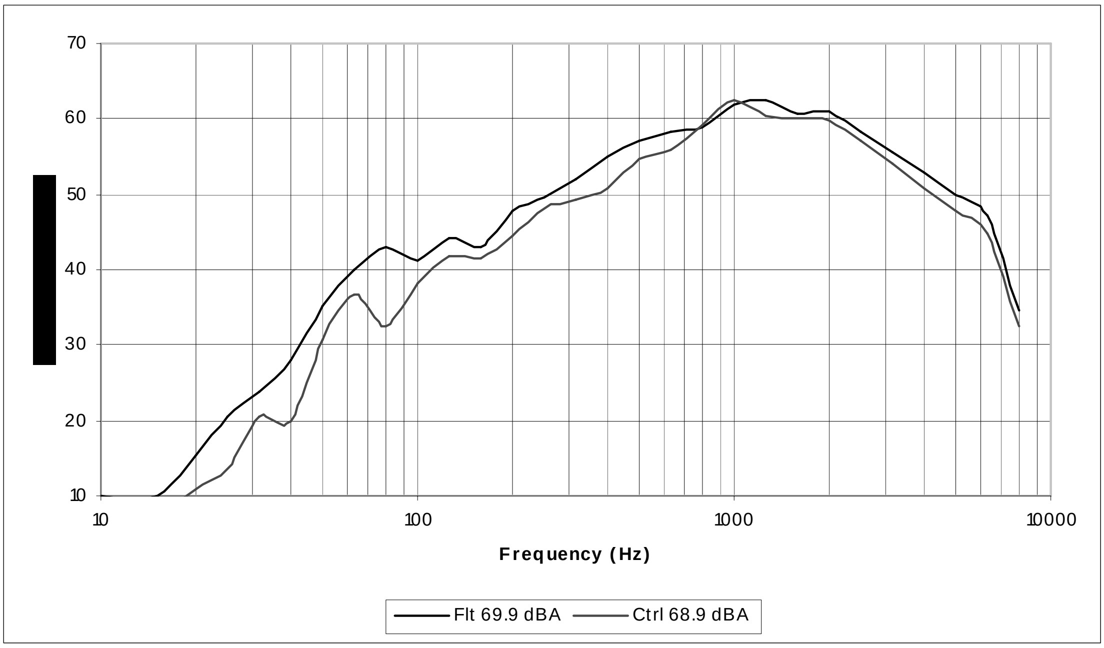

Figure 6 Fleet vs. control - light vehicle cruise-by noise levels: dense graded AC.

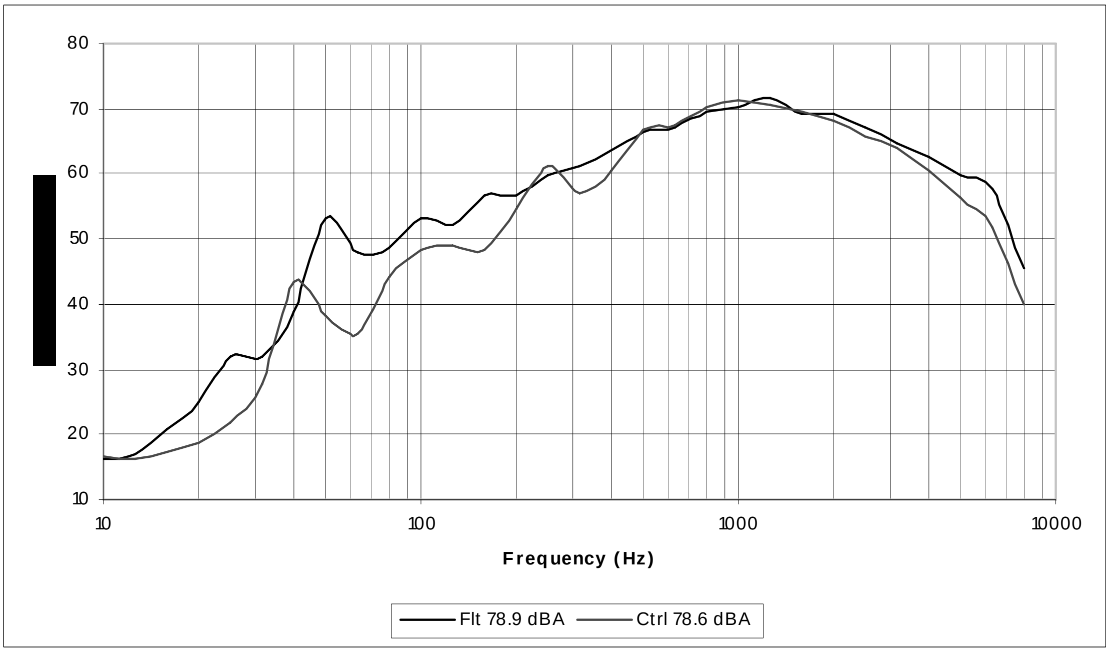

Figure 7 Fleet vs. control - heavy vehicle cruise-by noise levels: dense graded AC.

3.2 Surface effects

Table 8 shows the overall differences between road surfaces for traffic speeds of 50 km/h. In addition, the differences in noise level have been compared to the noise level from traffic on dense graded AC.

Table 8 also shows that the heavy vehicle traffic is less sensitive to changes in road surface at 50 km/h, compared to light vehicles.

A plot of texture depth versus noise is shown in Figure 8**.** A texture depth/noise relationship is not strong, with many of the two coat seals giving a much higher noise than expected for their mean profile depth. Their noise effect is very similar to the single coat chip. It appears that MPD as a measure of texture depth does not sufficiently describe a surface within terms of its noise generating potential.

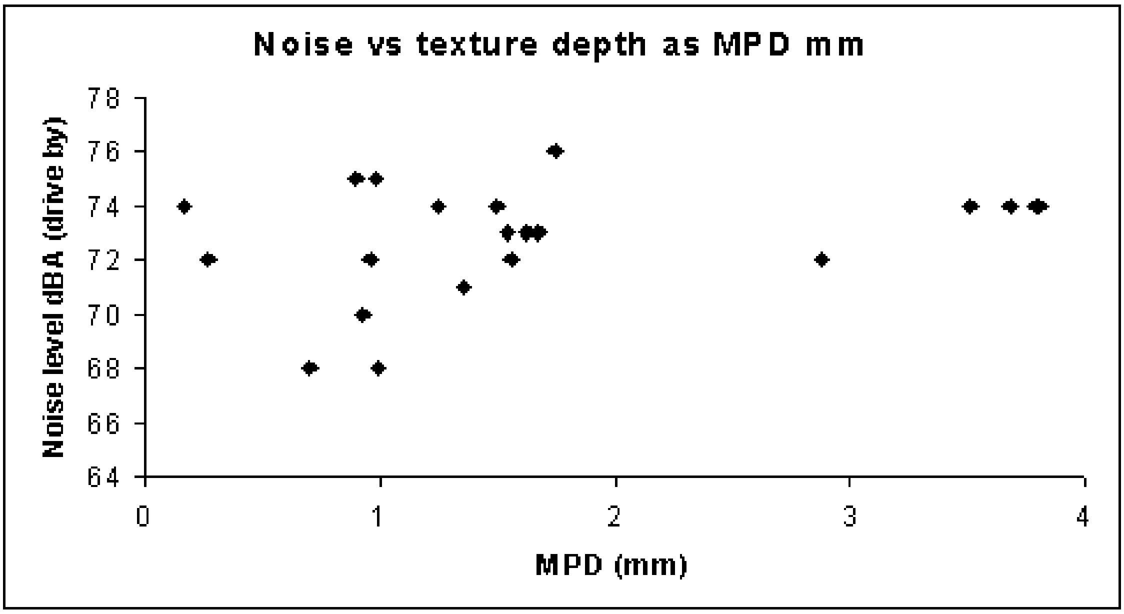

Figure 8 Relationship of road surface texture (mean profile depth) at trial sites and noise level generated (dBA).

3.3 New surfaces compared to old surfaces

The level and spectral content of vehicle cruise-by noise was measured immediately prior to resealing of the road surface, and again soon after the resealing was completed. This enabled a comparison of the noise levels of road surfaces near end of life and in new condition.

Table 8 Effects of different surfaces at 50 km/h for light vehicle and heavy vehicle.

Vehicle Type	Average Noise Level (dBA)												
	Bituminous Mixes				Chipseal over Bitumen layer								
	AC (dBA)	Slurry (dBA)	OGPA (dBA)	Cape Seal (dBA)	7 mm (dBA)	10 mm (dBA)	12/7 mm (dBA)	12 mm (dBA)	16/7 mm (dBA)	16/10 mm (dBA)	19/12 mm (dBA)	16 mm (dBA)	19 mm (dBA)
Control LV	68	69	69	68	71	71	74	72	75	74	74	73	75
Typical fleet LV	69	70	69	68	72	72	74	72	75	74	73	73	75
Difference relative to AC: LV	N/A	+1	0	-1	+3	+3	+5	+3	+6	+5	+4	+4	+6
Control HV	79	76	77	76	77	79	79	77	80	80	-	80	-
Difference relative to AC: HV	N/A	-3	-2	-3	-2	0	0	-2	+1	+1	-	+1	-

Note:

- AC: asphaltic concrete
- Slurry: slurry seal (or micro surfacing)
- OGPA: open graded porous asphalt
- Cape Seal: slurry seal over a chipseal. Results are for type 2 over grade 3 chip
- 7 mm: nominal chip sizes, single coat
- 12/7 mm: nominal chip sizes; two coat seal

3.3.1 Noise level comparisons - 'before' and 'after' resealing

Table 9 Overall noise level changes at surveyed sites for light vehicles at 50 km/h.

Location		Surface Treatment			Noise Level Change (dBA)
1	Esplanade	Grade 3/5	→	AC	-7.0
2	Marine Parade	Grade 5	→	AC	-2.2
3	Cuba St	Grade 3/6 VF	→	Grade 3/6	-0.9
4	Moxham Ave	Grade 3	→	Slurry	-4.2
5	Epuni St	Grade 4/6	→	Grade 3/5	+1.7
6	Muritai Rd	Grade 3/6	→	Grade 6	-3.3
7	Naenae Rd	Grade 4/6	→	Grade 3/5	+0.7
8	Ruahine St	Grade 3	→	OGPA	-6.0
9	Abilene Cres	Slurry	→	Grade 4/6	+6.0
10	Stokes Valley Rd	Grade 6	→	Grade 3	+1.0
11	Brees St	Grade 4/5	→	Grade 4	+1.4
12	Scapa Tce	Grade 6	→	AC	-3.9

Table 9 shows the overall change in light vehicle noise levels on surfaces in their 'end-of-life' condition compared with light vehicle noise levels on the surface it has been replaced by at each site.

From Table 9 it can be seen that for light vehicles at 50 km/h, noise level differences of up to 6 to 7 dBA due to the effects of road surface can be expected, especially where the proportion of heavy traffic is low.

3.3.2 Effects of aging

Because measurements of vehicle noise were carried out on road surfaces in both the 'end of life' condition and 'as new' condition, it was possible to compare the noise effects for those surfaces which differed only in age.

The changes in noise levels due to surface aging were found to be relatively small. For all the chipseal surfaces in the study, the noise for light vehicles on the newly laid chip was around 0 dBA to 1 dBA higher than for the noise for light vehicles on the more worn older chip.

For both dense graded AC and OGPA, this small effect was reversed. In these cases, the noise for light vehicles on the newly laid AC or OGPA was found to be up to 2 dBA less than for the noise for light vehicles on the more worn older surface. This trend is consistent with chipseals becoming more smooth over wear, whereas the AC will roughen as the bitumen oxidizes and the fine portion is lost.

However, the spectra of the various surfaces demonstrated some consistent trends. It was noted that the noise from light vehicles on older, worn chipseals had a lower component between 100 Hz to 1 kHz than the noise from light vehicles on the new chipseals of the same nominal chip size. Conversely, noise from light vehicles on these older, worn chipseals had a higher component between 1 and 8 kHz than the noise from light vehicles on the new chipseals of the same nominal chip size.

Figure 9 shows the spectral difference for the noise from light vehicles on both 'new' and 'old' grade 3 chipseal. Note that the new chip is around 5 dBA louder than the older chip between about 80 Hz and 200 Hz. Conversely, noise from light vehicles on the new chip is around 5 dBA less than that for the older chip between about 2 and 6 kHz. The significance of this is that the noise from light vehicles on the new chipseals would be perceived as having more 'rumble' compared with the old chipseals, while the noise from light vehicles on the older chipseals would be perceived as having more of a 'hiss' compared with new chipseals.

Figure 9 shows a small peak at 7 kHz labelled cidadas. These measurements were made in summer and the effect of cidadas on overall noise levels identified and isolated.

This pattern of the newer chipseal generating a louder low frequency component and quieter high frequency component compared to older chipseals was found to be consistent for all the chipseals studied, although the differences tended to reduce as the texture reduced.

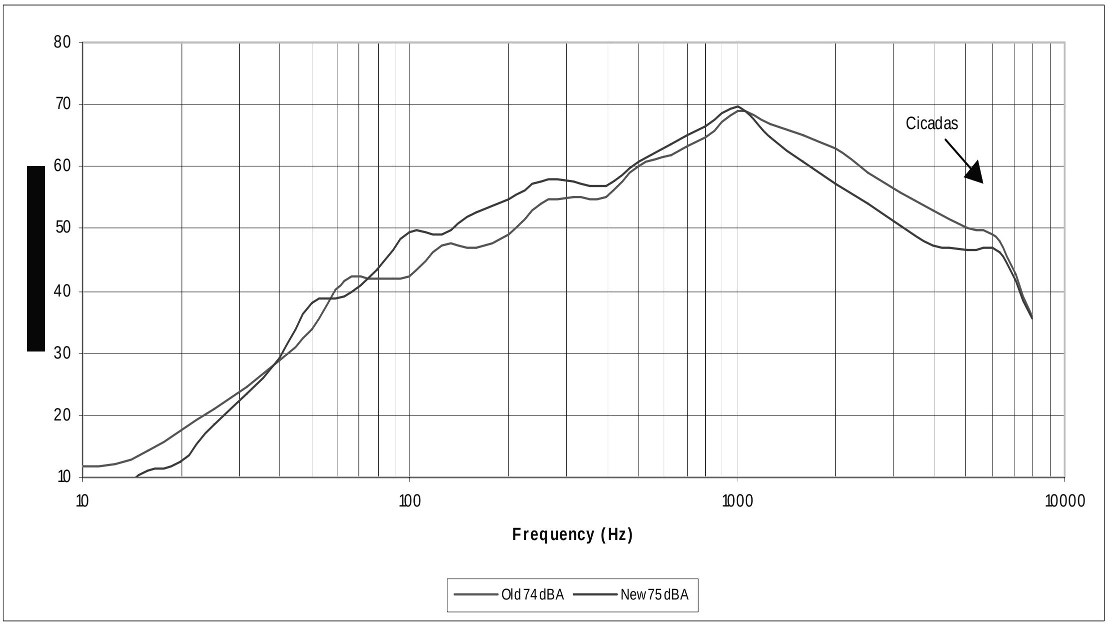

Figure 9 Means of light vehicle noise on both 'new' and 'old' coarse (grade 3) chipseal surfaces at 50 km/h.

Figure 10 shows the spectral distribution for the noise from light vehicles on both 'new' and 'old' dense graded AC. From this it can be seen that while there appears to be little tonal difference, the noise from light vehicles on the older surfaces is slightly noisier over most of the spectrum than that for the new surfaces.

A comparison of Figures 9 and 10 shows that as the chipseal ages the noise spectra becomes more like that for AC and as AC ages the noise spectra becomes more like that for chipseal.

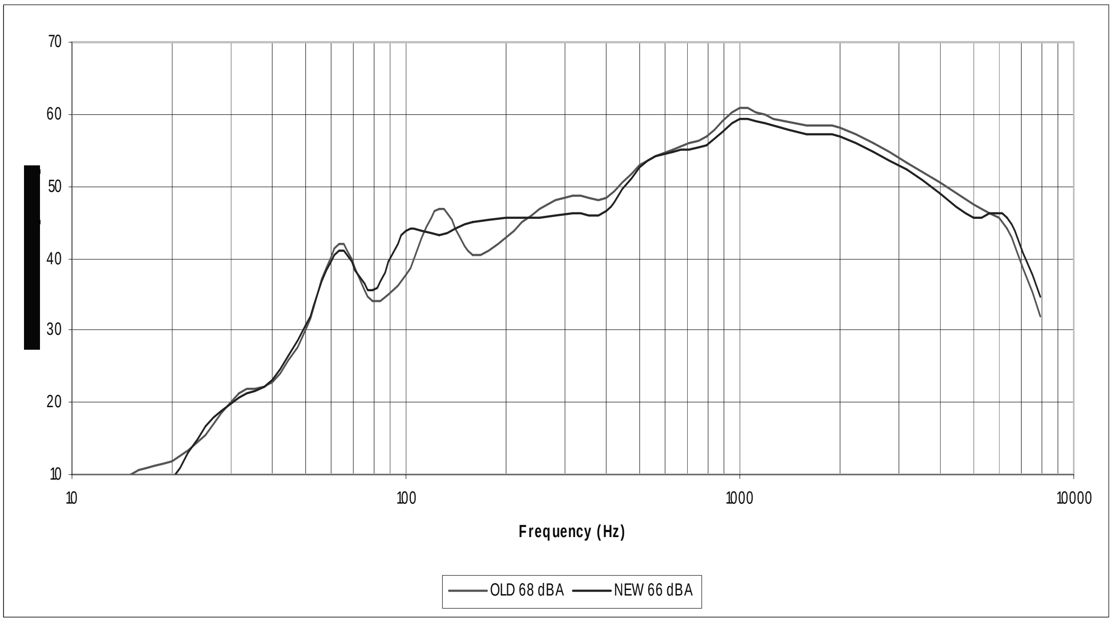

Figure 10 Means of light vehicle noise on both 'new' and 'old' dense graded AC surfaces at 50 km/h.

3.4 Effects of traffic speed

A series of measurements was carried out at a selection of sites with traffic travelling at speeds of 70 to 100 km/h. As for the 50 km/h urban and suburban sites, measurements of both fleet vehicles and control vehicles were included.

3.4.1 Control vehicles compared to fleet vehicles – open road

For the speed variations reported here, the control vehicle data were used, as it was not possible to have any real control over the fleet vehicle speeds. However, if it is assumed that the general traffic was travelling at the posted speed limit of the site, the correlation between the control light vehicle and fleet light vehicles, both for overall noise levels and for spectra, was similar to that for the 50 km/h sites.

Figure 11 shows a typical light fleet/light control vehicle correlation at 100 km/h on a coarse chipseal.

The spectra of the heavy control vehicle and the fleet heavy vehicles at open road speeds did not show such a close correlation. This appeared to be largely due to the fact that the control heavy vehicle was a 6 x 4 tractor unit only, whereas the open road heavy vehicle fleet consisted of the tractor unit together with the articulated trailer arrangement. These formed the A-train and B-train configuration which appeared to be a major component of the open road heavy vehicle fleet.

The difference shown in Figure 12 of about 5 dBA is consistent with the effects of more tyres and for these tyres to be under load. However within the important tyre/road area effect around 1 kHz the pattern of the spectra for the test tractor and tractor fleet are similar.

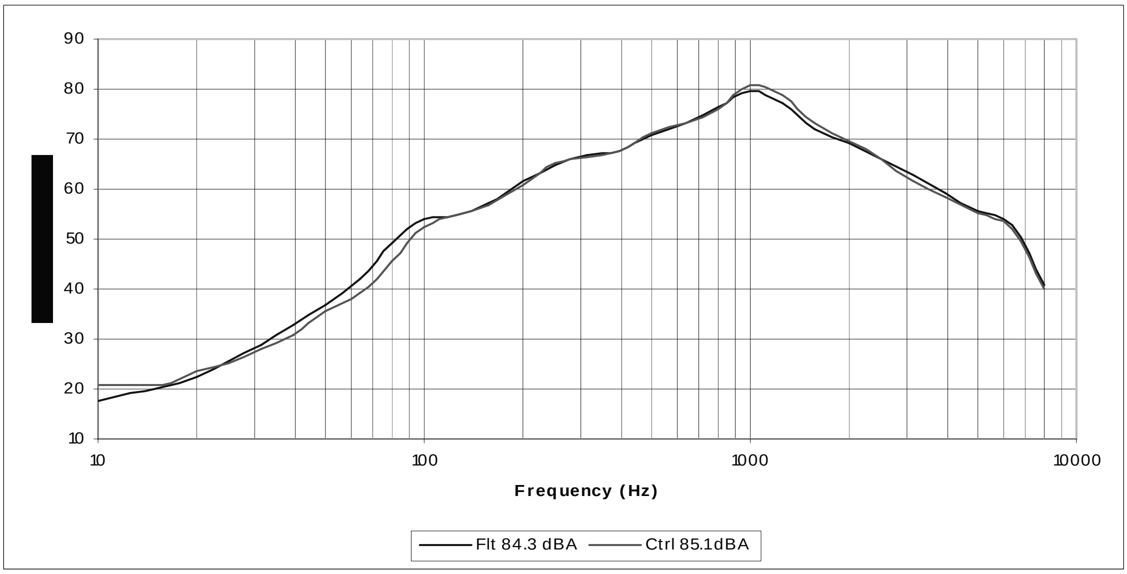

Figure 11 Fleet vs. control light vehicles – grade 2/4 chip at 100 km/h.

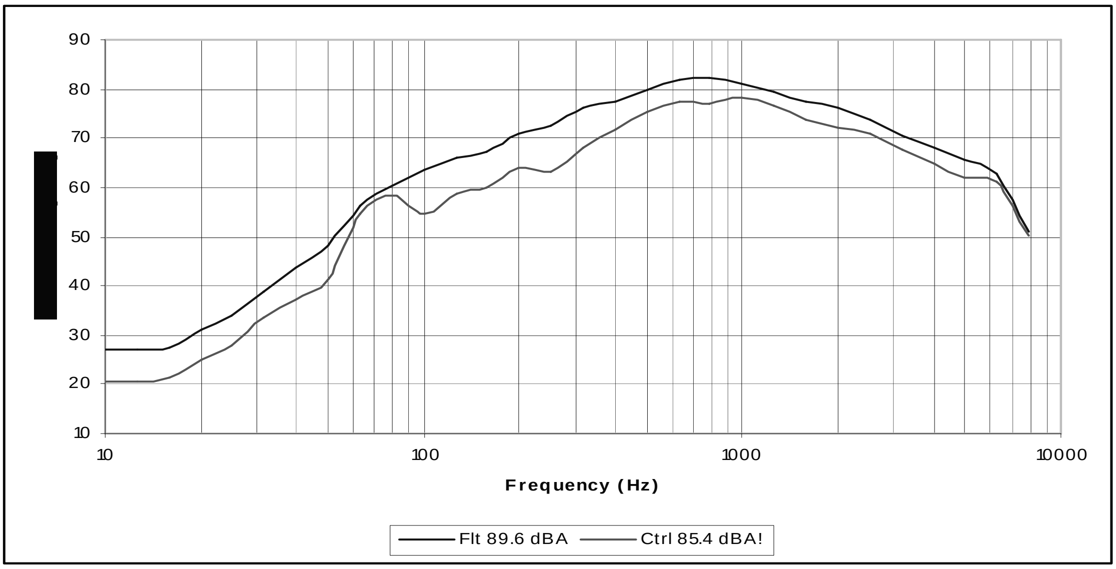

Figure 12 Fleet vs. control heavy vehicles – grade 2 chip at 100 km/h.

Figure 12 also shows that, although the drive train noise is evident in the control vehicle spectrum (between 50 and 100 Hz), it is not shown in the fleet mean spectrum. It is likely that because the fleet vehicles have many more wheels than the test vehicle, the tyre/road noise dominates and the engine noise is masked.

3.4.2 Noise differences due to speed

Table 10 shows the effects of different speeds on the vehicle noise level for various road surfaces. From this it can be seen that, when the speed of light vehicles increases from

50 to 70 km/h. their noise increases by 4 dBA for the AC, OGPA and finer chipseal surfaces, and by 5 to 6 dBA for the coarser chipseals. There is a further increase of about 4 to 6 dBA moving from 70 to 100 km/h.

Table 10 Effects of surfaces on cruise-by noise levels at three different speeds.

Vehicle	Speed km/h	Average noise level (dBA)					
		AC (dBA)	OGPA (dBA)	16/10 mm (dBA)	16 mm (dBA)	19/12 mm (dBA)	19 mm (dBA)
Car	50	68	69	74	74	74	75
	70	72	73	78	78	79	81
	90	-	-	-	-	-	-
	100	-	77	83	83	85	84
Truck	50		77	80	80	-	-
	70		80	82	82	81	83
	90		82	85	84	84	85

Table 10 shows that at 100 km/h noise from a light vehicle on OGPA is around 6 dBA quieter than noise from a light vehicle on grade 3 (16 mm) chip, or 7 dBA quieter compared with noise from a light vehicle on grade 2 (19 mm) chip. This is consistent with the CRTN and Nordic noise models and with existing knowledge. However, although it was often thought that chipseal was 3 dBA more noisy than AC and OGPA was 3 dBA less, it appears that at 50 and 70 km/h AC and OGPA have a similar effect (a difference in effect of only 1 dBA) and both are about 6 dBA less than chipseal. Table 10 also shows that the difference in noise effects between any two surface types is the same from 50 km/ph through to 100 km/h. It would therefore be reasonable to take the effect of AC at 100 km/h to be only 1 dBA more than OGPA. Although AC is unlikely to be used on 100 km/h road sections, this finding is significant when modelling noise, because models such as CRTN and the Nordic model are predicting for a baseline of an AC surface.

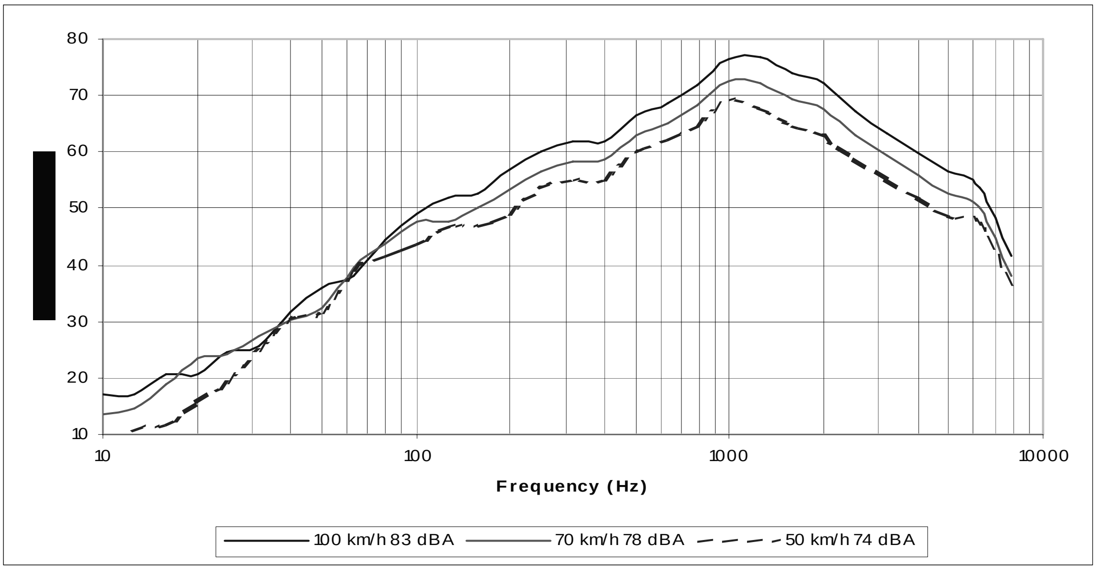

Figure 13 LV control: noise differences due to speed - coarse (grade 3) chipseal.

Figure 13 shows the spectra for a light vehicle at 3 different speeds on a grade 3 chipseal. For each speed the spectra are similar from 100 Hz to 8 kHz and for each surface type the relative spectral content of the vehicle noise remains unchanged by vehicle speed. For finer textured surfaces such as grade 4 chip and for both dense graded AC and OGPA, the effect is similar.

Figure 14 shows that the effect for heavy vehicles is not as clearly defined. Additionally heavy vehicle noise does not appear to be as speed dependent as light vehicles. This is consistent with the old Nordic Model 1974, but inconsistent with the 1995 model which gives heavy vehicle noise a greater speed dependency than cars. However, the engine noise section of the spectra, i.e. between 20 and 80 Hz, shows a peak that is specific to each of the test speeds. For finer textured surfaces such as grade 4 chip and for both dense graded AC and OGPA, the effect has been found to be similar.

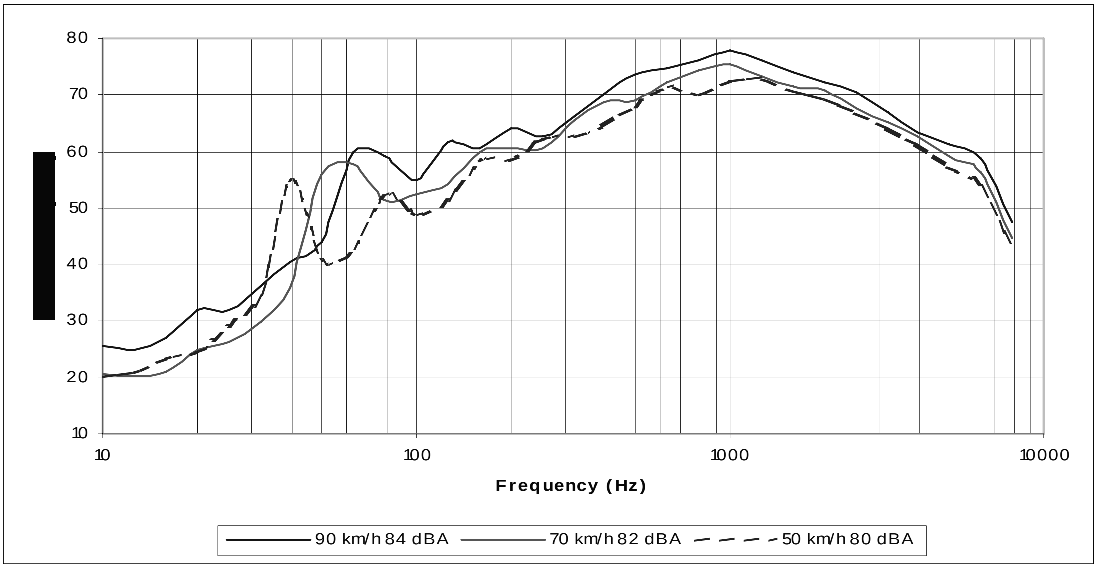

Figure 14 HV control: noise differences due to speed - coarse (grade 3) chipseal.

Table 11 shows the noise levels of passing vehicles travelling across OGPA onto a calcined bauxite surface. The spectra content of the noise effect of the two surfaces is almost the same total noise level, both for the light vehicles. In addition the spectra content of the noise effect of the two surfaces (not shown here) is almost the same apart from there being a little more tonal content in the high frequencies for the calcined bauxite.

Table 11 Effect of calcined bauxite (CaBx) relative to OGPA at 100 km/h.

Light Vehicles		Heavy Vehicles	
OGPA	**CaBx**	**OGPA**	**CaBx**
73	73	84	84

This effect is of interest as usually it is thought that standard OGPA has a sound absorbing effect. However given that the calcined bauxite is a fine grit in a non porous surface and the close match of OGPA and AC, it appears that the OGPA offers noise reduction primarily through having a smooth surface with a fine texture rather than by its porous nature.

4. Additional Discussion on Noise Measurement

Tables 8 and 9 show that the road surface has a significant noise effect for cars travelling at 50 km/h. Relative to asphalt, chipseals commonly show a difference of +3 to +7 dBA. The chipseal effect for trucks is much less, at -2 to +1 dBA relative to asphaltic concrete. It has also been found that, for trucks, some bituminous surfaces may be quieter when compared to asphalt. Bitumen surfaces have more of a texture than that of asphalt concrete, but their texture is fine in comparison to chipseal. This is consistent with the literature for higher speed areas.

For cars there is no significant difference between dense asphalt and open graded porous asphalt at 50km/h. This is quite different to expectations. Both the Transit New Zealand Noise Guidelines and Transit New Zealand Research Report No. 28 expect a difference of –3 or –5 dBA. A possible explanation is that in New Zealand OGPA is typically used in depths of 30 mm, and the percentage voids is about 20%. In addition most of the asphalt is based on 10 mm chip, while the OGPA is mainly 14 mm chip.

Table 10 shows that, as expected, the total vehicle noise increases with speed. However, as can be seen from Figures 12 and 13, the noise effects of the different road surfaces at 50 km/h are the same for 70k m/h and 100 km/h. This is true for both trucks and cars. (The test truck was driven only up to the legal speed of 90 km/h).

Table 10 also gives an indication that the effect of speed as contained in both the CRTN and Nordic models may need to be revisited. For cars, the CRTN model predicts a 5 dBA increase in noise level for a speed increase from 50 to 100 km/h, while the Nordic predicts 6 dBA. But, as Table 10 shows, increases of around 8 to 9 dBA occurred in the tests for cars; for one two-coat seal surface the increase was 11 dBA. For trucks noise increases were less than predicted by the other models. Instead of a 7 dBA increase as predicted by Nordic model, noise increases were only about 4 to 5 dBA.

Figures 13 and 14 show the noise spectra for a car and a truck on chipseal for three speeds. From these it can be seen that, particularly for cars, the main effect is an increase in noise level but little change in the tonal content.

5. Community Annoyance

The second part of this study was to identify whether the change in noise level that occurs when the road is resealed results in changes in the community's feeling of annoyance caused by that noise. This stage first required the identification, from the literature, of appropriate methods to measure the community response.

5.1 Noise and annoyance

Noise annoyance is defined as, "a feeling of displeasure or a negative attitude associated with the exposure to an unwanted sound" (Fields and Hall, 1987, p. 3). It is a construct made up of psychological and attitudinal components that operate together in conjunction with a general physiological sensitivity to noise.

The human ear is not equally sensitive to all frequencies of sound. Put generally, we are more sensitive to higher frequencies and less sensitive to lower frequencies (those below 1000 Hz). Consequently a low frequency tone must have more intensity than a tone of higher frequency to be perceived as equal in loudness (Sanders and McCormick, 1993).

People judge annoyance in context and relative to their expectations. For example, aircraft noise is five times more annoying, in laboratory conditions, to those who live far away from an airport than it is to those who live close (Chefitz and Borsky, 1978). In addition, personal characteristics, such as a general sensitivity to noise, history of exposure, and fear of the noise source influence how annoyed a person feels (Guski, 2001).

While noise annoyance must be distinguished from perceived loudness, there is a well-established relationship between the percentage of people who will be become highly annoyed and the sound level intensity measured in dBA (Shultz, 1978). However, for a road-resealing situation where the noise level suddenly changes, the dose/reaction relationship presented by Shultz probably no longer applies. In particular, the annoyance caused by an increase in noise exposure is typically found to be greater than that experienced by populations constantly exposed to the same higher level of noise, as predicted by annoyance models. Annoyance where there is a change in noise levels is thought to follow different rules to annoyance where the noise level remains constant (Griffiths & Row, 1989).

5.2 Methods of measuring community response

Despite differences in the measures used, correlations between reactions (annoyance) and noise exposure level (some physical measure) are impressively consistent (Job, 1988). Methods for measuring noise annoyance have been developed using social science survey techniques and have become relatively common, with more than 350 published studies (for a review see, Job 1988). There are a number of techniques employed to measure annoyance, including single item measures, weighted indices (Bullen et al 1985), percentage ‘highly annoyed’ and measures of reaction such as community complaints (Luz et al 1983).

Recently, Fields et al (1998) produced recommendations for the formatting of questionnaire items to allow for comparable reaction measures from different investigations. There are eight essential elements to ensure comparability, ranging from asking all respondents without ‘filtering’ (in the social science sense) and anchoring the bottom of the scale with the expression “Not at all”. Notwithstanding the recommendations of Fields et al (1998), investigations of the reliability and validity of noise annoyance measures continue to appear. Job et al. (2001), for example, examined the reliability and validity of measures of general and specific measures of noise annoyance. They conclude that the specific measures, as recommended by Fields et al (1998) are less reliable than more general reactions to the noise source.

Job et al (2000) employed a twelve-item ‘noise induced behavioural disturbance index’ to corroborate the scales of general and specific noise annoyance. This scale follows from Langon (1976) who used a six-point behavioural disturbance scale. Job et al used the scale to validate the ‘annoyance scales’. While annoyance correlates well with behavioural disturbance, the relationship is modified by the strategies of participants to cope with the noise (Glass and Singer, 1972; Guski et al, 1978 cited in Guski, 2001). Coping strategies are such things as closing windows, speaking louder, moving to other rooms and changing times when particular activities are undertaken. Thus, where it is possible to distinguish conceptually between levels of annoyance and levels of behavioural disturbance, both measures are an indicator of reactions to environmental noise and both are highly correlated. When investigating the dose/reaction relationship, i.e. the change in response to the changed road surface noise, quantifying both the annoyance and the behavioural disturbance provides two measures to understand this relationship. This course was followed in this study.

5.3 Hypotheses to be tested

Several alternative explanations were generated that might possibly account for the complaints arising from the reseal of low speed zone roads.

1. The reseal changes the surface to create a greater surface noise than is estimated by current physical models so that the dose is actually much higher than otherwise recognised.
2. Annoyance is generated due to tonal differences between the before and after reseal surfaces.
3. Although noise is targeted, the concern is actually created by issues to do with the reseal such as frustration at delay or at loose gravel and sticky bitumen. A corollary of this is the notion that people will adjust their level of annoyance over time, because the source of complaint will be removed soon after reseal if it is genuinely not the sound volume.

5.4 Survey method

The design of the research was a 'within–subjects' or 'repeated measures' experiment. Thus, participants were surveyed before and after reseal to determine the influence of any change on their measurable levels of annoyance and behavioural disturbance. The independent variable was the manipulation of the road surface or the change in conditions between the first and second interviews. The data obtained were analysed using repeated measures t-tests.

All those who lived adjacent to the reseal area were potential participants. All houses were sent a letter advising the occupants of the study and provided with details of a scheduled date for interviews involving a questionnaire. Participants were sent the letter to orient them to the road noise and to give them the opportunity to make a different time to be interviewed. Interviewers approached the households to solicit participants between 5.00 pm and 7.00 pm. If no one was present then the interviewers left a reminder note in the letterbox that they had called and requesting the householders contact them if they wished to be included in the study. Interviewers made scheduled times to visit those who telephoned. The before-seal version of the survey requested the 'best' time after reseal for the participants to be interviewed.

5.5 Participants

One hundred and thirty-eight participants from 12 locations (streets) formed the survey population. The participants were all domiciled in residential addresses on streets due for resealing as a consequence of normal maintenance and upgrading by the council. There were 62 males and 74 females (with 2 missing), ranging in age from '16 to 25' to '86 or more'. Approximately 82% were unaware that their street was scheduled for reseal at the first interview but 99% were aware that the road had been resealed at the second interview. The letter outlining the interviewer's intention to call to discuss road surface noise was read by 82% of the participants.

5.6 The Survey measures

Reaction to change in noise dosage was measured with three scales presented within a 44-item survey. The first measure was a 10-point semantic differential scale, anchored with 'not at all annoying' and 'extremely annoying'. The item was introduced following the standards developed by Fields et al (1988) and asked participants to record how much the road noise annoyed, bothered or disturbed. This scale was corroborated with a Likert scale which was asked at the end of the survey that ranged 'not at all, a little, moderately, very and extremely'. Two objects were considered. The first was traffic on the road. The second was the noise generated by trucks. Thus the first two scales measuring noise annoyance were the same except they addressed different objects. A third measure was a 13-item behavioural disturbance index that followed from the research of Job et al (2001). Job et al found that scales measuring a reaction to noise are more reliable than scales of annoyance. Job identified that 'annoyance' consists of psychological/attitudinal components as well as sensitivity to noise. As a consequence the survey presented 20 items concerning attitudes towards noise and two items concerning noise sensitivity. The remaining items concerned requests for demographic details.

6. Survey Results and Discussion

6.1 Scale reliability measures

Composite scales such as the Behavioural Disturbance Index are tested against statistical criteria to determine the validity of combining several items into a single measure. The most widely used technique is Cronbach's Alpha, which is based on the average inter-tem correlation. This technique applied to the pre and post scale scores revealed the impressively high value of Cronbach Alpha of .86 on both occasions (Alpha greater than .80 is regarded as acceptable, Howell, 1989). These results give confidence in the scale items being associated together such that the composite score measures the same thing (whether or not this is noise annoyance).

The global measure of annoyance was tested for reliability by repeating the question in an alternative format towards the end of the survey. The two presentations of the main annoyance measure yield a strong correlation ($r = .81$, $p. < .001$) in the before-reseal version and a similarly strong correlation in the after-reseal version ($r = .79$, $p. < .001$). The scale measuring annoyance was adapted to ask participants to consider truck noise. This was done to measure reliability across scales, because resealing the road surface should have less influence on the emitted sound, at urban driving speeds, since the dominant source of truck noise is the engine. Again, strong correlations were found between the surveys ($r = .68$, $p. < .001$).

6.2 Measures of reaction to change in noise dosage

The main dependent measures were:

- perceived annoyance for traffic;
- annoyance specifically for trucks; and
- a behavioural disturbance index developed from Job (2001).

The means for 'before resealing' and 'after resealing' are recorded in Table 12. This table shows the means and standard deviation (in brackets) of the three scales measuring traffic noise annoyance, before and after road surface resealing. The extent of annoyance is in relation to the scale ranging from 0 ('not at all annoying') to 10 ('extremely annoying').

'Behavioural Disturbances' are reported as the item score for the 13 items, with larger scores indicating greater behavioural disturbance. The behavioural disturbance index makes no adjustment for incomplete forms and records only the total reported behavioural disturbances.

Figure 15 below shows the change in traffic noise annoyance with resealing, while Figure 16 illustrates the change in behavioural disturbance with resealing. Overall the relationship between surface change and annoyance levels, as measured using the Fields et al (1998) recommended global measure, is $r (138) = .367$, $p. < .001$. The Behavioural Disturbance index correlates moderately with the changes in sound level intensity $r (138) = .337$, $p. <.001$.

Table 12 Means and standard deviations of three dependent measures: traffic noise annoyance, truck noise annoyance and behavioural disturbance due to traffic noise.

Location	Change in dbA	Traffic Noise		Truck Noise		Behavioural Disturbances	
		Before Resealing	After Resealing	Before Resealing	After Resealing	Before Resealing	After Resealing
1. Esplanade (n = 14)	-7.0	6.43 (2.8)	4.24 (2.5)*	7.64 (2.6)	5.96 (2.6)*	5.64 (3.2)	3.79 (3.5)*
2. Marine Parade (n = 12)	-2.4	1.83 (1.8)	1.17 (1.1)	1.00 (0.8)	0.86 (0.7)	0.67 (1.2)	0.08 (0.3)
3. Cuba St (n = 4)	-0.9	5.75 (1.7)	5.00 (3.9)	7.25 (1.0)	6.00 (4.5)	4.25 (3.4)	4.75 (4.6)
4. Moxham Ave (n = 13)	-4.2	5.12 (2.7)	4.92 (2.4)	4.50 (2.9)	4.78 (2.3)	4.31 (4.0)	3.77 (4.2)
5. Epuni St (n = 15)	+1.7	3.87 (2.5)	5.13 (2.9)	5.33 (3.5)	5.77 (3.3)	1.87 (2.5)	2.20 (2.8)
6. Muritai Rd (n = 16)	-3.3	5.04 (3.2)	5.52 (2.6)	6.13 (3.5)	6.73 (2.4)	3.56 (3.5)	3.44 (2.9)
7. Naenae Rd (n = 3)	+0.7	5.83 (1.4)	7.00 (1.7)*	6.87 (2.6)	7.00 (3.6)	5.67 (1.5)	6.00 (4.0)
8. Ruahine St (n = 11)	-6.0	6.96 (1.7)	6.45 (1.8)	7.06 (1.6)	7.09 (2.3)	6.00 (1.9)	3.36 (2.3)**
9. Abilene Cres (n = 13)	+6.0	1.92 (1.9)	3.62 (2.9)*	3.50 (2.6)	4.38 (3.2)	0.08 (0.3)	0.92 (1.7)
10. Stokes Valley Rd (n = 18)	+1.0	4.50 (2.8)	5.67 (3.1)*	4.73 (3.2)	5.67 (2.8)	2.72 (3.1)	4.22 (2.9)*
11. Brees St (n = 7)	+1.4	3.91 (3.3)	3.44 (2.8)	2.42 (3.2)	2.34 (3.6)	2.43 (3.0)	0.86 (2.3)
12. Scapa Terrace (n = 12)	-3.9	3.00 (2.7)	2.17 (1.2)	4.85 (3.3)	3.30 (2.5)	0.67 (1.1)	0.33 (1.2)

The individual site samples provide some limited measure of mean annoyance in response to the overall sound level intensity, measured as an equivalent noise level, Leq (24 hours). This noise level is a single figure calculated for each site as an average value for all houses adjacent that site. The correlation between mean disturbance and sound level intensity is moderate r (138) = .451, p. <.001. The correlation remains moderate after resealing, r (138) = .297, p. < .001. When controlling for the initial differences in sound level intensity, the mean level of change in annoyance correlates moderately with the change in sound level intensity (r^2 = .372, F (2,135) = 41.62, p. < .001). However, the change in behavioural disturbance correlates more strongly than noise annoyance measures with the change in sound level intensity when controlling for the initial differences in site sound level intensity (r^2 = .47, F (2, 135) = 61.45, p. < .001).

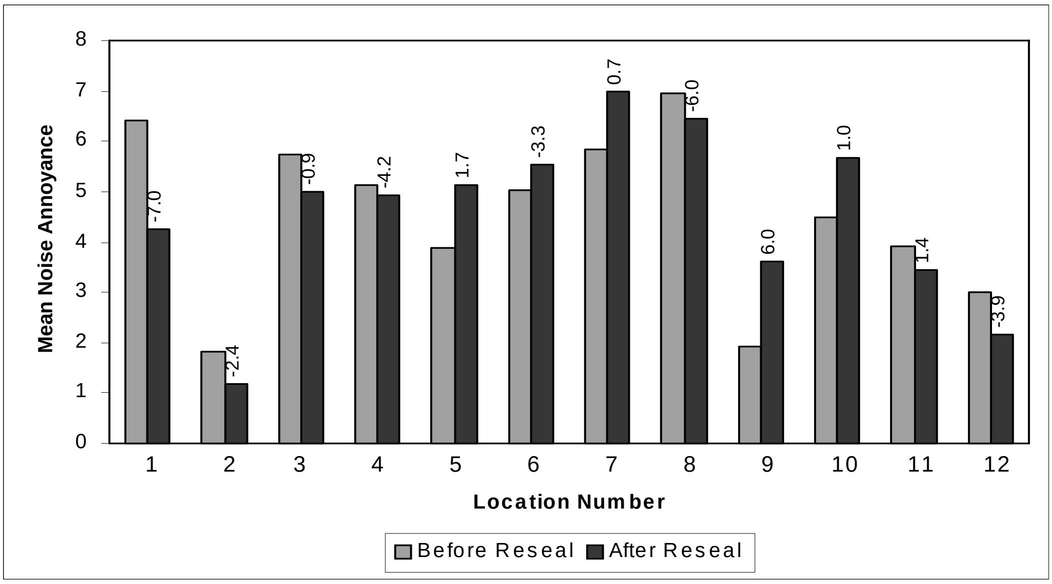

Figure 15 Means for annoyance scale (N = 95) for 12 reseal locations.

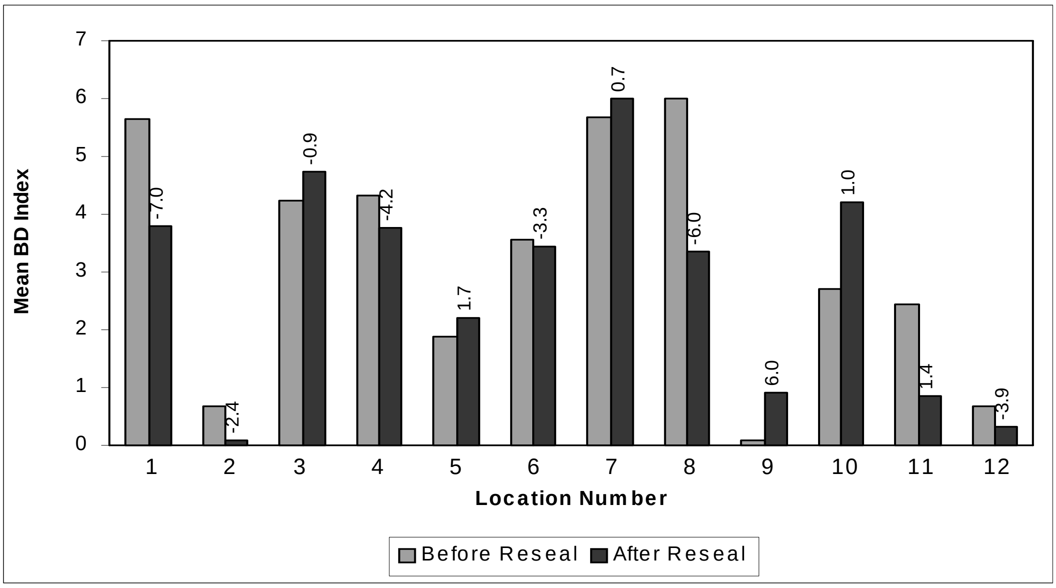

Figure 16 Means for behavioural disturbance index (N = 95) for 12 reseal locations.

Traffic noise annoyance shows a significant increase at site 10 (Stokes Valley Road), when measured on the scale recommended by Fields et al (1998). The same site shows an increase in behavioural disturbance, as measured by the scale following Job et al (2001). Conversely, Site 1 (Esplanade) shows a significant decrease in annoyance together with a significant decrease in behavioural disturbance. Thus both the measures of Fields et al and Job et al identified differences in behaviour or annoyance corresponding to both increased and decreased actual physical noise. However, Site 8 (Ruahine Street) shows a significant decrease in behavioural disturbance not matched by a detected decrease in annoyance. In contrast, Site 9 (Abilene Crescent) shows differences in annoyance not matched by differences in behavioural disturbance. The likely explanation for these data is traffic volume. A large difference in physical noise in a quiet area may produce a change in mean annoyance but not develop any behavioural change, because the noise events are too infrequent to reach the threshold required for behavioural alteration. The reverse is also true.

These data show evidence for behavioural adaptation that occurs in the absence of significant alteration in levels of annoyance. Put another way, people alter their behaviour to accommodate changes in noise at levels below those that would be detected using noise annoyance scales. Notwithstanding these observations, behavioural adjustment was found to be more highly correlated with changes in noise dosage and therefore is a more sensitive measure of reaction to noise.

7. Tonal Characteristics

The overall increase in dBA is a mean estimate derived from a range of frequencies (10 – 10 000 Hz). It is well established that pure tones are differentially perceived louder depending on the frequency that is altered. Noise annoyance then is likely to be related to frequency. To assess whether a particular frequency accounts for the variation of noise annoyance, a stepwise regression was conducted for noise annoyance on the dBA change for 8, 1/3 octave bands observed, represented by the midpoint in the frequency range 501 Hz - 2561 Hz. When the change in response to the noise annoyance scale is used as the dependent variable, all frequency ranges are eliminated except for 794 Hz. This octave band represents the factor predicting the observed variation in noise annoyance, r^2 = .131 (1, 136) F= 20.43, p. < .001. When the dependent variable is change in behavioural disturbance a similar result is found. Behavioural disturbance is predicted by 1000 Hz octave band r^2 = .127 (1, 136) F = 19.82, p. < .001; with other frequency ranges providing no significant improvement in prediction.

8. Long Term Habituation

Three sites (Esplanade, Ruahine Street and Stokes Valley Road) were revisited after six months. These sites showed significant differences in residents' responses to noise and therefore potentially could develop an acceptance or habituation over time. Table 14 presents the means (standard deviations in brackets) for the sites of measures of annoyance and behavioural disturbance. Figures 17 and 18 present graphically the observed alteration in annoyance and behavioural disturbance over time. Repeated analyses of variance (ANOVAs) were undertaken to assess the differences in means for the sites, with Bonferroni adjustments being undertaken to determine post hoc differences. In this way it was possible to assess the level of before reseal annoyance, after reseal annoyance and follow-up annoyance (six months later) to determine whether they had changed in the period after the reseal.

Multivariate tests on the repeated measures show significant effects concerning noise annoyance for the Esplanade site, Wilk's Lambda F = 5.478, p. < .032, with post hoc tests establishing that before reseal and six months after reseal there is no significant difference in annoyance. It appears that improvements in community annoyance degrade to approximately the before reseal levels. The Ruahine Street and Stokes Valley Road sites do not show any significant differences across the repeated measure but demonstrate the trends observed for the Esplanade site: the elimination of effects observed immediately after reseal, returning to before reseal levels. The measures for the behavioural disturbance index are not significant.

Table 13 Six-month observations of general annoyance and behavioural disturbance at three sites showing significant variation after reseal.

Responses to Noise		Site					
		Esplanade		Ruahine Street		Stokes Valley Road	
		Mean	SD	Mean	SD	Mean	SD
Annoyance	Before Reseal	6.60	(0.52)	6.83	(0.79)	4.30	(0.87)
	After Reseal	4.74	(0.48)	6.00	(0.63)	4.71	(0.88)
	Six Months After Reseal	6.60	(0.43)	7.33	(0.67)	4.40	(0.67)
Behavioural Disturbance	Before Reseal	6.10	(2.96)	5.83	(1.83)	2.70	(3.43)
	After Reseal	3.90	(2.96)	3.33	(1.63)	3.00	(2.45)
	Six Months After Reseal	3.30	(2.63)	4.50	(1.87)	2.40	(2.63)

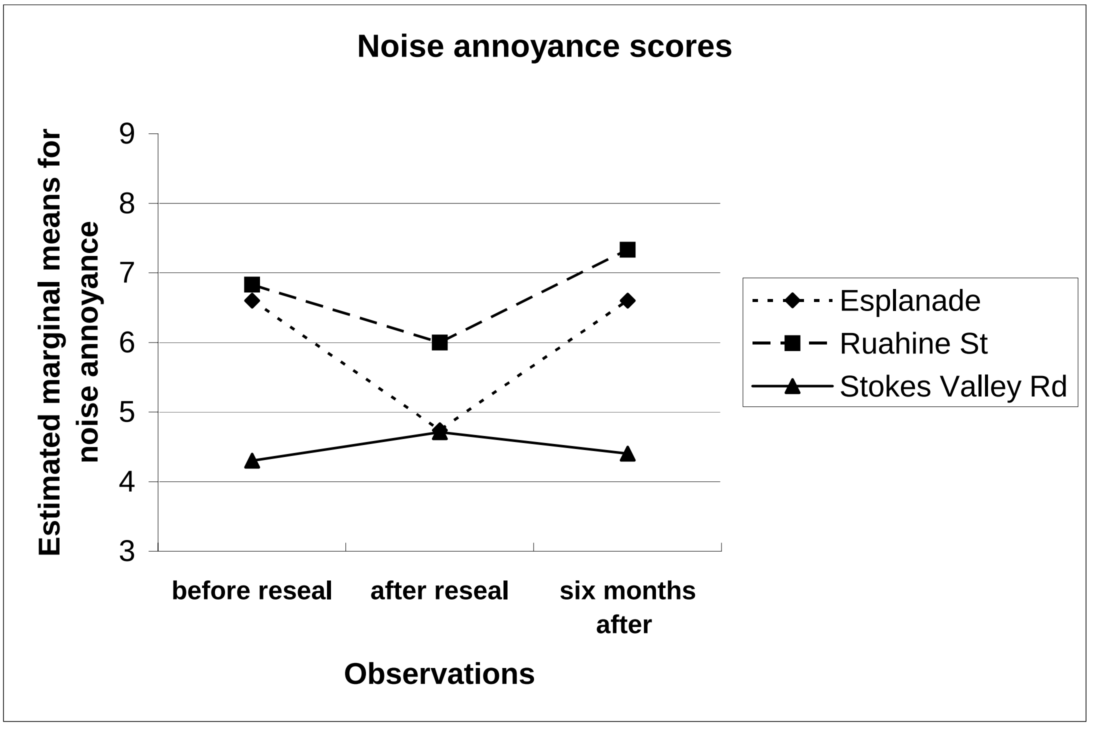

Figure 17 Noise annoyance scores for repeated observations with six months follow-up.

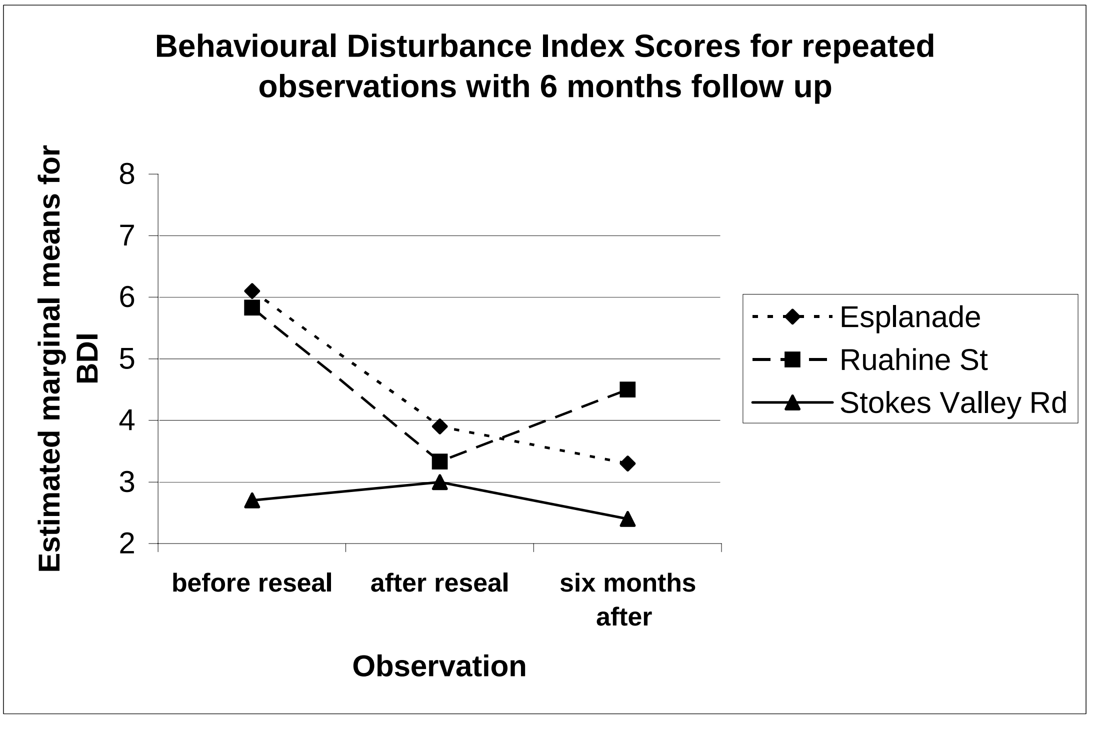

Figure 18 Behavioural disturbance index scores for repeated observations with six months follow-up.

9. Other After Reseal Observations

Participants in the study completed a 20-item questionnaire concerning potential sources of noise and their responses to it. These questions helped to interpret the findings of the annoyance and disturbance scales. ‘Before’ and ‘After’ comparisons were analysed with repeated measures t-tests. These comparisons revealed the ability of people to detect the source of change in their noise environment. The results suggest that people are deliberate in their consideration of the effect that the road surface has in the change to the noise environment.

Residents at site 1 (The Esplanade), which reduced its average noise by 7.0 dBA, increased their agreement that they ‘don’t mind the traffic noise on their street’ (t (12) = 2.309, p. < .05). These residents were also less likely to describe their street as ‘noisy’ (t (13) = 3.229, p. < .01). Site 12 (Scapa Terrace) also reduced in noise and here residents correctly disagreed that the ‘noise outside had gotten (sic) worse recently’ (t (12) =2.887, p.< .05). Residents of site 5 (Epuni St) were more likely to agree that the ‘noise outside their house had gotten (sic) worse recently’, (t (11) = 2.70, p. <. 05) and therefore recognised an increase in noise of as little as 1.7 dBA. At site 8 (Ruahine St) residents obtained a large reduction in noise exposure, with the traffic noise being reduced by 6dBA following the reseal. This was recognised in the after reseal disagreement with the statement that ‘traffic noise has gotten (sic) worse recently’ (t (11) = 3.63, p. < .05).

Moxham Avenue (site 4) residents benefited from a 4.2 dBA reduction in traffic noise but became likely to disagree that ‘a better road surface would result in less noise’, (t (12) = 2.80, p. < .05). Following the resurfacing these people were also more likely to disagree that the ‘traffic noise was ‘bad’ when they first moved in’, (t (12) = 2.30, p. < .04). After reseal, these residents tended to agree more strongly that they ‘enjoyed peace and quiet’ (t (12) = 2.92, p. < .05). Traffic noise at site 6 (Muritai Rd) reduced by 3.3 dBA but residents became more inclined to disagree that ‘they would eventually adjust to an increase in traffic noise’, (t (15) = 2.16, p.< .05). These seemingly contradictory results show something of the elastic relationship between changes in the noise environment and the effect on residents’ concerns. While it is clear that increases in noise are noticed and met with negative responses, decreases are met with negative responses also. Improving the noise environment highlighted the importance of ‘peace and quiet’ for Moxham Avenue residents who then seem to demand it more.

Site 9 (Abilene Crescent) had the greatest increase in traffic noise but was also a site with low traffic volumes. The 6 dBA increase in noise after reseal was not reflected in a significant change in either indicators of annoyance or in behavioural disturbance. However, residents were more inclined to disagree that ‘they don't mind the noise of traffic on their street’, (t (11) =3.71, p. < .05) and recognised that the noise on the street ‘had gotten (sic) worse recently’, (t (11) = 1.94, p. < .05). More important, the residents were more likely to agree, ‘a better road surface would result in less noise’, (t (11) = 2.64, p. < .05).

In contrast to those sites where the reseal brought decreases in noise, a small increase in overall noise after reseal on Stokes Valley Road (site 10), a high traffic volume road, led to significant increases in indicators of annoyance, behavioural disturbance, and attitudes towards the traffic noise. Residents showed increased tendency:

- to disagree that 'they don't mind the traffic noise', ($t(17) = 2.4$, $p. < .05$);
- to recognise that 'the noise had gotten (sic) worse recently', ($t(18) = 2.15$, $p. < .05$);
- and to claim, 'a better road surface would reduce the traffic noise', ($t(18) = 2.65$, $p. < .05$).

These people were also more likely to disagree that they thought the noise was 'bad' when they first moved in ($t(18) = 2.15$, $p. < .05$) and disagree that 'if traffic speed were reduced it would reduce the noise to an acceptable level', ($t(18) = 2.40$, $p. < .05$).

Sites 3, 7 and 11, (Cuba Street, Naenae Road and Brees Street) showed no differences in any of the twenty items. Residents at site 2 (Marine Parade) reduced their concern that 'younger people in cars are responsible for the noise', ($t(11) = 2.63$, $p. < .05$), and became more likely to disagree that 'other people put up with roads that are much more noisy' ($t(11) = 2.61$, $p. < .05$).

10. Discussion of Community Annoyance

The three hypotheses to be tested are listed in Section 5.3 on page 35. From these, hypothesis 1 is confirmed. The effect of a changed surface on the physical noise level is greater than previously thought. Hypothesis 2 is supported to the extent that an 800 Hz to 1000 Hz range accounts for the observed variation in annoyance. Hypothesis 3 is rejected. Results are contrary to the expectation that people become annoyed at factors tangentially associated with resealing, rather than noise per se. Moderate to strong correlations are found between the level of the physical change of the noise measured in dBA and the change in annoyance. The survey responses suggest people can identify the source of the noise that accounts for their change in annoyance and alteration of behaviour. In general people noticed the change in noise in their area, identified the change as being caused by the road surface and could correctly indicate whether the noise level had increased or decreased.

Guski, (2001) suggests that a short term decrease in noise level of less than 6 dBA will not have a significant effect on the number of highly annoyed residents. This is known to be true for large-scale samples that can estimate the percentage of 'highly annoyed'; in contrast, our results establish that 'mean' annoyance levels significantly decrease with a noise reduction of 7 dBA, due to quieter road surfaces. Moreover, significant differences in mean behavioural disturbance occur when a road surface change results in a 6 dbA reduction in road surface noise. The Fields et al (1998) global measure of noise annoyance fails to detect a change for the same change in noise level. Our results suggest that behavioural adjustment and annoyance interact in a complex way to produce reactions to changes in the noise environment. It is however apparent here that behavioural disturbance is more sensitive measure than mean annoyance, as it has a higher correlation to noise volume changes. One reason for this might be that behavioural disturbance events can occur through single noise events that are not detected in physical noise measures which average events across time. So for example, a loud noise at night might wake residents and this might be detected by the behavioural disturbance measures but not be sufficiently enduring to cause annoyance nor be detected by general physical noise measures.

Guski (2001) also recognises that a few dBA increase in noise level can increase noise effects significantly. The results of this research confirm this proposition. Small increases in overall noise (as little as 1 dBA) produce significant increases in both behavioural disturbance and noise annoyance. Participants correctly identify the source of the noise increase as the road surface rather than the speed of the traffic or some other characteristic of the environment such as increased traffic.

Behavioural change such as closing windows, raising one's voice or altering one's scheduled activities as a consequence of traffic noise is a natural adaptive response to a negative stimulus. These results support the contention that behavioural change mediates annoyance. Guski (2001) reports that the control people have over behavioural change, or 'coping strategies', is related to their noise annoyance. There is likely to be a threshold in which the individual's coping strategies in the form of behavioural adjustments become exhausted and annoyance begins. The observation from this research that behavioural change measures are more sensitive to small changes in noise than in annoyance scales fits well with this theory.

The tonal characteristics of the change due to reseal suggest that an 800-1000 Hz range is responsible for the change in noise annoyance. Although it is generally recognised that humans are more sensitive to frequencies higher than 1000 Hz, this must be balanced in the case of road surface resealing by how much of the traffic noise penetrates into houses. Because lower frequencies have a greater penetration it is reasonable to suppose that only a limited range of frequencies will have the interactive effect of annoyance and penetration. If the result is generalised to a wider context, intervention strategies could be worked out which focus on ameliorating a narrow range of frequencies.

In the noise annoyance literature it is generally conceded that people do not develop sensory adaptation or mental habituation to noise, except under contrived conditions (Scharf, 1983). In particular, there is no evidence of long-term adaptation or habituation to road traffic noise annoyance (Weinstein, 1982). Notwithstanding, there are examples of apparent habituation evident in our results. In the three cases of significant alteration to the mean level of annoyance and behavioural disturbance, the means return to before seal levels after six months. This is the expected observation if people adjust to the noise environment, though we note differences in the monitored adjustments in annoyance and of recorded changes in behaviour. It appears behavioural disturbance endures whereas noise annoyance does not. The size of our sampling for this aspect of the research severely constrains the interpretation of the observed trends. However, these observations underscore the importance of determining the relationship between behavioural change and annoyance.

There are several limitations that restrict the conclusions of this study. Foremost, there were few sites where a large increase in noise dosage occurred, principally because before and after sealing programmes are designed to improve the road surface. Often a higher quality surface is a quieter road surface.

It has been established in research elsewhere that the number of 'fairly annoyed' people has increased over time, reflecting a trend towards a greater sensitivity to environmental noise, whereas the number of highly annoyed people has remained constant (Guski, 2001). To this end, measures of 'mean annoyance' are useful and valuable predictors of shifts in noise annoyance. However, the connotations of 'mean annoyance' are not clear because the estimate is not widely used or validated against external criteria, as opposed to the case with 'percent highly annoyed'. In contrast, mean behavioural disturbance can take a natural interpretation. There is a need to relate a shift in mean annoyance to behavioural disturbance, though no attempt has been made to do this here.

Our sample size was restricted to the number of people affected by the reseal, and there are natural limits to the number of houses, the number of residents next to the street, and the portion of the street to be resealed. A larger number of households can be accessed through sampling of more sites, but the methodology needed to obtain adequate before and after samples of these small populations can be expensive.

11. Report Conclusions

1. The road surface significantly effects traffic noise at speeds of 40 - 50 km/h. For light vehicles these are +3 to +6 dBA, and for heavy vehicles -3 to +2 dBA relative to asphaltic concrete. This +6 dBA difference between road surface types equates to 40% of the noise difference between a high noise area, which is about 70 dBA, and a low noise area, which is about 55 dBA.

2. The road surface effect is substantially the same at 40 - 50 km/h as it is at 80 - 100 km/h.

3. Two-coat seals (as made in New Zealand) are no less noisy than single coat seals, and within this study were more noisy.

4. As road surfaces age, the change in overall traffic noise level is small, around 1 dBA to 2 dBA less. However, the tonality of the noise can change with time and traffic volume.

5. Both of the existing noise models used in New Zealand, the CRTN model and its New Zealand variation TNZ 28, are seriously deficient in accounting for surface effects especially in urban areas. These models should be revised or replaced with true Leq models.

6. Residents adjacent to streets being resealed detect changes in noise as small as 1 dBA. The residents correctly identified the source of annoyance as being the road surface, and not the volume of traffic, speed of cars, trucks or other characteristics of the road surface, such as service covers.

7. Small increases in traffic noise level are matched with changes in behavioural disturbance. This is true even if the change is less than +3 dBA (c.f. Raw & Griffiths, 1988). The reverse is also true: behavioural disturbance reduction can be anticipated even when the reduction in noise is small.

8. The 800 – 1000 Hz frequency band correlates to the traffic noise annoyance observed.

9. Long term monitoring showed limited evidence of noise habituation with respect to noise annoyance, but improvements to behavioural disturbance appear to be more permanent.

10. The behavioural disturbances index, following Job (2001), is a more sensitive measure of noise annoyance than those recommended by Field et al (1998). Whereas a decrease in noise did not correspond with a reduced level of annoyance using the Fields et al recommend scale, the behavioural disturbance index detected significant improvements for those affected.

11. The annoyance and behavioural disturbance observed arise from change in noise dosage not from other dissatisfactions.

12. Guidelines for Road Surface Noise

The third part of this study was to interpret the findings of the research to produce guidance for roading engineers in surface selection from a noise perspective. The study identified the effect of road surface types on noise and the effect of these changes in noise on community annoyance. The road surface effect for light vehicles differs from the effect for heavy vehicles. The two different effects need to be combined to obtain the total effect for vehicle streams composed of both vehicle types.

Community annoyance and behaviour is coupled with the overall road traffic noise level. This study shows that quite large changes in quiet suburban streets were noticed but there was little change in annoyance or behavioural disturbance. It also indicates that, although satisfaction with an improvement to a noise environment in a busy street can degrade over time, the benefits in reducing the measures that people have to make to cope with noise, remain.

Therefore in order to produce guidelines for road controlling authorities to best use lower noise surfaces (as these are usually more expensive either as a capital cost, e.g. asphaltic concrete, or increased maintenance, e.g. finer chip), the effect of the road surface on the total traffic stream needs to be identified. Together with this, it is necessary to identify where the improvement in noise environment will be effective.

12.1 Combining the road surface effect

Although the CRTN model is the most commonly used model in New Zealand, it does not calculate the noise from the separate streams of light and heavy vehicles separately. So it is not easily used to determine the combined effect of the road surface. A model such as the Nordic model, which calculates the noise of the streams separately, is best for this purpose. For light vehicles, the *noise generation component* is calculated as below. (The noise at the houses is less than that shown because noise level decreases with distance and these effects are not included in this part of the calculation.)

The noise calculation is done in terms of Leq, a measure of average noise that is biased towards the higher levels.

For light vehicles (cars and vans)

- $\text{Leq}_{\text{(light)}} = 73.5 + 25 \log \left(\frac{V_L}{50}\right) + 10 \log \left(\frac{Q_L}{T}\right) + \text{surface correction (light vehicles)}$

For heavy vehicles

- $\text{Leq}_{\text{(heavy)}} = 81 + 30 \log \left(\frac{V_H}{50}\right) + 10 \log \left(\frac{Q_H}{T}\right) + \text{surface correction (heavy vehicles)}$

Where

- V_L and V_H are the speeds of the light and heavy vehicles.
- Q_L and Q_H are the volumes of light and heavy vehicles in time *T* (seconds) for which the equivalent sound level Leq is calculated.

The overall noise level is calculated by combining $Leq_{(light)}$ with $Leq_{(heavy)}$ as an addition done logarithmically, that is converted to real numbers, added together, and the sum shown as dBA, that is, as 10 log(the sum of the two levels).

Table 14 consolidates Table 1 into 5 main surface type groups of similar effect.

Table 14 Effect of road surface type on noise, relative to dense asphalt (dBA).

Vehicle type	Surface type				
	Dense asphalt (dBA)	OGPA (dBA)	Fine chip #4,5,6 (dBA)	Medium chip#3 (dBA)	Coarse chip#2 and two coat seals (dBA)
Light vehicles	0	0	3	4	6
Heavy vehicles	0	-2	-2	1	1

Table 16 (overleaf) has been produced from a series of calculations as outlined above to produce the net surface effect. It shows the net surface effect for any volume of traffic, with the ratio of light to heavy vehicles identified.

For any given street therefore, the roading engineer can use this table to assess the effect (or benefit) of choosing one surface type over another.

For example, if a street was already surfaced with grade 3 chip, then a significant noise reduction (about 3.5 dBA) could be achieved by using an asphaltic concrete, provided the volume of heavy traffic was small. However if the street had a high proportion of heavy vehicles, e.g. 20% heavies, then the benefit of AC is only a 0.8 dBA reduction in noise. Therefore there would now be further advantages in considering OGPA.

Table 15 Combined surface effect noise from light and heavy vehicles (dBA).

% heavy vehicles	Combined surface effect on noise from light and heavy vehicles (dBA)				
	Dense asphalt	OGPA	Fine chip #4,5,6	Medium chip#3	Coarse chip#2 and two coat seals
0	0	0	3.0	4.0	6.0
3	0	-0.3	3.0	3.7	5.5
10	0	-0.8	1.5	1.5	4.5
20	0	-1.0	0.8	0.8	3.5

12.2 Determining the extent to which selecting a more quiet or more noisy road surface reduces community impact

Noise annoyance dose/reaction relationships are normally associated to the Shultz Curve (Shultz, 1978), but this relationship is for a constant noise exposure and does not predict the change in reaction due to a change in dosage.

For the purposes of producing initial guidelines we have defined a new measure of 'acutely affected' and devised a framework to describe acceptable and unacceptable change. Further research is however recommended to develop further the measure of 'acutely affected' and confirm or revise the initial value that we have set. At this stage the initial value has been set conservatively with respect to the outcomes that it will produce for needing quieter surfaces.

Tables 17 and 18 below can be used to predict the change in the percentage of people acutely affected by road traffic noise through the influence of a change in the noise dosage in three before reseal noise environments. For the two measures 'behavioural disturbance' and 'noise annoyance', the tables predict percentage changes in the level of those acutely affected by noise dosage.

The measure 'acutely affected' is determined by examining the baseline distributions of the behavioural disturbance and noise annoyance scales before to reseal and has been defined as a value of 6 or more on the 13-point behavioural disturbance scale, as this demarcates 85% of the distribution. The noise annoyance scale traditionally defines highly annoyed from the top 2 categories on a 7-point scale or 29% of the distribution. Following Fields et al (1998) this requires a demarcation for our distribution at 6 on the 11-point scale. It needs to be recognised that a Shultz curve allows a residual 'highly annoyed' of approximately 10% even in very quiet environments.

The following equations were used to estimate the mean, 90% percentile and percentage above the standard that defines the acutely affected.

(1) For the behavioural disturbance scale:

Predicted Mean BD = 0.697 + 0.69(base annoyance) + 0.153(change in Leq_{24})

Base annoyance is calculated from the mean reported levels of annoyance for the area, considered in three bands:

- Under 60 Leq_{24}, M = 2.01, SD = (3.02);
- 60 - 70 Leq_{24}, M = 2.77, SD = (2.94);
- Over 70 Leq_{24}, M = 5.8, SD = (2.69).

The 90^{th} Percentile is calculated from the Standard Deviation, assuming a normal distribution.

Table 16 Behavioural disturbance.

Change in noise level (dBA)	Under 60 Leq_{24}			60-70 Leq_{24}			over 70 Leq_{24}		
	Mean	90%	% over 6	Mean	90%	% over 6	Mean	90%	% over 6
-5.5	1.14	5.03	-0.05	1.98	5.77	-0.01	4.18	7.65	0.17
-5	1.22	5.12	-0.04	2.07	5.86	0.00	4.27	7.74	0.18
-4.5	1.31	5.21	-0.04	2.16	5.95	0.00	4.36	7.83	0.19
-4	1.40	5.30	-0.04	2.24	6.04	0.01	4.44	7.91	0.20
-3.5	1.49	5.39	-0.03	2.33	6.13	0.01	4.53	8.00	0.21
-3	1.58	5.47	-0.03	2.42	6.21	0.02	4.62	8.09	0.23
-2.5	1.67	5.56	-0.02	2.51	6.30	0.02	4.71	8.18	0.24
-2	1.76	5.65	-0.02	2.60	6.39	0.03	4.80	8.27	0.25
-1.5	1.84	5.74	-0.01	2.69	6.48	0.04	4.89	8.36	0.26
-1	1.93	5.83	-0.01	2.78	6.57	0.04	4.98	8.45	0.27
-0.5	2.02	5.92	-0.01	2.86	6.66	0.05	5.06	8.53	0.28
0	2.11	6.01	0.00	2.95	6.75	0.06	5.15	8.62	0.29
0.5	2.20	6.09	0.01	3.04	6.83	0.06	5.24	8.71	0.30
1	2.29	6.18	0.01	3.13	6.92	0.07	5.33	8.80	0.31
1.5	2.38	6.27	0.02	3.22	7.01	0.08	5.42	8.89	0.32
2	2.46	6.36	0.02	3.31	7.10	0.09	5.51	8.98	0.34
2.5	2.55	6.45	0.03	3.39	7.19	0.10	5.60	9.07	0.35
3	2.64	6.54	0.03	3.48	7.28	0.10	5.68	9.15	0.36
3.5	2.73	6.62	0.04	3.57	7.36	0.11	5.77	9.24	0.37
4	2.82	6.71	0.05	3.66	7.45	0.12	5.86	9.33	0.38
4.5	2.91	6.80	0.05	3.75	7.54	0.13	5.95	9.42	0.39
5	2.99	6.89	0.06	3.84	7.63	0.14	6.04	9.51	0.41
5.5	3.08	6.98	0.07	3.93	7.72	0.15	6.13	9.60	0.42
6	3.17	7.07	0.08	4.01	7.81	0.16	6.21	9.68	0.43

(2) For the highly annoyed scale:

Predicted Mean HA = 1.81 + 0.622 (base annoyance) + 0.159(change in Leq_{24})

Base annoyance is calculated from the mean reported levels of annoyance for the area considered in three bands:

- Under 60 Leq_{24} M = 3.53, SD = (2.91);
- 60 - 70 Leq_{24} M = 4.49, SD = (2.53);
- Over 70 Leq_{24} M = 6.66, SD = (2.39).

The 90th percentile is calculated from the standard deviation, assuming a normal distribution.

Table 17 Noise annoyance.

Change in noise level (dBA)	Under 60 Leq_{24}			60-70 Leq_{24}			over 70 Leq_{24}		
	Mean	90%	++%HA	Mean	90%	++%HA	Mean	90%	++%HA
-5.5	3.12	6.88	0.07	3.72	6.97	0.13	5.07	8.16	0.28
-5	3.20	6.95	0.08	3.80	6.45	0.13	5.15	8.24	0.29
-4.5	3.28	7.03	0.08	3.88	6.53	0.14	5.23	8.32	0.30
-4	3.36	7.11	0.09	3.96	6.61	0.15	5.31	8.40	0.31
-3.5	3.44	7.19	0.10	4.04	6.69	0.16	5.39	8.48	0.32
-3	3.52	7.27	0.11	4.12	6.77	0.17	5.47	8.56	0.33
-2.5	3.60	7.35	0.11	4.20	6.85	0.18	5.55	8.64	0.34
-2	3.68	7.43	0.12	4.27	6.93	0.18	5.62	8.72	0.35
-1.5	3.76	7.51	0.13	4.35	7.01	0.19	5.70	8.80	0.36
-1	3.84	7.59	0.14	4.43	7.09	0.20	5.78	8.88	0.37
-0.5	3.92	7.67	0.15	4.51	7.17	0.21	5.86	8.96	0.38
0	4.00	7.75	0.15	4.59	7.25	0.22	5.94	9.04	0.39
0.5	4.08	7.83	0.16	4.67	7.33	0.23	6.02	9.12	0.40
1	4.15	7.91	0.17	4.75	7.41	0.24	6.10	9.20	0.41
1.5	4.23	7.99	0.18	4.83	7.48	0.25	6.18	9.28	0.42
2	4.31	8.07	0.19	4.91	7.56	0.26	6.26	9.36	0.44
2.5	4.39	8.15	0.20	4.99	7.64	0.27	6.34	9.44	0.45
3	4.47	8.23	0.21	5.07	7.72	0.28	6.42	9.52	0.46
3.5	4.55	8.31	0.22	5.15	7.80	0.29	6.50	9.60	0.47
4	4.63	8.39	0.23	5.23	7.88	0.30	6.58	9.67	0.48
4.5	4.71	8.47	0.24	5.31	7.96	0.31	6.66	9.75	0.49
5	4.79	8.54	0.25	5.39	8.04	0.32	6.74	9.83	0.50
5.5	4.87	8.62	0.26	5.47	8.12	0.33	6.82	9.91	0.51
6	4.95	8.70	0.26	5.55	8.20	0.34	6.90	9.99	0.52

Table 18 below is derived in particular from Table 17. Table 17 shows also the percent of population that are above the 'acutely affected' level and how this percentage increases or decreases in relation to the extent of change in noise level. To provide guidance on surface selection to roading engineers, we needed to divide this percentage of the population that is 'acutely affected' into intervals with regard to the extent of change that is likely and the total change in percentage exposed in quiet and noisy areas.

This table is based on the change in percentage of the population that is exposed above the 'acute level' of behavioural disturbance, in 5% increments as follows:

- A 15% reduction in exposed population is regarded as a big improvement in the noise environment;
- A 10% reduction is an improvement;
- A 5% reduction is a small improvement;
- A 5% increase has made the noise environment a little worse;
- A 10% increase has made the noise environment worse;
- A 15% increase has made the noise environment much worse.

Table 18 Extent that the noise environment is improved for the adjacent community by selecting a quieter or noisier road surface.

<table>
<tr><th colspan="2">Change in noise level from road surface change</th><th>Less than 60 dBA Leq_{24}</th><th>Between 60 to 69 dBA Leq_{24}</th><th>Above 70 dBA Leq_{24}</th></tr>
<tr><td rowspan="3">Reduction</td><td>More than –3.6</td><td rowspan="2">Small Improvement</td><td>Improvement</td><td>Big Improvement</td></tr>
<tr><td>–3.5 to –1.1</td><td>Small Improvement</td><td>Improvement</td></tr>
<tr><td>–1 to 0</td><td>Little Change</td><td>Little Change</td><td>Small Improvement</td></tr>
<tr><td>No Change</td><td>0</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td rowspan="3">Increase</td><td>0 to 1</td><td>Little Change</td><td>Little Change</td><td>A Little Worse</td></tr>
<tr><td>1.1 to 3.5</td><td rowspan="2">A Little Worse</td><td>A Little Worse</td><td>Worse</td></tr>
<tr><td>3.6 and greater</td><td>Worse</td><td>Much Worse</td></tr>
</table>

13. Recommendations for Further Research

1. The effects of a range of bituminous road surfaces on road traffic noise needs to be expanded. These surfaces include:
   - dense grade asphaltic concrete for a range of formulation types,
   - stone mastic asphaltic,
   - open graded porous asphalts especially speciality ‘low noise’ formulations, and
   - hybrid types such as cape-seals.

2. Noise models that are currently used in New Zealand (e.g. CRTN) or potential models (e.g. Nordic) need to be modified so as to incorporate revised road surface effects appropriate to New Zealand.

3. The relationship between behavioural disturbance and annoyance locates the intervention strategies for coping with complaints about noise. If Guski’s suggestion is correct, then ‘coping strategies’ (behaviours) mediate the relationship between noise dosage and reaction, in the form of complaints, residual annoyance or behavioural effects (such as sleep disturbance). This develops two lines of research:
   a. The scales measuring ‘mean annoyance’ and ‘behavioural disturbance’ need to be correlated with noise dosage.
   b. The importance of behavioural reactions on individuals needs to be mapped on to traditional measures of noise annoyance.

4. There are benefits in applying the behavioural disturbance scale to attempt to understand regular ‘one-off’ noise events (such as trucks, engine braking, train crossing signals, rattling utility covers and so on).

5. Measures of ‘acute behavioural disturbance’ need to be better defined and the initial guidelines on road surface selection for noise modified in response to this better definition.

14. References

Arana, M. 2001. Prediction of urban noise. In *Environmental Urban Noise,* A Garcia (ed). Southampton: WIT Press.

Berglund, B and Lindvall, T. 1995 (Eds) Community Noise. *Archives of the Centre for Sensory Research 1(2)* 1-180. Stockholm University and Karolinska Institute.

Bullen, R. B., Job, R. F. S. and Burgess, D. H. 1985. Reaction to aircraft noise on RAAF bases. *National Acoustics Laboratories Commissioned report No. 7.* Australian Government Printing Services, Canberra.

Department of Transport (DOT) (Welsh Office) 1988 *Calculation of Road Traffic Noise*. Her Majesty's Stationery Office, London

Dravitzki, V.D and Wood, C. W. B 2003. Road surface effects on noise at urban driving speeds. *Proceedings of the Australian Road Research Board Transport Research Conference, Cairns, 23-28 May 2003.*

Fields, J. M., de Jong, R.G., Flindell, I. H., Gjestland, T., Job, R.F. S., Kura, S., Schuemer-Kohrs, A., Lercher, P., Vallet, M. and Yano, T. 1998. Recommendations for shared annoyance questions in noise annoyance surveys. *Proceedings of the 7th International Congress on Noise as a Public Health Problem, 2:* 481-486.

Glass, D. C and Singer, J. E. 1972. *Urban Stress. Experiments on Noise and Social Stressors.* New York: Academic Press.

Griffiths, I. D. and Raw, G. J. 1989. Adaptation to changes in traffic noise exposure. *Journal of Sound and Vibration 132(2):* 331-336.

Guski, R. 2001. Community response to environmental noise. In *Environmental Urban Noise,* A Garcia (ed). Southampton: WIT Press

Guski, R., Wichman, U., Rohrmann, B. and Finke, H. O. 1978. Konstrucktion und Anwendung eines Fragebogens zur Sozialwissenscaftlichen Untersuchung der Auswirkungen von Umweltlarm. *Zeitschrift fur Sozialpsychologie, 9:* 50-65.

Howell, D. 1989. *Statistical methods for psychology.* Belmont: Duxbury

Job, R. F. S. 1988. Community response to noise. A review of factors influencing the relationship between noise exposure and reaction. *Journal of the Acoustics Society of America. 83:* 91-1001.

Job, R. F. S., Hatfield, J., Carter, N. l., Peploe, P., Taylor, R., and Morrell, S. 2001. General scales of community reaction to noise (Dissatisfaction and Perceived Affectedness) are more reliable than scales of annoyance. *Journal of the Acoustics Society of America 110, 2:* 939-946.

Langdon, F. J. 1976. Noise nuisance caused by road traffic in residential areas: Part 1, *Journal of Sound and Vibration 47:* 243-263.

Luz, G. A., Raspet, R., and Schomer, P. D. 1983. An analysis of community complaints to noise. *Journal of the Acoustics Society of America. 73:* 1229-1235.

Raw, G. J, and Griffith, I.D. 1985. The effect of changes in aircraft noise exposure. *Journal of Sound and Vibration 101:* 273-275.

Raw, G. J, and Griffith, I.D. 1988. The effect of changes in traffic noise exposure. *Journal of Sound and Vibration 126:* 550-552.

Scharf, B. 1983. Loudness adaptation. In *Hearing research and Theory. Vol 2.* J.V Tobias (ed.) New York, Academic Press.

Schultz, T. J. 1978. Synthesis of social surveys on noise annoyance. *Journal of the Acoustics Society of America 64:* 377-405.

Weinstein, N. D. 1982. Community noise problems: evidence against adaptation. *Journal of Environmental Psychology. 2:* 87-97.

Appendices

A Noise properties of Cape seal road surfaces

B Survey Form

Appendix A

Noise properties of Cape seal road surfaces.

A.1 Introduction

Land Transport New Zealand Research project 292 investigated the effect that different road surface types have on road traffic noise. This study revealed that a surface type new to New Zealand known as Cape seal, is one of the quietest surface types available and is comparable to open graded porous asphalt. Cape seal as a surface type was developed originally in South Africa. It consists of a first layer of standard chipseal, over which is applied a second layer of slurry seal, the intention being to achieve a surface with the appearance and qualities similar to dense asphaltic concrete, but with a deeper surface texture. Within this basic design variations are achieved by varying the chip size of the first chipseal layer (i.e. grades 2, 3 or 4) and varying the type of slurry seal, e.g. type 1 (fine) through to type 3 or 4 (coarse or very coarse). The cost of Cape seal is only about half that of either open graded or dense asphaltic concrete. Only one Cape seal surface had been tested in the previous work but if this low noise performance could be confirmed by tests over a number of Cape seal surfaces it would provide a low cost, low noise surface for more widespread use in New Zealand.

A.2 Test sites

Three new sites of Cape seal were tested. These were the only test sites available in the Wellington region which had characteristics suitable for the test method. Additionally three sites tested previously in project 292 were tested so as to provide the necessary linkage to the previous work.

Table A1 Test sites used.

Location	Speed Zone km/h	Surface Type	Site
Marine Parade, Seatoun	50	Dense AC	Reference
Island Bay Parade	50	Cape seal	Reference
SH1 Te Horo	100	Grade 2/4	Reference
Chatsworth Road	50	Cape seal grade 3:type 2	New test
Rutherford Street	50	Cape seal grade 3:type 1	New test
SH1 Te Horo	100	Cape seal grade 2/4:type 3	New test

At each test site, tests were made using the techniques reported in Land Transport New Zealand Project 292. A reference vehicle was used in the cruise-by technique, so that all sites could be compared. (This vehicle is a different vehicle from that used in the 2002 work as the 2002 vehicle was no longer available.) Additional representative noise levels were obtained by aggregating the noise effect of 10-15 vehicles at each site, referred to as the ‘fleet noise’.

A.3 Results

The results for the reference light vehicle are shown in table A2. The results for a number of the fleet vehicles are shown in table A3.

Table A2 Noise level : reference vehicle.

Location	Speed (km/h)	Surface	Year	Noise level (dBA)
Marine Parade, Seatoun	50	Dense AC	2002	66*
			2003	67
Island Bay Parade	50	Cape seal grade 3:type 2	2002	68*
			2003	70
SH1 Te Horo	50	Grade 2/4 chip	2002	76
	100	Grade 2/4 chip	2003	83
Chatsworth Road	50	Cape seal grade 3:type 2	2003	70
Rutherford Street	50	Cape seal grade 3:type 1	2003	67
SH1 Te Horo	50	Cape seal grade 2/4:type 3	2003	72
	100	Cape seal grade 2/4:type 3	2003	79

* *Different reference vehicles*

Table A3 Noise level : vehicle fleet.

Location	Speed (km/h)	Surface	Year	*.1.1.1.1 Noise Level* (dBA)	
				Light vehicles	Heavy vehicles
Marine Parade, Seatoun	50	Dense AC	2002	68	
			2003	66	
Island Bay Parade	50	Cape seal	2002	69	77
			2003	71	79
SH1 Te Horo	100	Grade 2/4 Chip	2002	84	90
			2003	84	89
Chatsworth Road	50	Cape seal	2003	N/A	
Rutherford Street	50	Cape seal	2003	68	80
SH1 Te Horo	100	Cape seal	2003	81	89

A.4 Analysis

The analysis is complicated by two of the reference surfaces appearing to not be stable with respect to measured noise from the 2002 and 2003 years. This is not unexpected as it is known that surfaces may change 1 dBA within the first year. A second complication is that the original reference vehicle was no longer available and an alternate had to be used.

The SH1 site at Te Horo, where the grade 2/4 two coat chip was about 5-6 years old, showed the best stability with respect to noise. This surface could then be used as the benchmark, but measurements here needed to be adjusted for speed. Figure A1 below shows the stability of the noise level and spectra for this site over the two test periods.

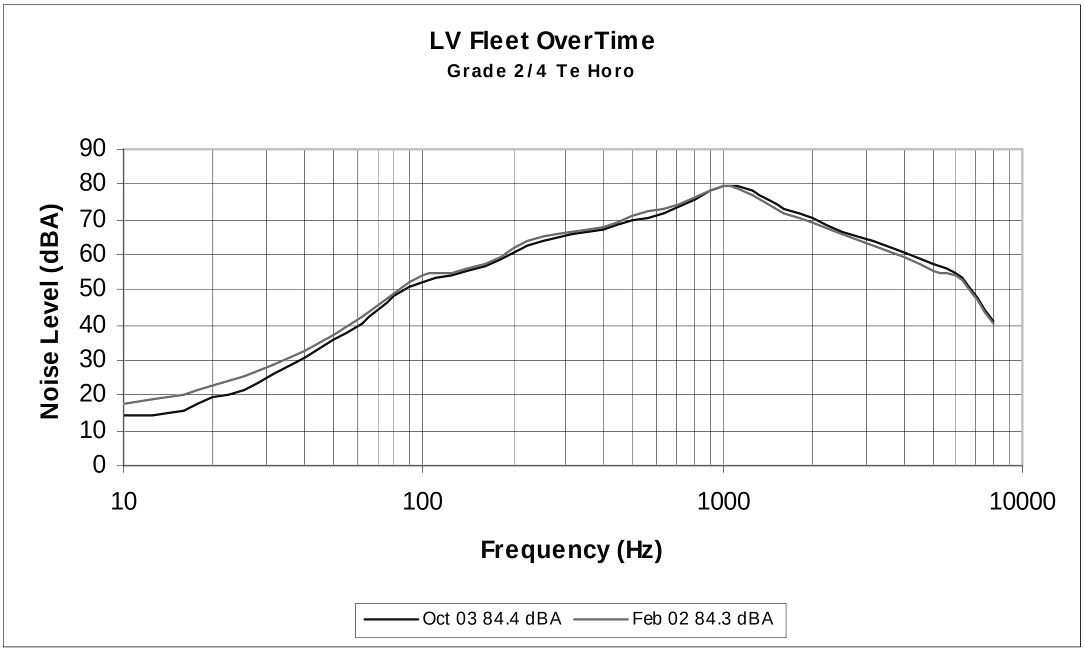

Figure A1 **Noise level of light vehicle fleet on Grade 2/4 chipseal over two test periods (February 2002 and October 2003).**

Table A2 shows that, at the two sites where measurements were made at 50 and 100 km/h, the noise difference for speed is about 7 dBA. On this basis the noise levels in table A3 which were determined at 100 km/h can be reduced by 7 dBA, that is, to what they would have been if they had been measured at 50 km/h.

Project 292 showed that, for light vehicles, grade 2/4 two coat chipseal has a noise level of + 6 dBA relative to asphaltic concrete.

Table A4 lists the noise levels of each site relative to AC, calculated relative to grade 2/4 chipseal.

Table A4 Noise levels, for light vehicles, of each site relative to AC (calculated on basis of grade 2/4 chipseal being + 6 dBA).

Site	Noise level (dBA)	Relative to AC (dBA)
SH1 Te Horo	77	+6
Island Bay Parade Cape seal #3, type 2	71	0
SH1 Te Horo Cape seal #2, type 3	74	+3
Rutherford Street Cape seal #3, type 1	68	-3

Figure A2 shows the noise level and spectra of the reference vehicle on each of the four Cape seal surfaces and illustrates that, as with chipseals, there is no single noise level for the generic type, but instead needs to be linked to a specific mix design.

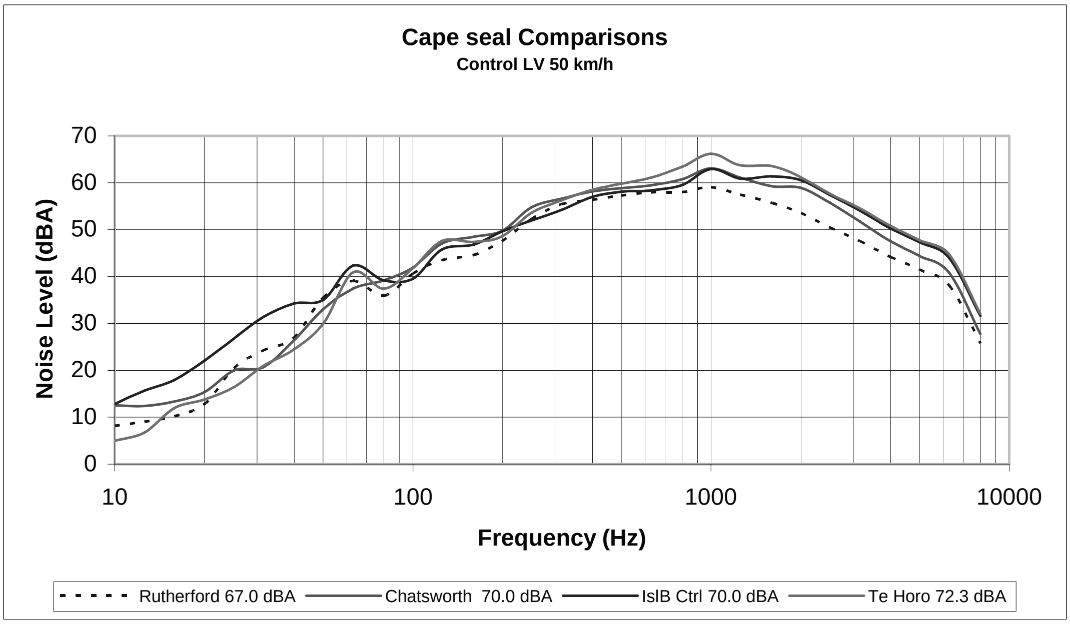

Figure A2 Noise of the reference vehicles on each of the four Cape seal surfaces.

There is insufficient data for certainty concerning the effect on noise from trucks. Allowance needs to be made in Table A2 for the trucks at Te Horo being predominantly large B trains moving at close to 100 km/h, whereas the heavy vehicles in urban areas are smaller or are buses moving at 50 km/h. Figure A3 below shows that at 100 km/h the grade 2/4 chipseal and the Cape seal have almost identical effects on heavy vehicle tyre noise. Project 292 showed that, for trucks, grade2/4 surfaces were probably about 1 dBA noisier than asphaltic concrete.

Given that the type 3 Cape seal has the same noise effect as the grade 2/4 chipseal, the indications are that, for heavy vehicles, the finer grade Cape seals (type 1 and type 2) will be either the same as asphaltic concrete or about 1 dBA less noisy.

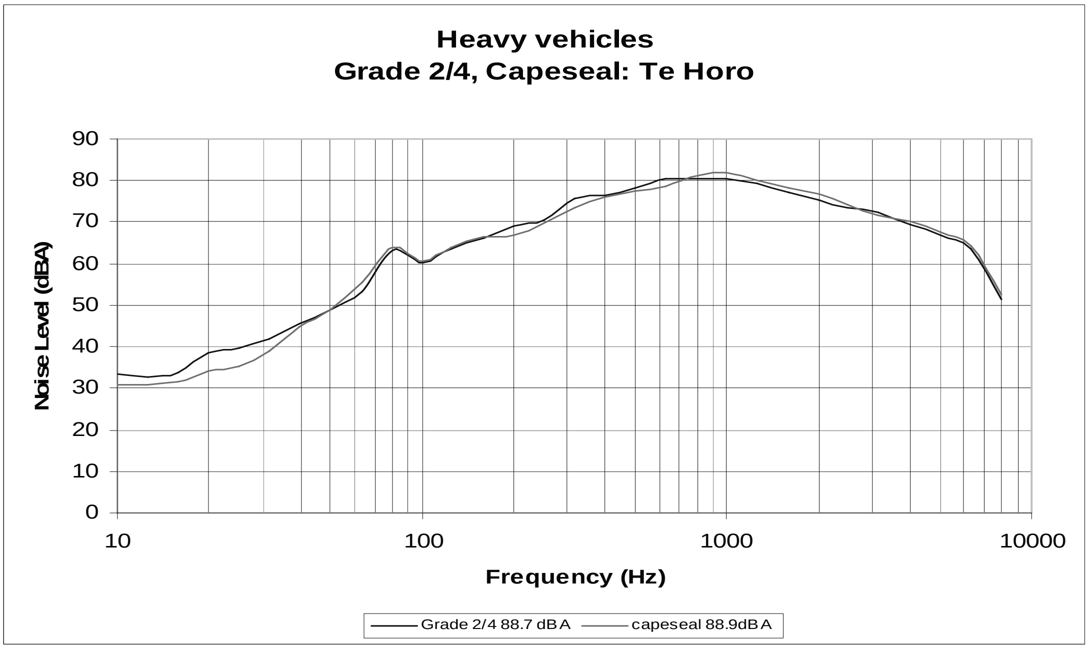

Figure A3 **Comparison of heavy vehicle noise on Grade2/4 chipseal and Cape seal at Te Horo.**

Appendix B

Survey Form

OPUS INTERNATIONAL CONSULTANTS

Community Assessment of Road Noise

Dr Darren Walton
Opus International Consultants

Ph 04 587 0663 Fax 04 587 0604 email darren.walton@opus.co.nz

Today's date: _____/_____/_____ Address: ___________________________________

1. **Did you see the letter that was sent to your household concerning this road noise survey?** **Yes** ☐ **No** ☐

2. **Before we came did you realise that the surface of the road outside your house was going to be resealed?** **Yes** ☐ **No** ☐

3. **How long have you lived in this house?**

☐	☐	☐	☐	☐
Less than 3 months	Between 3-6 months	Between 6 months and 1 year	Between 1-5 years	5 years or more

General Response to Road Noise

> The following two questions ask you to consider how annoying road noise is in your household on a scale from 0 to 10. 0 is 'Not at all annoying' and 10 is 'Extremely annoying'.

4. Thinking about the last 12 months or so, when you are here at home, how much does the noise from the traffic on the road bother, annoy or disturb you?

0 1 2 3 4 5 6 7 8 9 10

Not at all Annoying **Extremely Annoying**

5. Thinking about the last 12 months or so, when you are here at home, and if there is noticeable noise from <u>trucks on the road</u> how much does this noise bother, annoy or disturb you (please leave this blank if you don't notice any trucks on your road)?

0 1 2 3 4 5 6 7 8 9 10

**Not at all Annoyin
g** **Extremely Annoying**

6. Thinking about the road surface <u>directly</u> outside your house, is there any particular feature that makes the road noise worse? For example, potholes, utility access covers (manholes), or joins in the road.

☐ No
☐ Yes. Please specify: ……………………………………………………………….
…………………………………………………………………………………………………
…………………………………………………………………………………………………

Noise Induced Activity Disturbance Scale

Which of the following things have occurred recently, while in your house, say, in the last two weeks?

7. Have you had difficulty talking on the telephone due to traffic noise?	**Yes** ☐	**No** ☐
8. Have you deliberately turned up the sound on the TV to overcome traffic noise?	**Yes** ☐	**No** ☐
9. Have you had to close a window or kept your windows closed to prevent traffic noise?	**Yes** ☐	**No** ☐
10. Have you considered moving house to a quieter location?	**Yes** ☐	**No** ☐
11. Have you had difficulty in hearing a conversation due to traffic noise?	**Yes** ☐	**No** ☐
12. Have you delayed doing something (e.g. gardening, entertaining) due to noise from the traffic?	**Yes** ☐	**No** ☐
13. Have you felt unable to relax due to the noise from the traffic?	**Yes** ☐	**No** ☐
14. Have you commented to others about how bad the noise from the traffic is?	**Yes** ☐	**No** ☐
15. Have you deliberately moved to another part of your house or property to be away from the traffic noise?	**Yes** ☐	**No** ☐
16. Have you had difficulty getting to sleep due to traffic?	**Yes** ☐	**No** ☐
17. Have you played music or something to overcome the noise of the traffic?	**Yes** ☐	**No** ☐
18. Have you avoided being at home when the traffic noise is bad (e.g. rush hour)?	**Yes** ☐	**No** ☐
19. Have you raised your voice to be heard above the traffic noise?	**Yes** ☐	**No** ☐

For each of the following statements we would like you to give a response on how much you agree or disagree with the statement.	**Strongly Agree**	**Agree**	**Not sure**	**Disagree**	**Strongly Disagree**
20. There is nothing that can be done about the traffic noise on my street.	☐	☐	☐	☐	☐
21. I don’t mind the traffic noise on my street.	☐	☐	☐	☐	☐
22. I can get very annoyed when the noise is from young people being silly in their cars.	☐	☐	☐	☐	☐
23. The traffic noise outside my house has gotten worse recently.	☐	☐	☐	☐	☐
24. The thing I dislike the most is the noise from trucks.	☐	☐	☐	☐	☐
25. The council does not concern itself with road noise.	☐	☐	☐	☐	☐
26. A better road surface than the one outside my house would result in less noise.	☐	☐	☐	☐	☐
27. Many other people put up with roads that are much more noisy than what I live with.	☐	☐	☐	☐	☐

	Strongly Agree	Agree	Not sure	Disagree	Strongly Disagree
28. The road noise outside my house is fine except for when I am tired.	☐	☐	☐	☐	☐
29. If the traffic noise increased a little I would get used to it.	☐	☐	☐	☐	☐
30. When I first moved in I thought the traffic noise was bad.	☐	☐	☐	☐	☐
31. I hardly notice any noise from the traffic outside my house.	☐	☐	☐	☐	☐
32. Other sources of noise (loud music, aircraft, etc) annoy me more than the traffic noise.	☐	☐	☐	☐	☐
33. If the traffic would just slow down the traffic noise would be much better.	☐	☐	☐	☐	☐
34. I really enjoy peace and quiet.	☐	☐	☐	☐	☐
35. I am easily woken by noise when I am asleep.	☐	☐	☐	☐	☐
36. I have a very good level of hearing.	☐	☐	☐	☐	☐
37. The amount of traffic noise is an important factor when choosing where to live.	☐	☐	☐	☐	☐
38. Overall the houses I have lived in previously are noisier than this one.	☐	☐	☐	☐	☐
39. I would describe my street as 'noisy'.	☐	☐	☐	☐	☐

Sensitivity to Noise

40. In general how sensitive to noise do you think you are?	☐ Not at all	☐ A little	☐ Moderately	☐ Very	☐ Extremely
41. Thinking about the last 12 months or so, when you are here at home, how much does the noise from the traffic on the road bother, annoy or disturb you?	☐ Not at all	☐ A little	☐ Moderately	☐ Very	☐ Extremely

42 Please indicate your gender

☐ Male ☐ Female

42. **Please indicate your age**

☐ Under 16
☐ 16-25
☐ 26-35
☐ 36-45
☐ 46-55
☐ 56-65
☐ 66-75
☐ 76-85
☐ 86 or more

43. **Do you have any hearing impairment?**

No

Yes Please Specify……………………………………….…………

Return Questions

We really appreciate that you have answered these questions. To be successful the research needs to be repeated, so we want to come back and ask you what you think of the traffic noise one more time. This would again take about 5-10 minutes and involve a very similar short interview/questionnaire.

Is it OK for us to come back and ask this sort of questionnaire again?

☐ Yes ☐ No

Identifier (Name, Nickname, Initials) ……………………………………………………………..

We want to know what the most convenient time and day is for us to return. (*Do not indicate when you will not be home--just indicate the best times for us to return*).

	Morning 10:30-12:00 am	Afternoon 2:00-4:00 pm	Early Evening 5:00-7:00 pm	Evening After 7:00 pm
Monday				
Tuesday				
Wednesday				
Thursday				
Friday				
Saturday				
Sunday				

If you provide a phone number it will be easier for us to get back to you. We will ring first. A cell phone number is fine.

Phone details………………………………..
Address
…………………………………………………………………………………………………..

Comments on the survey or on Road Traffic Noise
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