Low-Noise Road Surfaces Performance Monitoring

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Executive summary

Porous asphalt is the predominant surfacing on New Zealand motorways and other major roads especially where speeds are between 70 and 100 km/h. These surfaces provide reduced noise, reduced splash and spray, and improved friction at higher speeds; but while the surfaces usually have an eight year life before replacement, it is believed that clogging of the porous material may occur within three to four years so that the period the porous surface is effective is only half its actual life. Trials of materials with greater porosity and/or greater resistance to clogging were laid as part of other research projects in the period 1999 to 2003. The monitoring programme that is described in this report was initiated after the fact by NZTA (then Transit New Zealand) and undertaken by Opus Central Laboratories in the period 2004 to 2008.

The trial sites monitored were located on the Wellington motorway (SH1) near Porirua, on the Dunedin motorway near Fairfield, and on the Auckland northern motorway near the Silverdale interchange.

To measure the noise performance of the surfaces, this monitoring used methodologies that had also been applied in research reports LTNZ 292 and LTNZ 396. This method was a modified form of the pass-by method as described in ISO 11819-1 Acoustics – Measurement of the influence of road surfaces on traffic noise – Part 1: Statistical Pass-By method; but used a reduced sample size and measured the L_{eq} noise level over one second as the vehicle passed the measurement position. Separate measurements were made for cars and for trucks.

The monitoring also included measuring the porosity of the surfaces and observations of the deterioration or condition of the surfaces.

Over the monitoring period, a group of asphaltic concrete sites were also monitored. It was expected any changes in noise performance of the asphaltic concrete would be much less and occur more slowly than for the porous surfaces and so any noise performance changes could be isolated as effects of changes in the New Zealand vehicle fleet.

The materials trialled were:

	Porirua	Dunedin	Auckland
Conventional TNZ P/11 OGPA[1] 20 % voids	✓	✓	✓
Polymer modified OGPA 30 % voids (Higgins Flexiphalt A)	✓		
Polymer modified OGPA 30 % voids (Technics Mix A)	✓		
TNZ P/11 OGPA with high PSV chip	✓		
Proprietary dual layer OGPA (Wispa, Fulton Hogan)		✓	✓
Cleaned proprietary dual layer OGPA (Wispa, Fulton Hogan)			✓
Polymer modified binder OGPA		✓	
High strength OGPA		✓	
Dual layer OGPA 50 mm thick		✓	
Ultra-thin asphalt (Fulton Hogan Pavetex)		✓	
Macadam (Type 3 slurry seal)		✓	

Each of the sites had a different combination of surfaces under trial. The findings are as follows:

[1] Open graded porous asphalt

Porirua

The materials at the Porirua site consisted of two 30 % voids polymer modified binder (PMB) OGPA, a conventional TNZ P/11 OGPA, and a TNZ P/11 OGPA with high resistance to abrasion (made with chip of high polished stone value (PSV)).

Monitoring at this site extends from 1999 to 2007 but in the first few years a different processing routine was used for the data. This may have affected the earlier results so considering only from the 2002 year, the noise performances of all the trial surfaces deteriorate but by a similar amount of about 2 dB(A) for cars and 1 to 3 dB(A) for trucks. Some of this noise performance deterioration in the last year of the monitoring may have been due to surface defects such as cracking occurring.

The high voids PMB materials maintain an approximately 2 dB(A) advantage over the conventional OGPA.

The permeability of the Technics PMB OGPA and the high PSV OGPA are similar and very good, while the Higgins PMB OGPA has moderate permeability. However there appears to be little correlation between permeability and the noise performance.

Dunedin

The Macadam (type 3 slurry) and the ultra-thin asphalt surfaces were expected to change little in acoustic properties and this expectation was borne out. Relative to these surfaces, the noise-reducing performance of the porous surfaces decreased over the four years of the monitoring (that is the surfaces generated more noise). The change in noise performance was 2 to 4 dB(A) depending on the surface type and depending on whether the vehicle was a car or a truck.

While the conventional OGPA had the poorest noise performance of the porous surfaces, the pattern of performance becomes mixed over time. The three similar materials, conventional OGPA and high strength OGPA and PMB OGPA, start with similar noise performance but the noise performance of the high strength OGPA and the PMB OGPA remain stable over the trial period so that after four years they have an noise performance equivalent to the similarly aged deep thickness material Wispa and dual layer OGPA which have deteriorated more significantly (3 to 4 dB(A)) from their initial values.

The permeability of the materials is markedly different. Two (dual layer OGPA and OMB OGPA) are highly permeable and remain so over the four years, whereas the high strength OGPA has poor permeability at the start and this deteriorates with time to a very poor permeability. However there is little correlation between the permeability measurements and the noise performance; with the high strength OGPA and the PMB OGPA having equivalent noise performance and the noise performance of the dual layer OGPA deteriorating significantly (2 to 3 dB(A)).

Auckland

The Auckland site had only two materials, the conventional OGPA and the proprietary dual layer material Wispa; but the site was subdivided into sections of Wispa subject to a cleaning regime designed to unclog the porous surface.

The performance of the conventional OGPA and the Wispa was similar to that in Dunedin with a deterioration of noise performance of 3 to 4 dB(A) with the deterioration greater for cars than for trucks and relative performance over time (OGPA to Wispa) continuing roughly constant.

The effect of the cleaning regime is small, with either no reduction in noise at some sites or a 1 to 1.8 dB(A) reduction at other sites. However, while the cleaning process did increase permeability, the permeability before cleaning was already very good. Permeability was not fully monitored throughout the monitoring period at this site.

Conclusion

Overall the noise performance of porous road surfaces deteriorates quite quickly by typically 2 to 3 dB(A) over four or five years and in some cases deterioration over this period is as much as 4 dB(A). There is however variable performance both among road surfacing types and among applications of the same road surfacing; with a few trial sections exhibiting little change in noise performance.

There appears to be little correlation between the noise performance and the permeability of the road surfaces as measured by the methods outlined in this report, nor between change in acoustics properties and change in permeability.

This research has observed the performance of materials over time and measured one major road surface property, permeability, but has not established any causative links of material properties with changes in noise performance. A more in-depth study would be needed to identify the parameters of the porous surface that do influence the noise performance.

Contents

1 Introduction

Porous asphalt is widely used in New Zealand. It is the predominant surfacing on motorways and is becoming increasingly common as a noise reduction treatment in other areas.

The first Transit New Zealand specification for porous asphalt (friction course) was introduced in 1975 and was based on aggregate grading that would result in a total air void content of greater than 14 percent. In 1980, the specification was revised to ensure an air voids content of 20 percent or greater was achieved.

It has been considered the materials that are currently used in the porous asphalt surfaces for their free-draining characteristics, contributing to the reduction in aquaplaning potential, noise, and splash and spray of the road surface, may lose these characteristics within 3 to 4 years of porous asphalt construction. Even though the average life of porous asphalt is greater than 8 years, the effective life could be in reality less than half of this. The main factor contributing to this performance deterioration is the entry of detritus materials (silt, fine sand, or dirt) which clog the pore spaces and adhere to the binder.

The primary objective of the research reported here was to compare the noise and draining performance over time of a range of pavement surfacings. The surfacing trials were set up as part of other research projects and monitoring was formally started after most of the trials had been laid. There has been difficulty therefore in obtaining construction information concerning the mix designs and mix properties as laid.

Trial sites have been established on the Auckland motorway near Silverdale interchange, on the Wellington motorway near Porirua, on the Dunedin motorway near Fairfield and five controls sites in Lower Hutt urban area were used to ensure that changes in noise level were not associated with changed in the vehicle fleet. Table 1.1 provides a summary of the sites; their location, traffic parameters, and material type.

Noise measurements have been made using the pass-by method recording the passage of at least 10 to 15 heavy trucks and 20 to 23 passenger cars. Permeability measurements were made with a simple outflow device. Monitoring was performed from 1999 to 2007 on the Porirua sites and from 2004 to 2008 on the other sites.

In addition, research was performed into the precision of the noise measurement methodology, comparison with the international standard and the effect of recent rain on the test results. Details are given in the Appendices.

Table 1.1: The trial sites

Trial	Location	Date	AADT	Heavy vehicles	Surface type	Thick ness	Addi tives
Auckland	SH 1N RP 398/ 0.817 - 1.336	Apr 2003	25,362	7 %	Conventional OGPA	30 mm	
Auckland	SH 1N RP 398/ 1.336 - 2.350	Oct 2002	23,705	7 %	Wispa OGPA	70? mm	4% FH Paveflex
Porirua	SH 1N RP 1050/ 4.713 - 5.080	Feb 1999	19,018	5 %	TNZ P/11		
Porirua	SH 1N RP 1050/ 5.080 - 5.159	Apr 1999	21,247	5 %	Flexiphalt 150A (Higgins)		
Porirua	SH 1N RP 1050/ 5.150 - 5.283	Apr 1999	21,247	5 %	Technics Mix A		5%SBS
Porirua	SH 1N RP 1050/ 5.283 - 5.400	Apr 1999	21,247	5 %	TNZ P/11 with high PSV chip		
Dunedin	SH 1S RP 712/ 2.050 - 2.620	Dec 2002	16,135	6 %	High strength PMB OGPA	30 mm	?% SBS
Dunedin	SH 1S RP 715/ 0.030 - 0.710	Dec 2002	12,356	4 %	Wispa OGPA		
Dunedin	SH 1S RP 715/ 0.710 - 1.720	Dec 2002	12,356	4 %	Conventional OGPA with PMB	30 mm	?% SBS
Dunedin	SH 1S RP 715/ 1.720 - 2.120	Dec 2002	12,356	4 %	Dual layer OGPA	50 mm	
Dunedin	SH 1S RP 715/ 2.120 - 2.320	Dec 2001	12,356	4 %	Macadam (Type 3 slurry seal)		
Dunedin	SH 1S RP 715/ 2.320 - 2.720	Jan 2003	12,356	4 %	Conventional OGPA	30 mm	
Dunedin	SH 1S RP 715/ 2.720 - 4.500	Jan 2003	12,356	4 %	Ultra-thin asphalt (Fulton Hogan)	15 mm	

2 Methodology

The same measurement technique was used for each year and in addition the same operator performed all the measurements.

Noise measurements were carried out using two noise meters Rion NL-32 and Rion NL-31. Noise meters tracked the same vehicle as it travelled over each surface, enabling a comparison of noise levels, generated by the same vehicle on the different surfaces to be done.

The position of noise meters was at a distance of 2.5 metres from the edge of traffic lanes at all sites except the Porirua site. At Porirua, noise meters were positioned at a distance of 2.4 metres from the edge of traffic lane in order to be consistent with the monitoring performed before 2005. At all sites microphones were 1.2 metres above the road level.

The distances of these positions is closer than the 5 metres recommended in the ISO Standard ISO 11819-1 Acoustics – Measurement of the influence of road surfaces on traffic noise – Part 1: Statistical Pass-By method, but were chosen as a number of sites had deep drainage channels of steeply sloping embankments within 5 metres of the road. Tests showed the noise measurements at the closer distances (2.5 and 2.4 metres) were not affected by wind-wash from passing heavy vehicles.

It was found the distance between the noise meter (microphone position) and the edge of the traffic lane could be adopted as 2.5 metres at all monitoring sites. However the real distance between vehicle track line and the noise meter can vary significantly depending on the vehicle type, road width and driving conditions. Monitoring shows that on the motorway, this distance can vary approximately from 3.5 to 5 metres for light cars and from 3 to 4 metres for heavy trucks and buses. In the series of measurements made in 2005 to 2007, only vehicles travelling approximately in the centre of the traffic lane were recorded. Vehicles travelling very close or too far from the edge of the traffic lane were ignored.

2.1 Calibration

Noise meters were calibrated on-site with a portable noise calibrator. In addition, real time traffic noise measurements were undertaken at each trial site, with the two instruments installed next to each other, so the instruments measured noise levels from passing cars at the same point. The distance between the microphones was 10 to 15 centimetres. Both noise meters showed equal noise levels, so no correction to the output was required.

All instruments are calibrated by ECS Ltd, an IANZ Accredited Laboratory.

2.2 Permeability

Permeability tests were performed by measuring the time taken for 150ml of water to be absorbed into the surface when poured into an annulus of 150mm diameter. The test method was described in the previous report for the year 2005. This method is simple and fast and has been shown to correlate with a visual assessment of water spray.

The test method follows Appendix A of the TNZ P/23 Notes: 2005:

Field Permeability Testing for Open Graded Porous Asphalt

Permeability of Open Graded Porous Asphalt (OGPA) shall be checked after laying by placing a 150 mm diameter ring on the OGPA matt, sealing between the ring and the matt with a suitable silicon product.

The ring shall have sufficient mass and differences between internal and external diameters that it shall require the water to flow through the voids in the OGPA matt. A correctly sized CBR surcharge ring has normally been used for this test in the past.

Add 300 ml of water to the inside of the ring to saturate the matt. Once the level of this water has dropped flush with the top of the mat, add a further 150 ml of water to the ring in one quick pour and record the time with a stopwatch for this water to drain flush with matt surface again.

Repeat with two more 150 ml portions, added separately and record the times as detailed above. The period between adding 150 ml portions of water to the ring should be kept to a minimum with the only delay being to record the drainage times.

Permeability tests were performed adjacent to the noise monitoring locations and at two positions on the road surface: within the outer wheel track and between the two wheel tracks. On the road surface, the "outer wheel track" position (the trafficked zone) bears greater influence on the road surface noise than the "between wheel track" position (the non-trafficked zone). Thus, it is the "outer wheel track" position measurements, indicated on the graphs by the red circles) that should be the focus for analysis with respect to noise influence of the road surface.

3 Porirua site: SH1

3.1 Site description

The section of trial sites is located in the southbound lane of State Highway 1 (SH1), between RP 969/5.08 and RP 969/5.52 at Porirua. The standard TNZ P/11 mix was laid in February 1999 and three trial sections were laid two months later in April. The trial sections included Higgins Flexiphalt 150A (binder with 5% EMA (ethylene methyl acetate)), Technics "A" (with 5% SBS modified 80/100 bitumen) both with 30% air voids and a standard TNZ P/11 mix t(20% air voids)hat uses a high PSV (PSV = 62) chip. The construction and initial monitoring have been reported in N.J. Jamieson and J.E. Patrick, 2001. Increased Effective Life of Porous Asphalt. Transfund New Zealand Research Report No. 204, 32pp.

The trial sites were placed immediately south of the standard TNZ P/11 (1999) mix and are shown in Figure 3.1. A much older TNZ/P11 mix laid in 1989 lies immediately south of these trial sections. The extension and exact locations of these sites are shown in Table 3.1.

Figure 3.1: Schematic of Porirua trial site sections and noise meter positions

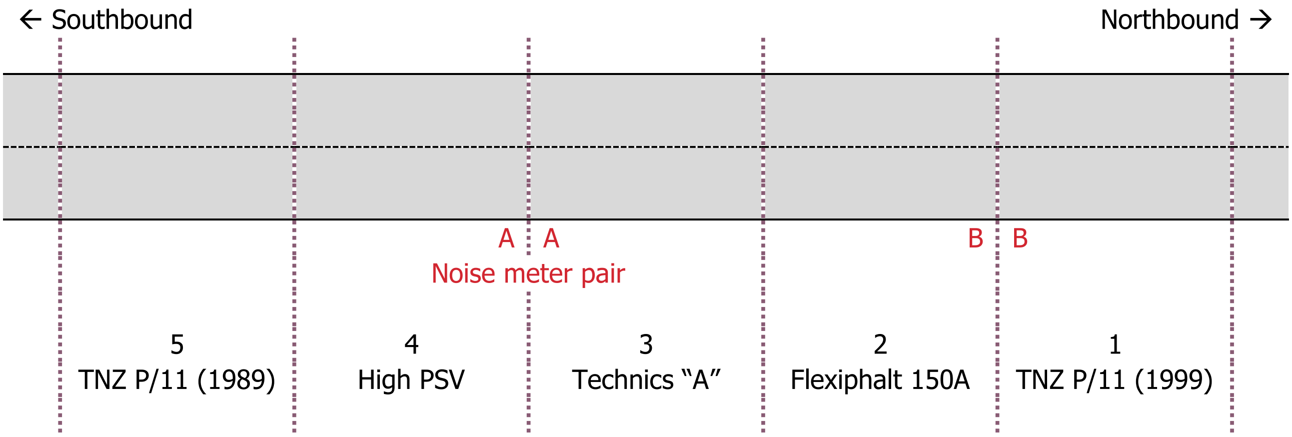


Table 3.1: Porirua site test sections

RS	Start RP	End RP	Length	Surfacing	Construction
969	4.713	5.080	367 m	1 TNZ P/11	Feb 1999
969	5.080	5.159	79 m	2 Higgins Flexiphalt 150A	Apr 1999
969	5.159	5.283	124 m	3 Technics "A"	Apr 1999
969	5.283	5.400	117m	4 TNZ P/11 using high PSV mix	Apr 1999
969	5.400			5 TNZ P/11 laid in 1989	Feb 1989

3.2 Noise levels

Results of measurements for cars and trucks are shown in Table 3.2. Variations in noise levels for cars recorded over the nine years are shown in Figure 3.2, and variations in noise levels for trucks recorded over four years (2004 to 2007) are shown in Figure 3.3.

Table 3.2: Porirua SH1 noise monitoring data (cars and trucks) from 1999 to 2007

Monitor year	Noise level dB(A)							
	1. TNZ P/11		2. Flexiphalt 150A		3. Technics "A"		4. High PSV	
	Cars	Trucks	Cars	Trucks	Cars	Trucks	Cars	Trucks
1999	78.0		76.1					
2000	76.7		75.7		74.4		74.8	
2001	75.5		74.6		73.5		75.2	
2002	76.1		75.3		74.2		76.2	
2003	76.4		74.3		74.2		76.4	
2004	78.2	88.4	76.6	87.3	76.0	87.6	77.9	88.2
2005	78.0	88.2	75.8	86.9	74.5	86.3	76.3	87.1
2006	78.2	89.1	75.8	88.1	76.1	87.8	77.2	88.1
2007	78.8	91.0	77.0	90.2	77.7	89.3	78.0	89.3

Figure 3.2: Porirua SH1 variations in the noise levels for cars from 1999 to 2007

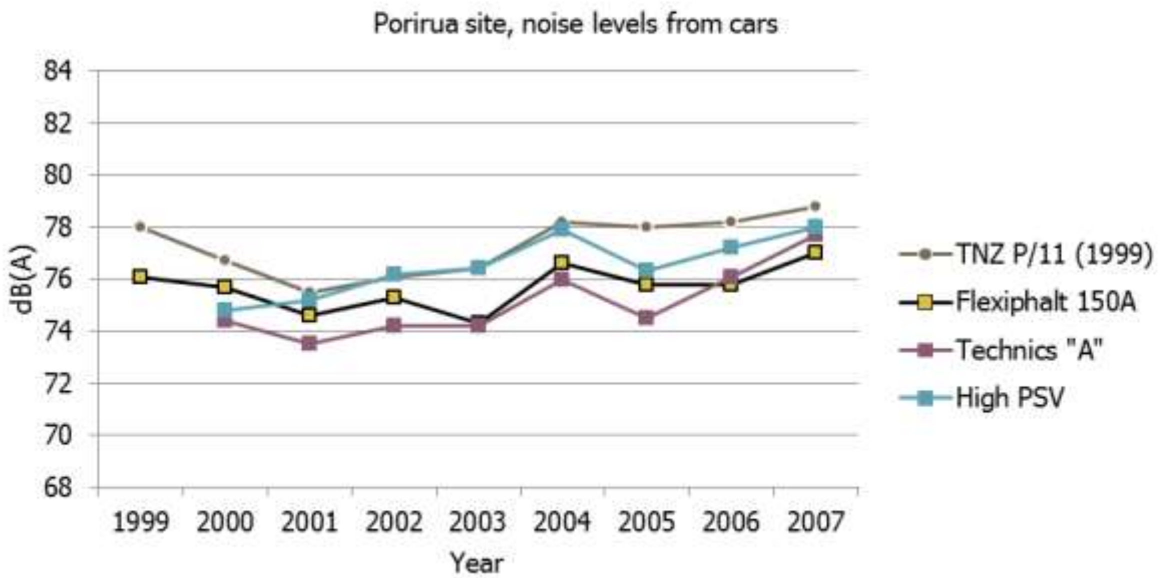
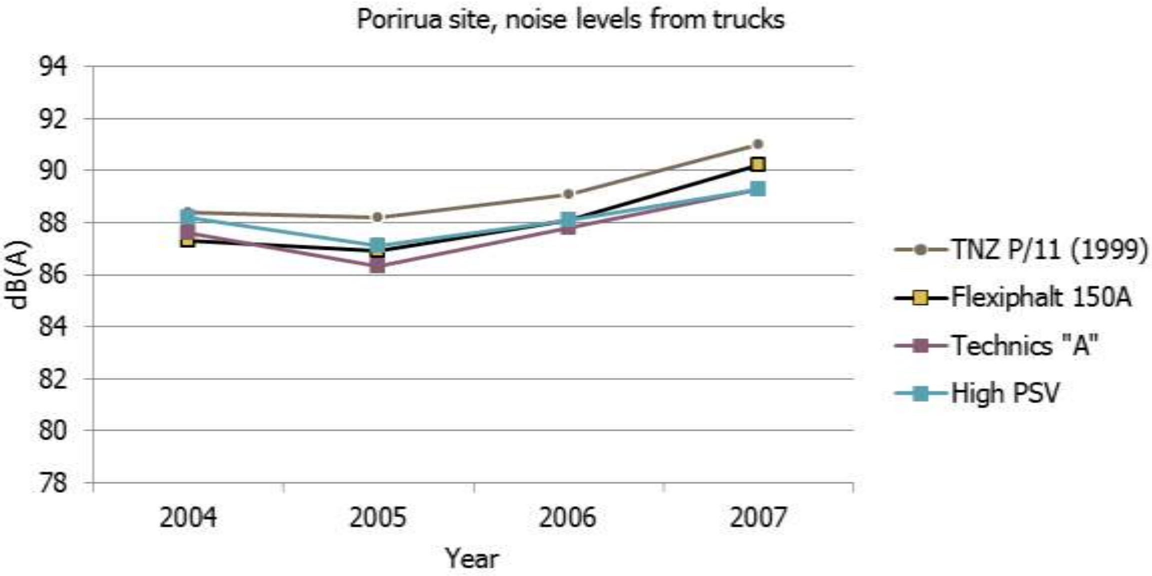


Figure 3.3: Porirua SH1 variations in the noise levels for trucks from 2004 to 2007



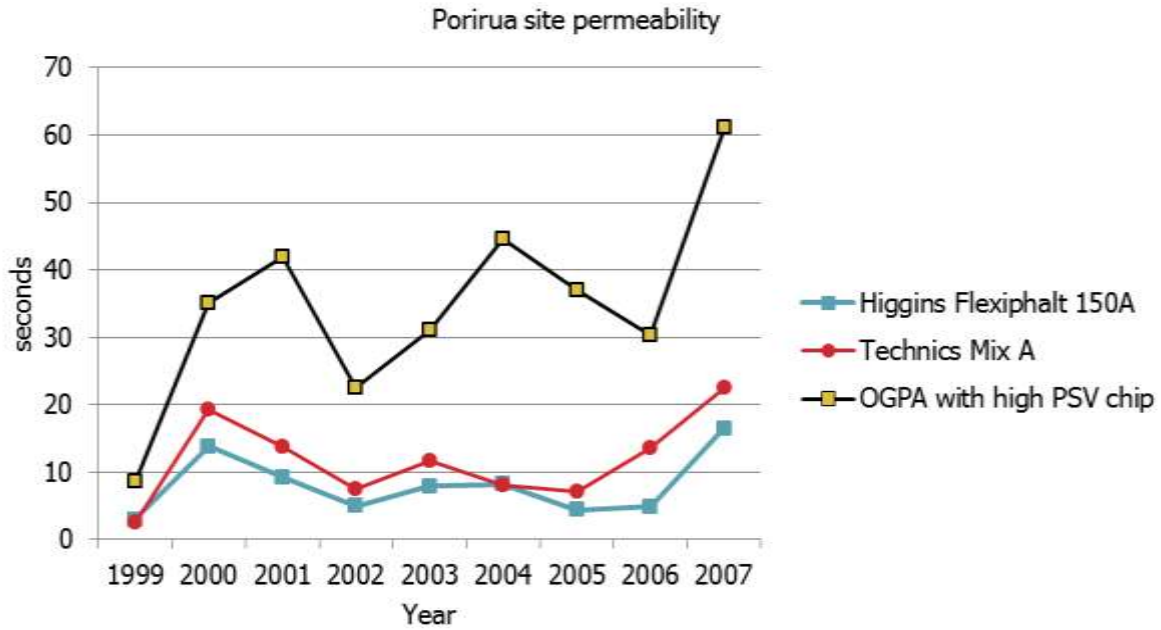
The measurements show consistent trends in that Higgins and Technics mixtures (30% air voids) perform better than TNZ P/11. Practically all surfaces had cracking or severe fatigue cracking by 2006/2007 and this could be the reason that the noise level has increased.

3.3 Permeability

Permeability measurements were performed in the left traffic lane of the southbound corridor in three locations across the lane.

Using results of permeability tests for the period from 2004 to 2007 the average annual values for each pavement have been calculated and are shown in Figure 3.4.

Figure 3.4: Porirua SH1 variations in the permeability from 1999 to 2007



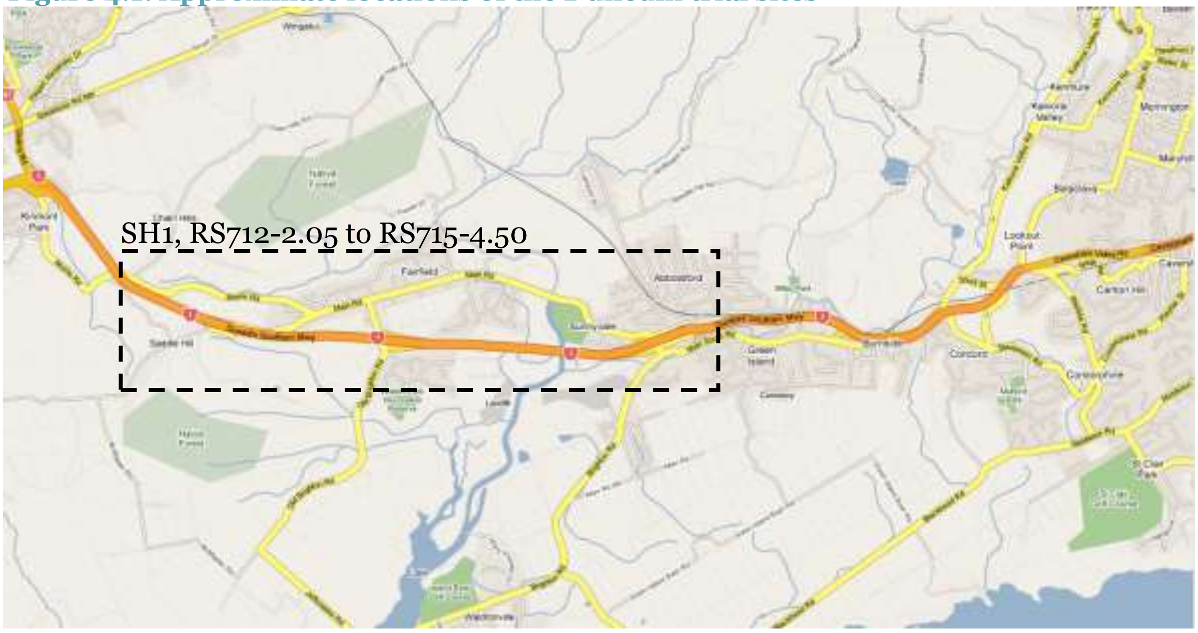
3.4 Surface condition

By 2007 the standard TNZ P11 mixes, Higgins Flexiphalt and Technics sites had cracking and pumping of fines at localised spots. The monitoring was stopped and the area resurfaced in 2008.

4 Dunedin site: SH1, Fairfield motorway

4.1 Site description

Figure 4.1: Approximate locations of the Dunedin trial sites



The Dunedin trial sites were located on SH1 to the west of Dunedin, between Abbottsford and Fairfield, as indicated in Figure 4.1.

The road section for monitoring is four lanes wide and approximately 4.8 km long. Traffic is free flowing at 100 km/h.

In December 2002, this section was surfaced with seven different types of asphaltic surfaces:

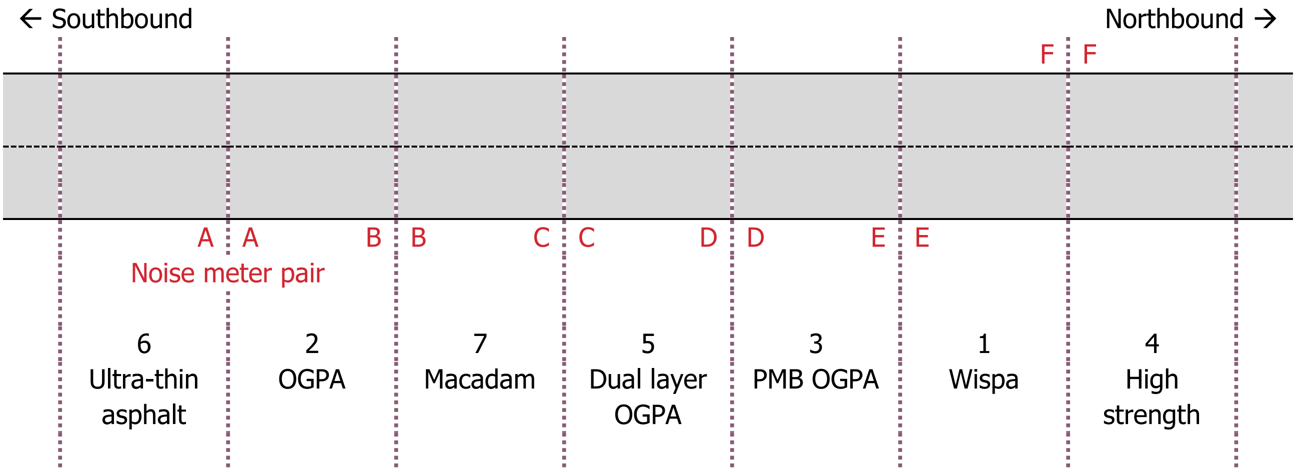
1. Wispa
2. Conventional 14 mm OGPA with B60 penetration grade binder; laid at 30 mm thick;
3. Conventional 14 mm OGPA with polymer modified binder; laid at 30 mm thick;
4. High strength 14 mm OGPA; laid at 30 mm thick;
5. Dual layer OGPA; laid at 50 mm thick total;
6. Fulton Hogan's ultra-thin asphalt (PAVEtex); laid at 15 mm thick; and
7. Macadam, a type 3 slurry seal.

Table 4.1 gives further details on the test sections and Figure 4.2 indicates how the sections were laid out. Figure 4.2 also shows positions of noise meter pairs. Each pair of noise meters is aligned with a pair of different road surfaces.

Table 4.1: Dunedin site test sections

RS	Start RP	End RP	Length	Surfacing		Construction
712	2.05	2.62	570 m	4	High strength OGPA	Dec 2002
715	0.03	0.71	680 m	1	Wispa	Dec 2002
715	0.71	1.72	1,010 m	3	PMB OGPA	Dec 2002
715	1.72	2.12	400 m	5	Dual layer OGPA	Dec 2002
715	2.12	2.32	200 m	7	Macadam, Type 3 slurry	Dec 2002
715	2.32	2.72	400 m	2	Conventional OGPA	Jan 2003
715	2.72	4.50	1,200 m	6	Ultra-thin asphalt	Jan 2003

Figure 4.2: Schematic of Dunedin trial site sections and noise meter positions



4.2 Noise levels

Results of measurements for the period of five years from 2004 to 2008 are shown in Table 4.2 and the trend over time shown in Figure 4.3 for cars and Figure 4.4 for trucks.

Table 4.2: Dunedin SH1 noise monitoring data (cars and trucks) from 2004 to 2008

Monitor year	Noise levels dB(A)													
	1. Wispa		2. OGPA		3. PMB OGPA		4. High strength		5. Dual layer		6. Ultra-thin		7. Macadam	
	Cars	Trks	Cars	Trks	Cars	Trks	Cars	Trks	Cars	Trks	Cars	Trks	Cars	Trks
2004	75.1	86.2	77.2	89.1	78.5	87.9	77.7	87.7	75.7	86.1	80.2	88.8	81.8	90.2
2005	75.7	87.3	78.5	89.0	77.9	89.2	78.3	89.0	75.6	88.0	81.0	90.7	82.1	90.7
2006	76.5	88.5	78.9	89.6	77.4	89.2	78.1	90.3	76.3	88.2	80.8	89.8	81.9	91.0
2007	78.1	88.7	80.5	90.9	78.2	89.2	78.6	91.0	77.4	89.1	82.2	92.2	82.7	92.1
2008	79.5	89.5	80.6	90.4	79.2	89.1	79.3	90.2	78.1	88.0	82.0	90.6	82.5	91.1
Change	4.4	3.4	3.4	1.3	0.7	1.2	1.7	2.5	2.4	1.9	1.8	1.8	0.7	0.9

Figure 4.3: Dunedin SH1 variations in the noise levels for cars from 2004 to 2008

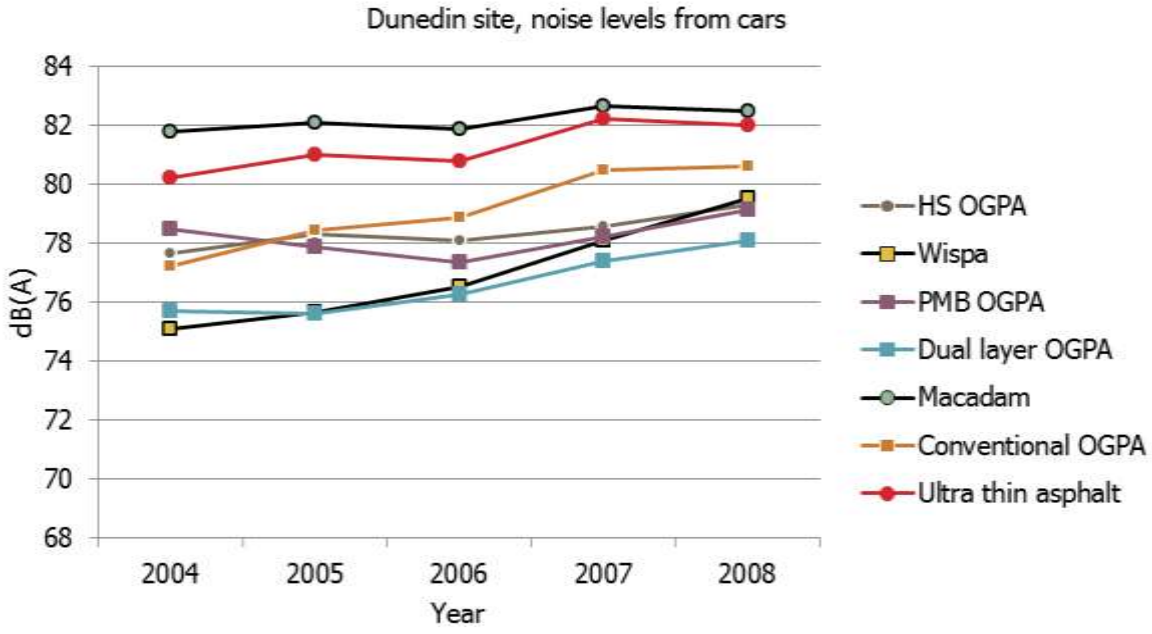
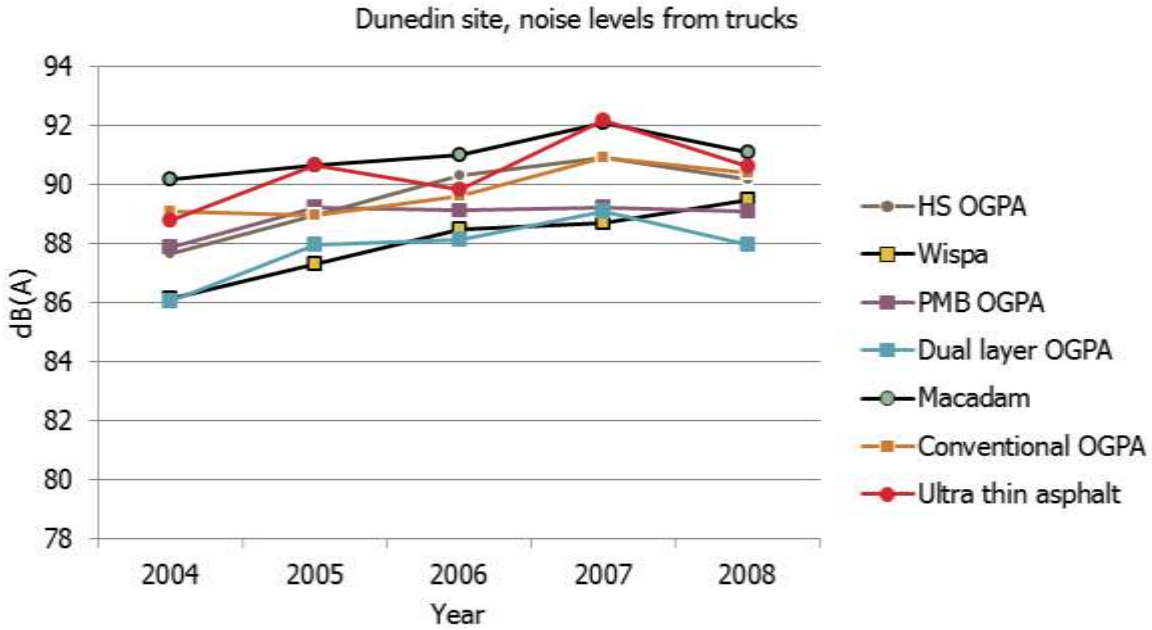


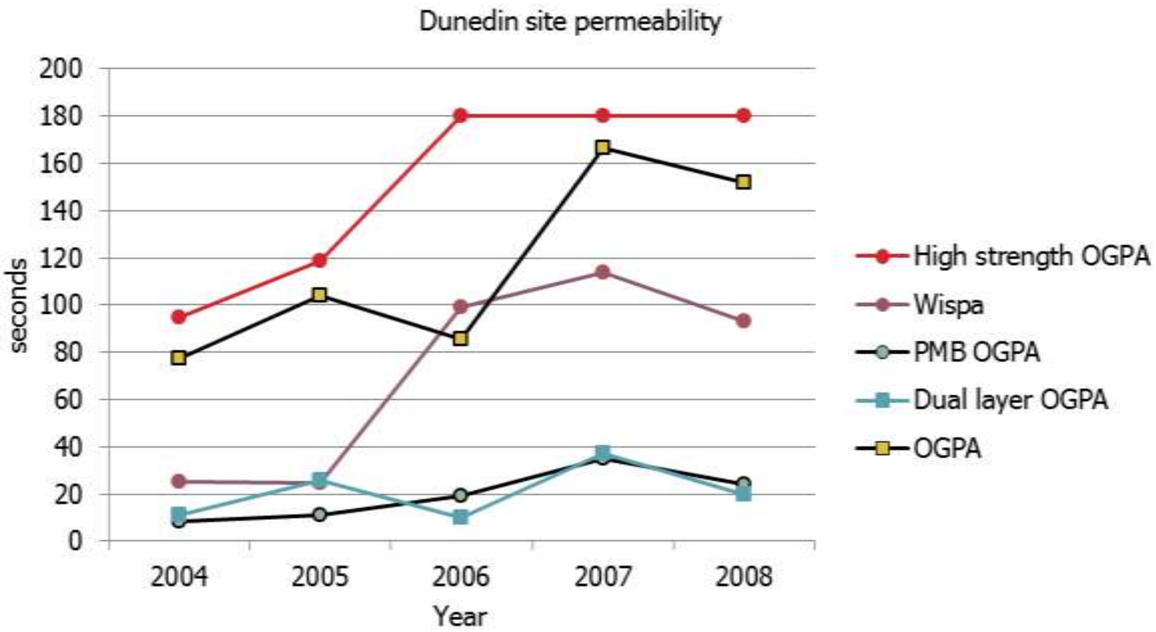
Figure 4.4: Dunedin SH1 variations in the noise levels for trucks from 2004 to 2008



4.3 Permeability

Permeability measurements were performed each year from 2004 to 2008 and the average annual values for each pavement are shown in Figure 4.5.

Figure 4.5: Dunedin SH1 variations in the permeability from 2004 to 2008



4.4 Surface condition

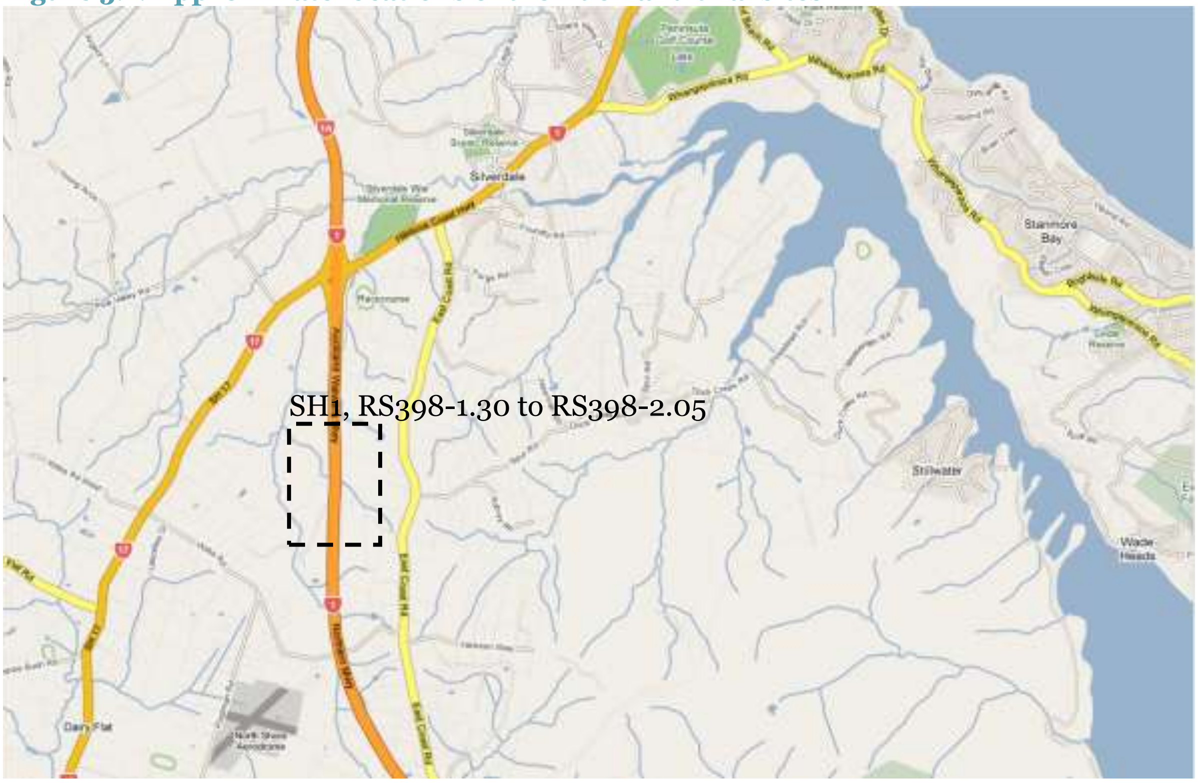
Physical examination of the various road surfaces at the Dunedin site found the roads surfaces were still in good condition in 2008.

In 2007 examination, the seal joint between the Dual layer OGPA section and the Macadam section has been repaired. The repair is poor and there is a 12 mm dip at the joint.

5 Auckland site: SH1, Silverdale interchange

This trial site is located on SH 1, the Albany Puhoi Motorway, south of the Silverdale Interchange, as shown in Figure 5.1. The road section for monitoring is two lanes wide and approximately 0.7 km long. Traffic is free flowing at 100 km/h.

Figure 5.1: Approximate locations of the Auckland trial sites



This section is surfaced with two different types of asphaltic surfaces:

1. Conventional 14 mm OGPA with B60 penetration grade binder; laid at 30 mm thick;
2. Wispa.

Table 5.1 gives further details on the test sections.

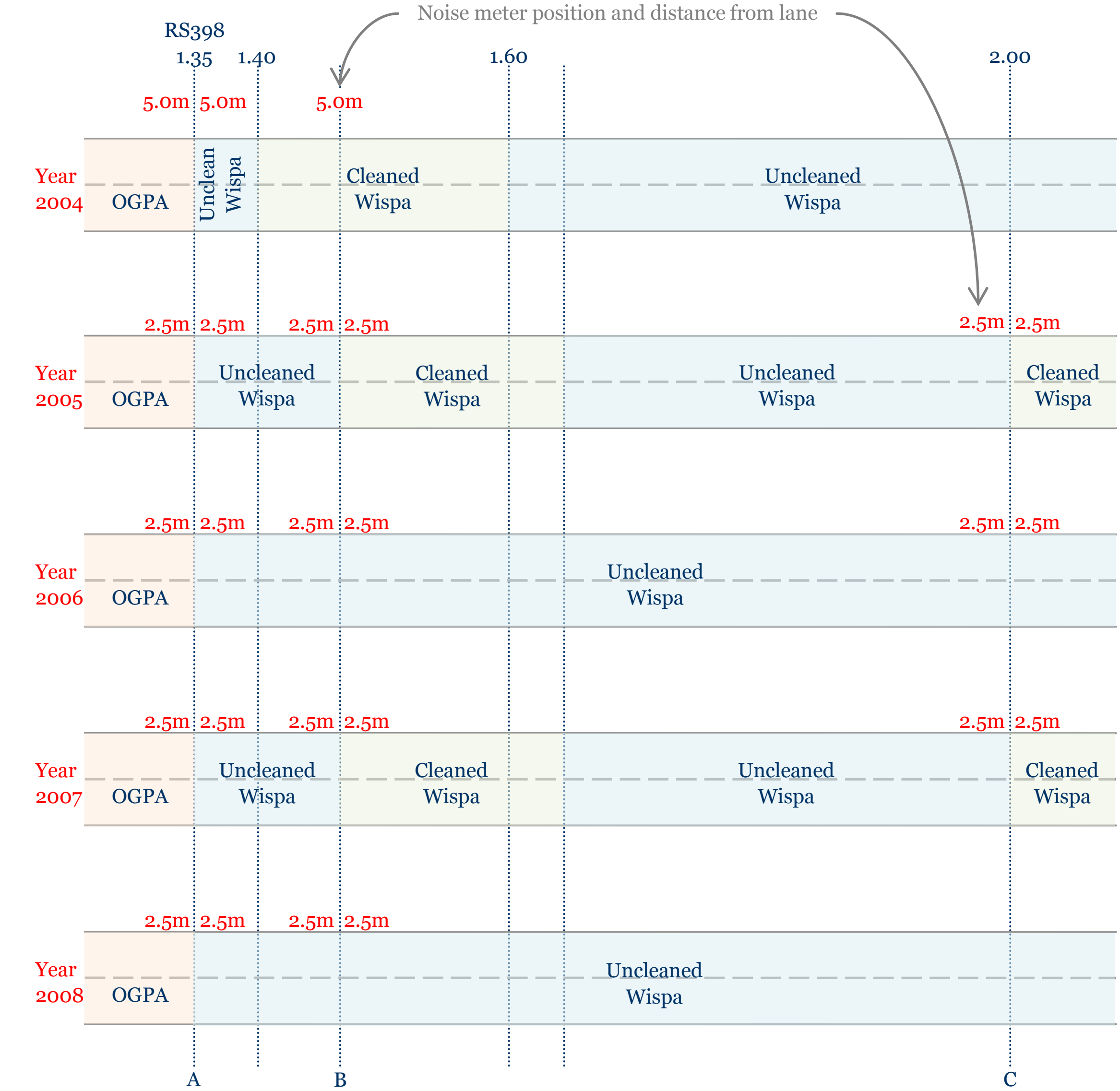
Table 5.1: Auckland site test sections

RS	Start RP	End RP	Length	Surfacing	Construction
398	0	1.35		1 OGPA	
398	1.35			2 Wispa	

Since the monitoring of 2004, sections of the Wispa surfacing have been cleaned between annual noise measurements. Figure 5.2 illustrates how the cleanings have occurred over the years and over the trial site length. Figure 5.2 also shows the positions of the noise meters for each year's monitoring.

In the first survey in 2004 the distance to the microphone was 5m this was reduced to 2.5 m for all subsequent readings. The results were adjusted to the position of 2.5 m from the edge of traffic line using correction factors from the TNOISE model.

Figure 5.2: schematic of Auckland trial site sections and noise meter positions



5.1 Noise levels

Monitor year	Noise levels dB(A)											
	1. OGPA		2. Wispa 398/1.35		2. Wispa 398/1.40		2. Wispa 398/1.45		2. Wispa 398/2.00		Wispa uncleaned	
	Cars	Trks	Cars	Trks	Cars	Trks	Cars	Trks	Cars	Trks	Cars	Trks
2004	78.3	86.3	74.8	83.5	75.1	84.6					74.9	84.1
2005	78.1	88.8	77.3	87.5			76.1	86.2	76.2	85.7	76.5	86.4
2006	79.1	89.9	77.8	88.3			77.7	86.8	77.6	86.9	77.7	87.3
2007	80.1	91.8	78.0	89.4			77.8	88.0	77.8	87.9	77.9	88.5
2008	81.3	90.4	80.7	89.9			79.8	86.8	80.1	87.0	80.2	87.9

Figure 5.3: Auckland SH1 variations in the noise levels for cars from 2004 to 2008

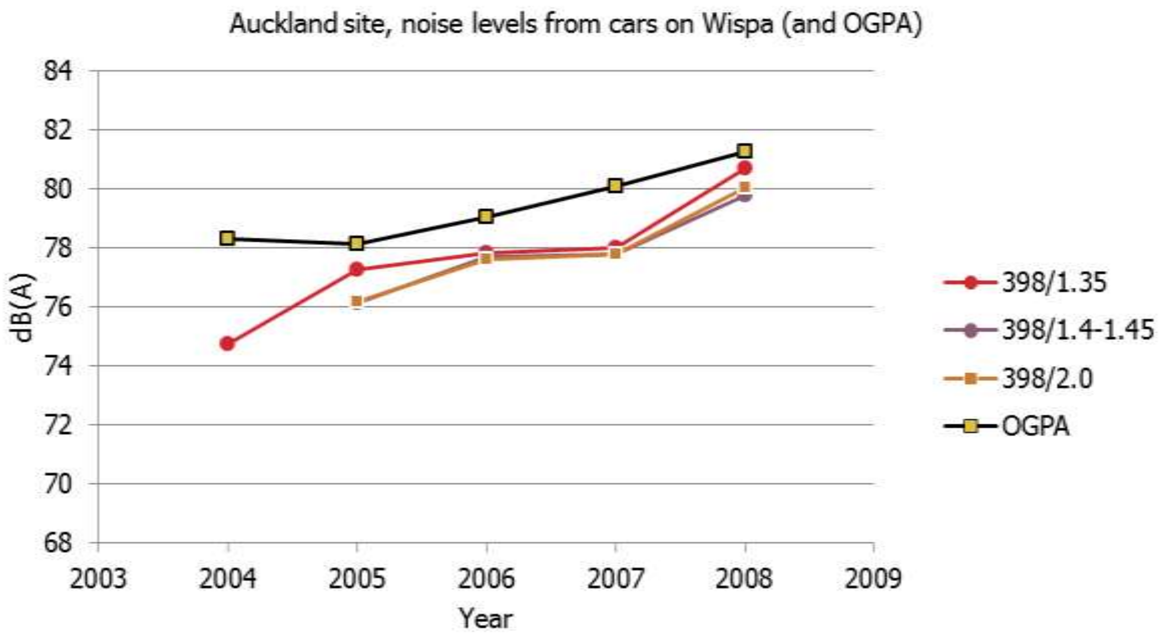
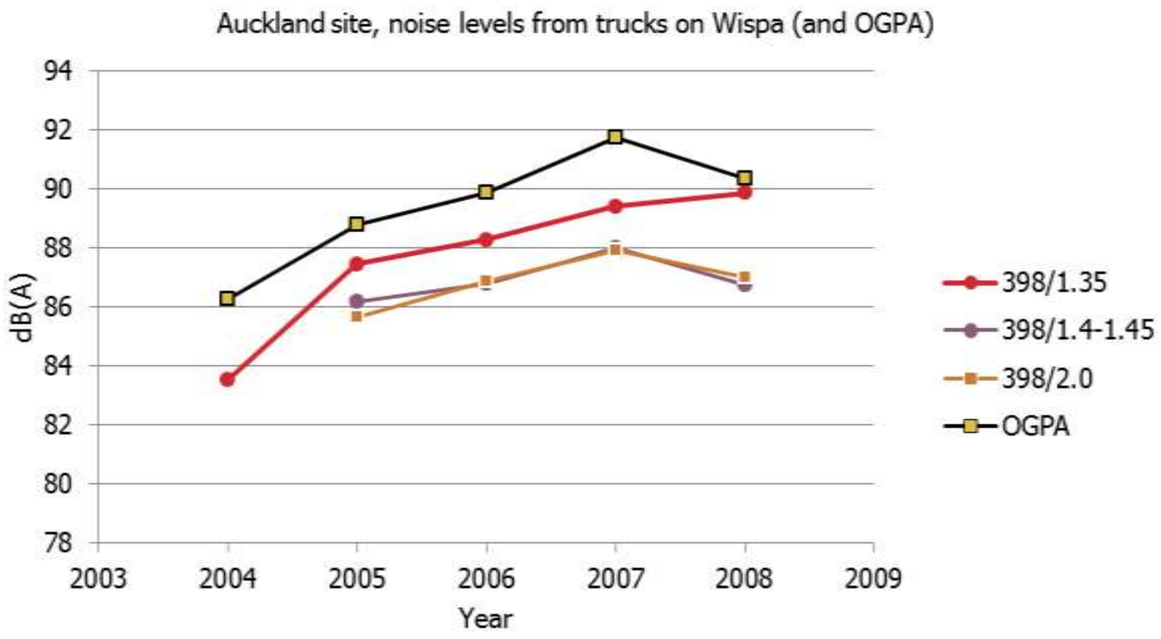


Figure 5.4: Auckland SH1 variations in the noise levels for trucks from 2004 to 2008



5.1.1 Effect of cleaning

A summary of the noise level tests of the cleaned and uncleaned sections of the Wispa sites is shown in Table 5.2.

Table 5.2: Comparison of the noise levels for cars on the cleaned and uncleaned sections of Wispa

Site	Year	Noise level dB(A)	
		Cleaned	Uncleaned
398/1.4	2004	73.9	74.9
398/1.4-1.45	2005	76.0	76.1
398/1.4-1.45	2005	76.4	77.8
398/2.0	2007	76.2	76.2
398/2.0	2007	76.2	77.8

5.2 Permeability

Table 12 gives the permeability data as obtained from 2005 to 2007. All the permeability readings show that the surfacing is very permeable and thus the cleaning has had little effect at this site.

Table 5.3: Comparison of the permeability for cleaned and uncleaned sections of Wispa

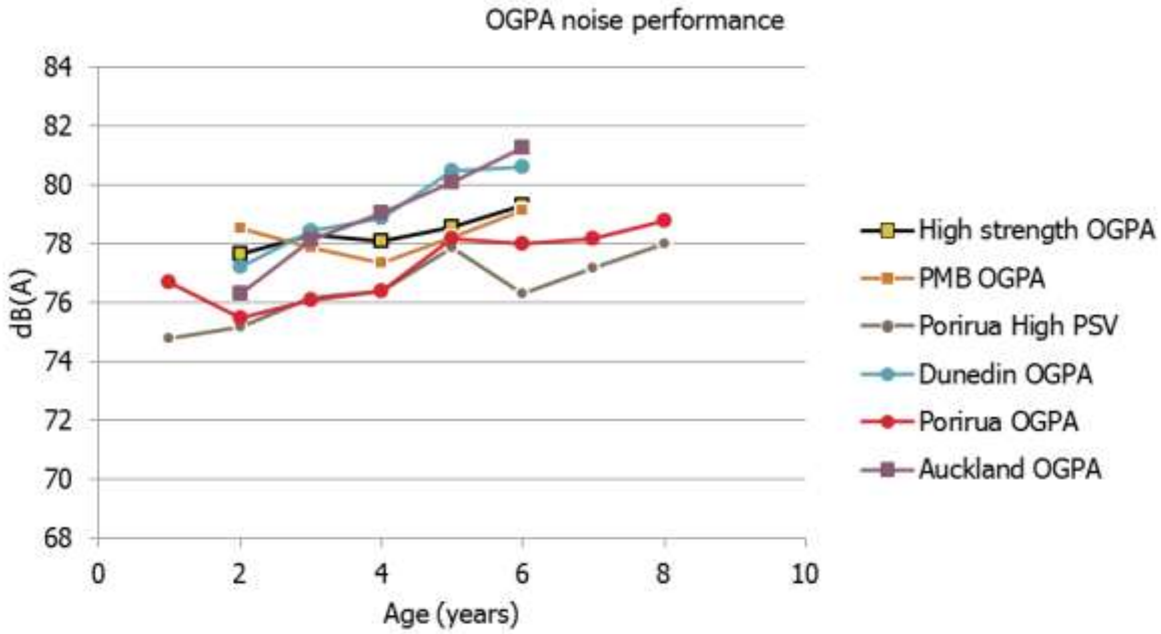
Site and lane Test position (m)	Permeability (s)				
	2005		2006	2007	
	Uncleaned	Cleaned	Uncleaned	Uncleaned	Cleaned
RP 398/1.4-1.6. Lane 1					
10	10	6	17	21	27
110	5	2	11	17	32
RP 398 2.0-2.2 Lane 1					
10	8	5	6		
110	8	3	7.5		

6 Discussion

6.1 20 % voids OGPA

Figure 6.1 compares the change in noise for three materials that are nominally the same material at the three sites and three other very similar materials. The increase in noise for the TNZ P/11 OGPA materials at the Dunedin and Auckland sites are similar but at the Porirua site the increase has been significantly less. Extrapolating the curves back to zero years indicates that the initial noise levels were similar. However once the other three similar materials are also considered, four of the six materials show a reasonably stable noise performance over time. This stability of performance and similar noise performance is delivered by materials of both good and poor permeability.

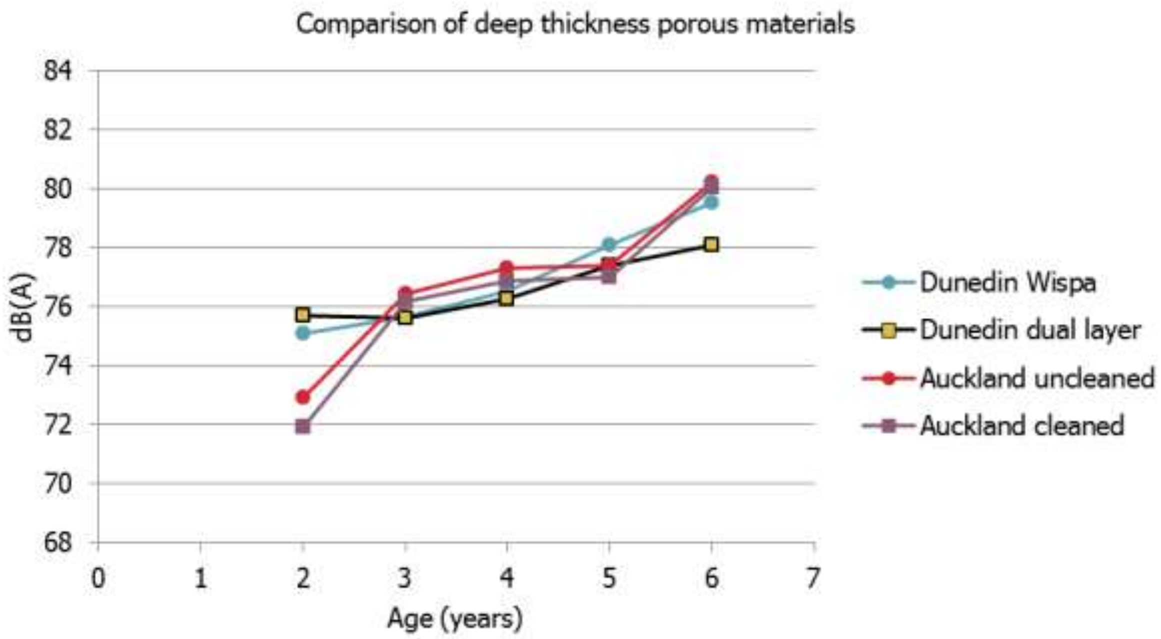
Figure 6.1: Comparison of ≈20 % void OGPA noise performance



6.2 Deep thickness porous materials

Figure 6.2 compares the performance of deep thickness porous road surfacing materials: Wispa and dual layer materials in Auckland and Dunedin. It can be seen that performance of the dual layer Wispa system is similar in both localities starting with good noise performance and deteriorating quite quickly. The dual layer materials are delivering a more stable noise performance and while initial noise performance is not as good as Wispa, the dual layer better maintains its noise performance to be ultimately the better performer.

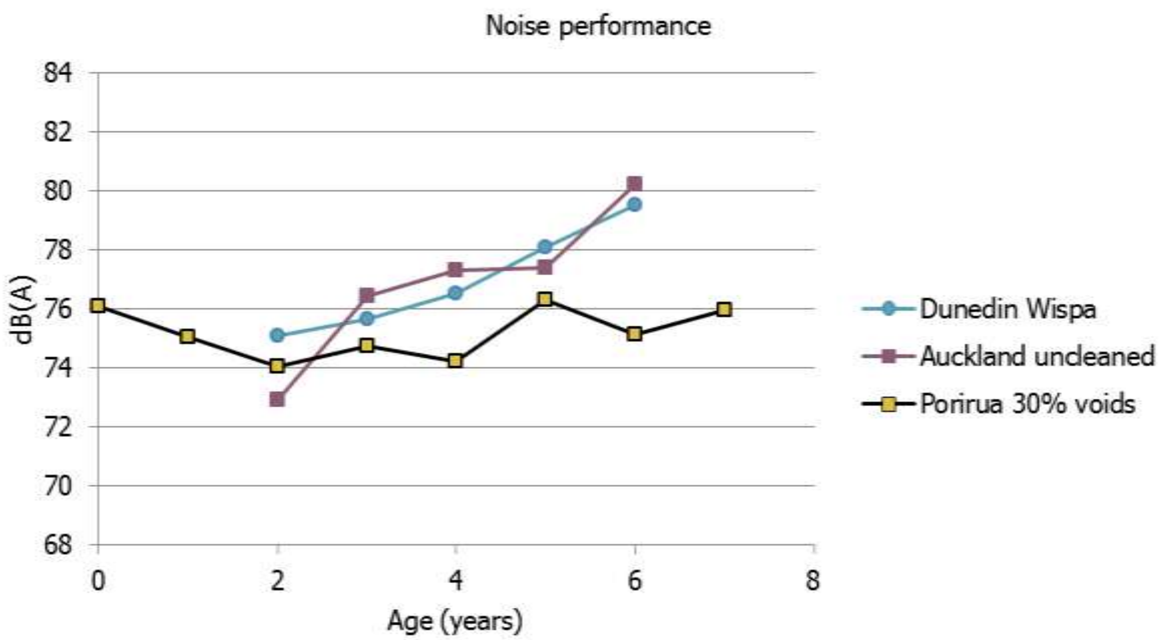
Figure 6.2: Comparison of Wispa noise performance



6.3 High voids (≈30 % voids) materials

Figure 6.3 compares the performance of the Wispa sites with the average of the two 30 % voids sites at Porirua. The 30 percent voids of Porirua is showing minimal change compared to the other Wispa sites. It is unclear whether is a function of the site (as per the 20 % void material) or a difference in the materials. Note from the indication provided by the dual layer material at Dunedin and the modified NZTA P/11 materials, it is likely a material difference, not a site difference.

Figure 6.3: Comparison of 30 percent voids porous materials



6.4 Overview of performance at the three main test sites

6.4.1 Porirua

The materials at the Porirua site consisted of two 30 % voids polymer modified binder (PMB) OGPA, a conventional TNZ P/11 OGPA, and a TNZ P/11 OGPA with high resistance to abrasion (made with chip of high polished stone value (PSV)).

Monitoring at this site extends from 1999 to 2007 but in the first few years a different processing routine was used for the data. This may have affected the earlier results so considering only from the 2002 year, the noise performances of all the trial surfaces deteriorate but by a similar amount of about 2 dB(A) for cars and 1 to 3 dB(A) for trucks. Some of this noise performance deterioration in the last year of the monitoring may have been due to surface defects such as cracking occurring.

The high voids PMB materials maintain an approximately 2 dB(A) advantage over the conventional OGPA.

The permeability of the Technics PMB OGPA and the high PSV OGPA are similar and very good, while the Higgins PMB OGPA has moderate permeability. However there appears to be little correlation between permeability and the noise performance.

6.4.2 Dunedin

The Macadam (type 3 slurry) and the ultra-thin asphalt surfaces were expected to change little in acoustic properties and this expectation was borne out. Relative to these surfaces, the noise-reducing performance of the porous surfaces decreased over the four years of the monitoring (that is the surfaces generated more noise). The change in noise performance was 2 to 4 dB(A) depending on the surface type and depending on whether the vehicle was a car or a truck.

While the conventional OGPA had the poorest noise performance of the porous surfaces, the pattern of performance becomes mixed over time. The three similar materials, conventional OGPA and high strength OGPA and PMB OGPA, start with similar noise performance but the noise performance of the high strength OGPA and the PMB OGPA remain stable over the trial period so that after four years they have an noise performance equivalent to the similarly aged high voids material Wispa and dual layer OGPA which have deteriorated more significantly (3 to 4 dB(A)) from their initial values.

The permeability of the materials is markedly different. Two (dual layer OGPA and OMB OGPA) are highly permeable and remain so over the four years, whereas the high strength OGPA has poor permeability at the start and this deteriorates with time to a very poor permeability. However there is little correlation between the permeability measurements and the noise performance; with the high strength OGPA and the PMB OGPA having equivalent noise performance and the noise performance of the dual layer OGPA deteriorating significantly (2 to 3 dB(A)).

6.4.3 Auckland

The Auckland site had only two materials, the conventional OGPA and the proprietary dual layer material Wispa; but the site was subdivided into sections of Wispa subject to a cleaning regime designed to unclog the porous surface.

The performance of the conventional OGPA and the Wispa was similar to that in Dunedin with a deterioration of noise performance of 3 to 4 dB(A) with the deterioration greater for cars than for trucks and relative performance over time (OGPA to Wispa) continuing roughly constant.

The effect of the cleaning regime is small, with either no reduction in noise at some sites or a 1 to 1.8 dB(A) reduction at other sites. However, while the cleaning process did increase permeability, the permeability before cleaning was already very good. Permeability was not fully monitored throughout the monitoring period at this site.

7 Conclusions

Overall the noise performance of porous road surfaces deteriorates quite quickly by typically 2 to 3 dB(A) over four or five years and in some cases deterioration over this period is as much as 4 dB(A). There is however variable performance both among road surfacing types and among applications of the same road surfacing; with a few trial sections exhibiting little change in noise performance.

There appears to be little correlation between the noise performance and the permeability of the road surfaces as measured by the methods outlined in this report, nor between change in acoustics properties and change in permeability.

This research has observed the performance of materials over time and measured one major road surface property, permeability, but has not established any causative links of material properties with changes in noise performance. A more in-depth study would be needed to identify the parameters of the porous surface that do influence the noise performance.

Appendix

A1. Control sites Lower Hutt, urban area sites (asphaltic concrete)

The drive by test method used in this project can only be used to compare surfaces over time if the noise profile of the traffic does not change but in a ten-year period as originally envisioned in this project, such a change is possible. To determine whether the vehicle fleet characteristics with respect to noise could be changing, measurements were intended to be made on five sites surfaced with asphaltic concrete. These sites had surfaces of different ages with the intention that over time, surfaces would age and be resealed but a similar mix of ages of the surfaces would be retained. Asphaltic concrete was chosen as the surface type as it was expected to be the most stable with respect to noise and ageing.

Five sites paved with AC-10 have been chosen in Lower Hutt urban area and noise levels were measured in 2005. Unfortunately three sites at Cambridge Terrace and one site at Waiwhetu Road were resealed in November – December 2005 with different surfacing. Four new sites were established in the same area. Two new sites at 87 Cambridge Terrace (northbound and southbound lines) are located about 350 – 400 m south of the previous two sites at Cambridge Terrace (Waterloo Bridge). New sites were paved with Mix-10 approximately at the same time as sites at Waterloo Bridge. Traffic conditions at these sites are similar with speed limit of 50 km/h and the real speed was nearly equal to the speed limit.

Two other new sites at Cambridge Tec/Treadwell Street intersection are also paved with Mix-10, however real speed at these sites is lower compared to Waiwhetu Road and 408 Cambridge Terrace sites. The real speed at Cambridge/Treadwell site is nearly equal to the speed limit of 50 km/h; meanwhile the real speed at Waiwhetu Road and 408 Cambridge Terrace sites was about 55 – 57 km/h.

A1.1 Description of sites

Wainui Road

This site is located at Our Lady of the Rosary School on the northbound traffic line of Wainui Road. The school playground is located about 25 – 30 m from the site and noise from the playground is clearly audible. In order to avoid interference with traffic noise, measurements were carried out at the time, when children were not present on the playground. This section of Wainui Road was paved with asphaltic concrete in January 2001. The speed limit at this site is 50 km/h.

87(1) Cambridge Terrace (Northbound)

This site is located about 350 - 400 m to the south from Waterloo Bridge at the south end of the Waterloo railway station. The dominant noise sources at this site were traffic noise on Cambridge Terrace and railway noise from passing trains. The speed limit at this site is 50 km/h and real speed is nearly equal to the speed limit.

87(1) Cambridge Terrace (Southbound)

This site was located across the road on the southbound line. Measurement conditions and dominant noise sources were similar to those at the site on the northbound line.

Cambridge Terrace/Treadwell Street Intersection (Cambridge Tce). Northbound)

This site is located on the northbound line opposite the house at 347 Cambridge terrace and 20 m north of Treadwell Street intersection. The speed limit for this section is 50 km/h, and real speed is nearly equal to the speed limit. The dominant noise sources at this site were traffic noise on Cambridge Terrace and noise of passing trains from near-by railway.

Cambridge Terrace/Treadwell Street Intersection (Cambridge Tce. Southbound)

This site is located on the southbound traffic line between intersections with Treadwell Street and Hillary Crescent. The speed limit for this section of Cambridge Terrace is 50 km/h, and real speed is equal to the speed limit. The dominant noise sources at this site were traffic noise on Cambridge Terrace and noise of passing trains from near-by railway.

A1.2 Results of noise monitoring

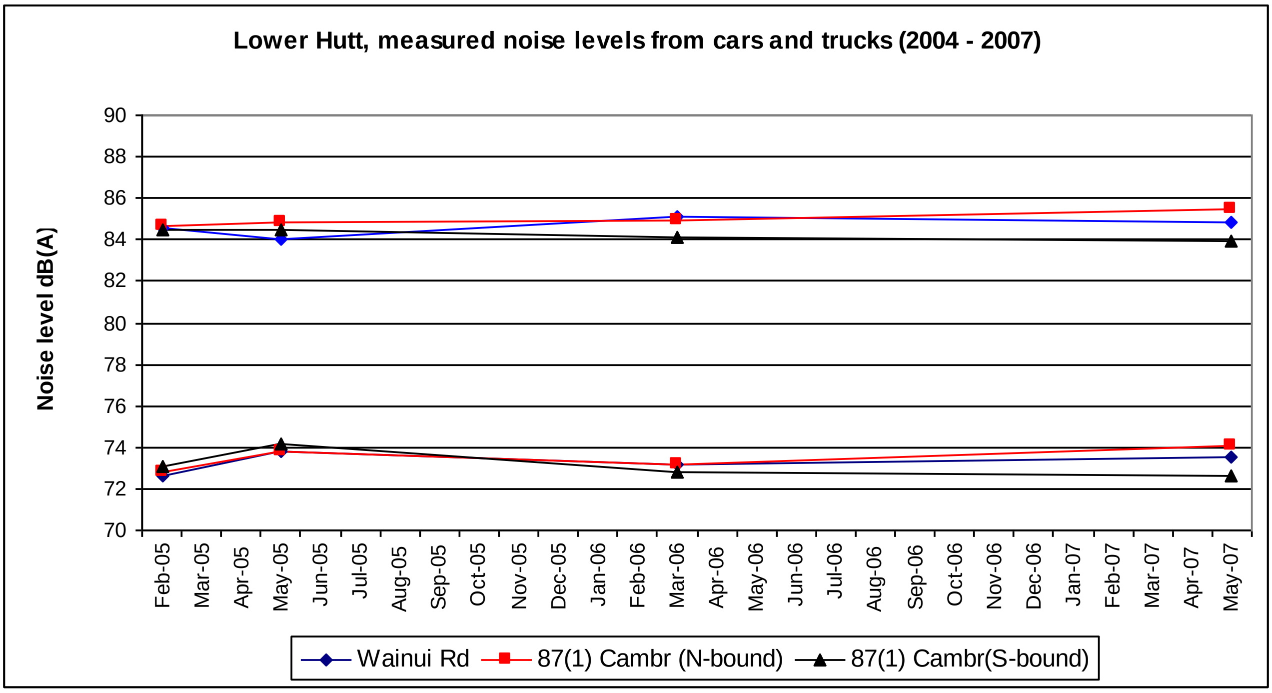
Results of measurements are shown in Table A1. The difference in noise levels measured in 2007 was in the range from 72.6 dB(A) to 74.1 dB(A) for cars and in the range from 83.6 dB(A) to 85.5 dB(A) for heavy trucks. It can be seen on the diagrams in Figure A1 that the variation of noise levels recorded in 2007 increased slightly compare to previous years.

Traffic conditions at all sites were similar with real speed nearly equal to the speed limit of 50 km/h.

Table A1: Lower Hutt urban area, Noise monitoring data 2005 - 2007

Pavement	Noise level dB(A)							
	February 2005		May 2005		March 2006		May 2007	
	cars	trucks	cars	trucks	cars	trucks	cars	trucks
408 Cambridge Terrace	73.6	84.6	74.4	83.9				
Cambridge Terrace (Nthbd)	72.8	84.7	73.8	84.8				
Cambridge Terrace (Sthbd)	73.1	84.5	74.2	84.5				
359 Waiwhetu Road	73.4	84.8	74.5	83.3				
Wainui Road	72.6	84.6	73.8	84.0	73.2	85.1	73.5	84.8
87(1) Cambridge Terrace (Nthbd)					73.2	84.9	74.1	85.5
87(1) Cambridge Terrace (Sthbd)					72.8	84.1	72.6	83.9
Cambridge/Treadwell (Nthbd)					73.2	85.4	73.8	84.7
Cambridge/Treadwell (Sthbd)					72.2	83.7	73.3	83.6

Figure A1: Lower Hutt urban area, measured noise levels from cars (2005 – 2007)



A1.3 Conclusion

It is concluded that over the monitoring period there has not been change in the vehicle fleet noise profile that would have affected the test results.

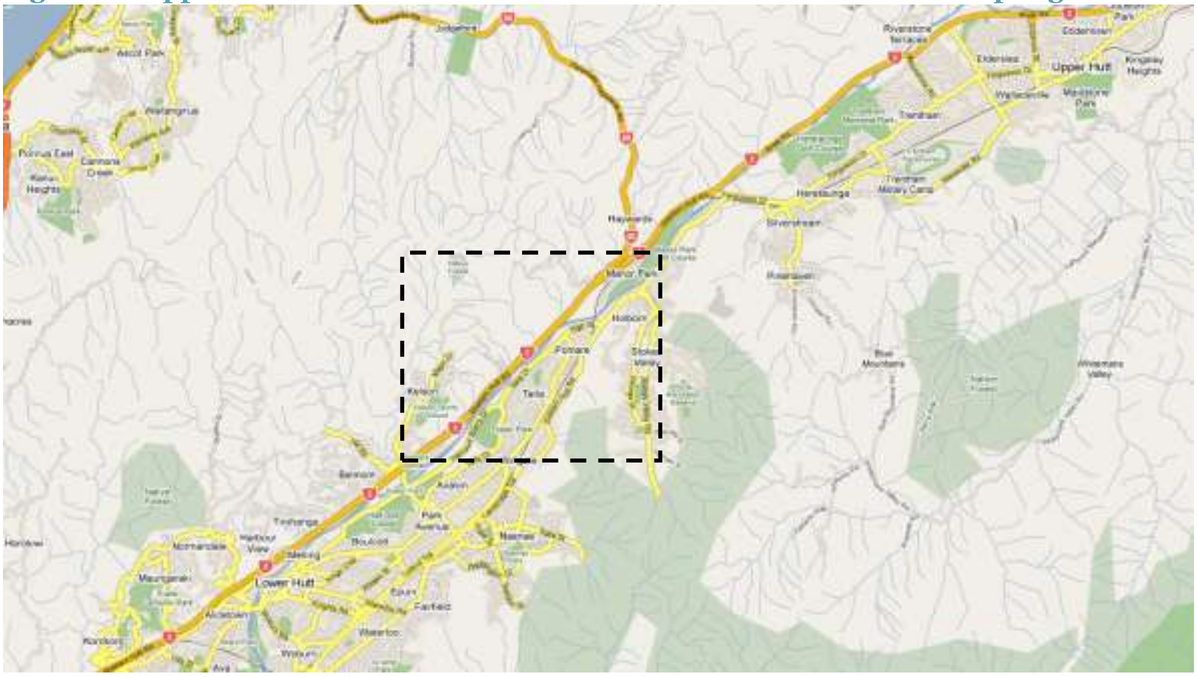
A2. Verification and validation of the noise measurement method

Review of the work of previous years of noise monitoring identified differences between aspects of the noise measurement method used and aspects of the relevant International Standard noise measurement method: ISO 11819-1 Acoustics – Measurement of the influence of road surfaces on traffic noise – Part 1: Statistical Pass-By method[2]. The Low Noise Surfacing Performance Monitoring 2007/2007 project brief included the task to "undertake a comparison of the New Zealand and European noise monitoring test methods".

For this work, noise measurements were undertaken on 25 September 2008 on State Highway 2 near Lower Hutt, northbound just south of State Highway 58, where the speed limit is set at 100 km/h. The approximate location is shown in Figure A2.

[2] ISO 11819-1:1997(E), *Acoustics – Measurement of the Influence of Road Surfaces on Traffic Noise – Part1: Statistical Pass-By Method*

Figure A2 Approximate location for noise measurements to validate sampling



Three aspects of noise measurement were identified for particular attention:

1. Sample size;
2. Determination of vehicle sound level; and
3. Definition of maximum sound level.

A2.1 Sample size

The ISO 11819-1 statistical pass-by method requires that noise measurements be taken from 100 passenger cars "to ensure that random errors do not become unacceptably large". The sample size of 100 was investigated to see the effect of using a sample size smaller than that recommended by the ISO 11819-1 standard.

Figure A3 shows the noise measurements taken from more than one hundred cars. The red line is the average of the noise measurements, calculated in a "running" form from the accumulated number of measurements taken to that point. The size of the 95 percent confidence interval is also shown and this is calculated in a "running" form as for the calculation of the average. Table A2 further describes the confidence intervals, or reliability, of the measurement data.

Figure A3 Noise measurements from an accumulating sample of cars. Shown by the red line is the (running) average calculated from the noise measurements taken and the (running) size of the 95 percent confidence interval

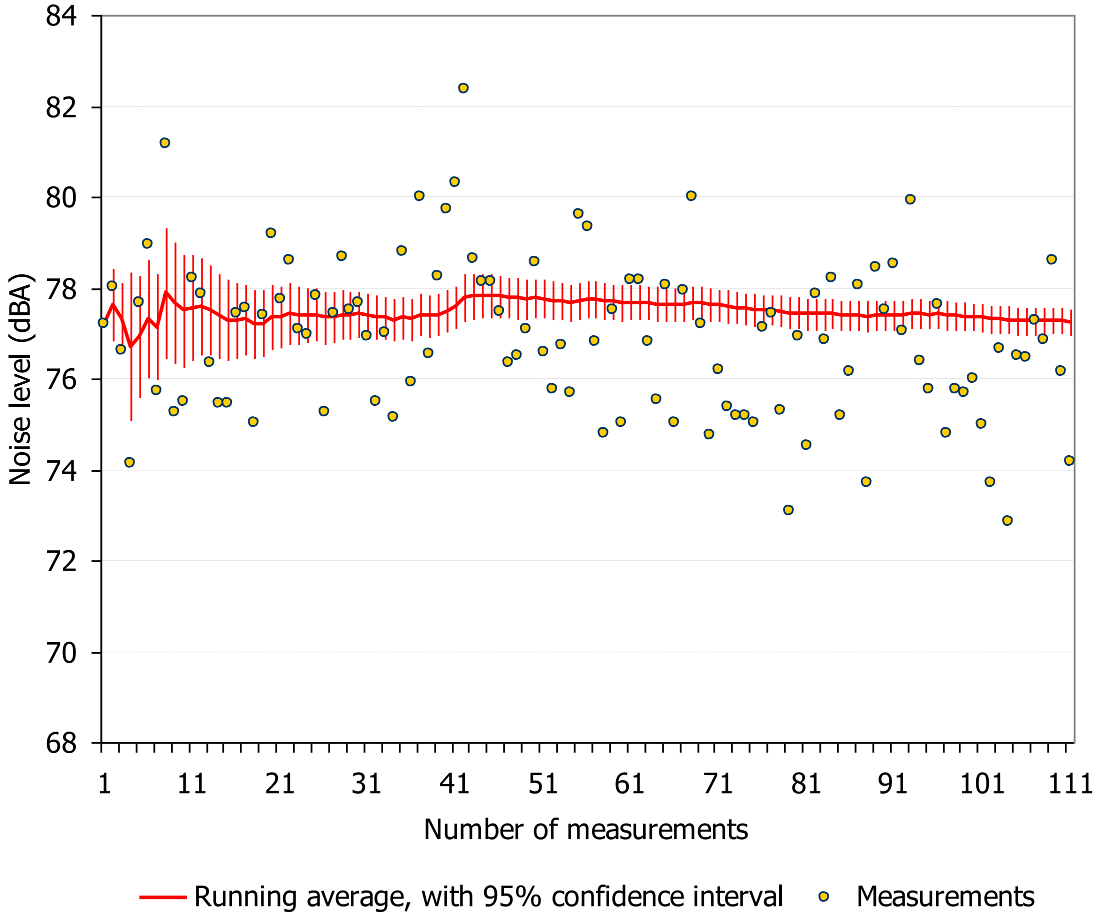


Table A2 Averages and confidence intervals calculated from *n* measurements

Number of measurements, *n*	5	10	15	20	25	40	70	100
Average from *n* measurements (dBA)	76.9	77.5	77.3	77.3	77.4	77.5	77.6	77.4
Size of 95 percent confidence interval (dBA)	1.353	1.271	0.908	0.742	0.609	0.475	0.383	0.325
Confidence interval as percent of running average	1.759	1.640	1.175	0.960	0.786	0.613	0.493	0.420

Inspection of Figure A3 and Table A2 shows the calculated average rapidly stabilises, with a sample size of approximately greater than ten. With only five samples, the 95 percent confidence interval is less than 2 percent of the average noise level; and is less than 1 percent of the average noise level with approximately twenty samples.

The noise measurement methodology of this project uses a sample size of at least twenty vehicles, but usually more than twenty noise measurements are used. With the results presented in Figure and Table A2, it is held that a sample size of twenty measurements is adequate for this project.

The sample size of twenty was checked further by forming five random groups of twenty noise measurements from the complete set of measurements taken on 25 September 2008. The average noise level was calculated from each group of measurements. The results are shown in Table .

Table A3 Comparison of average noise measurement from 100 measurements against the average noise measurement from twenty measurements randomly selected from the complete set of 100 measurements

Sample	Full set	Group 1	Group 2	Group 3	Group 4	Group 5
n	100	20	20	20	20	20
Average from *n* measurements (dBA)	77.4	77.7	77.1	77.1	77.1	77.3
Standard deviation from *n* measurements (dBA)	1.7	1.6	1.8	2.0	1.4	1.8
Size of 95 percent confidence interval (dBA)	0.325	0.690	0.787	0.896	0.600	0.770
Confidence interval as percent of average	0.420	0.888	1.021	1.161	0.778	0.997

The information of Table is compared with the ISO 11819-1 table of "Expected random errors in A-weighted sound pressure level (rounded to one decimal)":

Vehicle class	Standard deviation for individual vehicles around $L_{veh}I$	95% confidence interval around L_{veh}
Cars	1.5 dB	0.3 dB

Note the confidence intervals around the Vehicle Sound Levels assume the number of vehicles is 100 cars.

Generally, the standard deviations and confidence intervals calculated from each of the groups of 20 sampled measurements do not meet the expectations of the ISO 11819-1. Interestingly, the standard deviation and confidence interval calculated from the full set of 100 measurements also do not meet the expectations.

It is considered relevant that the ISO 11819-1 does note issues arising from the balancing of reasonable sample size and reasonable measurement duration. As examples:

> *Clause 6.1c Selection of measuring site: [...] The number of vehicles judged to be moving at constant speed shall be sufficient in order to allow a reasonable total measuring time.*

> *Clause 7.3 Minimum number of vehicles: [...] The minimum numbers are due to requirements on precision balanced against the time needed to measure the desired number of vehicle in the actual traffic.*

A2.2 Vehicle sound level

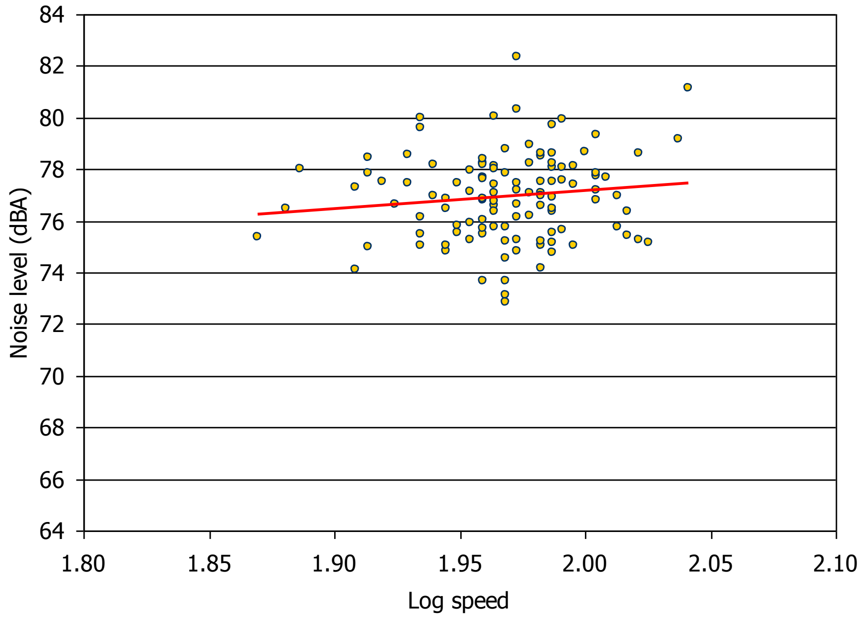
ISO 11819-1 reports its measurement results in terms of the Vehicle Sound Level, Lveh. For each of three vehicle types, each individual vehicle's maximum A-weighted pass-by sound pressure level is recorded together with the vehicle's pass-by speed. The logarithm of vehicle speed versus the vehicle pass-by noise level is plotted, and a regression line is calculated. From this line, the noise level is determined at one of three reference speeds, and this level is called the Vehicle Sound Level.

The relationship between the Vehicle Sound Level results according to ISO 11819-1 and the noise level results obtained through the methodology of this project (being also the methodology of previous years of noise monitoring) was inspected.

Figure A4 shows the plot prescribed by the ISO 11819-1 methodology, with a regression line shown. Using the regression line, and the ISO 11819-1 reference speeds of 80 km/h (for the medium road speed category) and 110 km/h (for the high road speed category), the Vehicle Sound Level is 76.5 and 77.4, respectively. Note that the average speed of vehicles sampled was 93 km/h.

The methodology of this project calculates and reports the noise level as an average of the measurements taken. Thus, from the same set of measurements, this project would report the average as 77.4 (as shown in Table).

Figure A4: Establishing Vehicle Sound Level through ISO 11819-1



A2.3 Maximum sound level

Both the methodology of ISO 11819-1 and the methodology of this project's monitoring record the "maximum sound level" of the vehicle's pass-by.

The methodology of this project finds the maximum sound level by recording the sound of the vehicle's pass-by, with a sampling rate of 16000 Hz, and selecting a continuous one second interval from that full record, so that the time-averaged sound level over the one second interval is the greatest L_{eq}(1 second) noise level from the vehicle's pass-by.

Clause 3.5 of ISO 11819-1 defines the maximum sound level as the:

> *Highest sound pressure level recorded by the measuring instrument during a vehicle pass-by, using the appropriate frequency weighting and time weighting F, for vehicles which are acoustically identifiable, i.e. are not significantly disturbed by other vehicles.*

ISO 11819-1 appears to provide little further guidance on the duration of measurement for the maximum sound level. The L_{max} (highest sound level occurring during an event) is not referred to within the standard.

The *Tyre/Road Noise Reference Book* states that:

> *The common and traditional measure for individual vehicle or tyre/road noise characterisation is the maximum sound pressure level occurring during a vehicle pass-by.*[3]
>
> *[...] For a transient sound such as the time history of a pass-by, it is more practical to normalise the [equivalent sound level] to 1 s.*[4]
>
> *[...] Another issue of relevance here is the measurement of the noise characteristics of road surfaces of a porous nature. It is well known that when sound propagates over a porous road surface, it is attenuated more and that this increased attenuation increases with the propagation distance. This means that sound from an approaching and departing vehicle is more attenuated than when the vehicle is opposite the microphone. In the former cases sound has propagated over a longer distance of porous surface. This should have the effect that noise reduction for a porous surface in relation to a dense surface is underestimated when one measures [the maximum sound level] since in this case sound has propagated a minimum distance over the surface.*[5]
>
> *[...] Consequently, measurements during a vehicle pass-by or coast-by are somewhat more accurate and representative when using [the equivalent sound level] instead of [the maximum sound level].*[6]

A2.4 Conclusion

For this project, it is concluded it is appropriate to define the noise level using the greatest L_{eq}(1 second). While larger sample sizes will always bring greater consistency and confidence, a sample size of at least twenty (and usually more) is sufficient to identify trends.

Further, it is proposed that in the definition, measurement, and calculation of the maximum sound level, consistency is the most significant aspect for this project.

A3. Test precision

The 2006 data was statistically analysed to determine the precision and expected "error" in the test results. Table A5 summarises the results.

3 Sandberg, U., and Ejsmont, J. (2002) *Tyre/road Noise Reference Book*. Informex, Sweden. Page 327.
4 Ibid. Page 327.
5 Ibid. Page 328.
6 Ibid. Page 328.

Table A5: Summary of 2006 test results

			Cars			Trucks		
Region	File	Surface	no	dB	s.d.	no	dB	s.d.
Auckland	OGPA-Whispa 2.5m	OGPA	22	78.96	1.06	11	89.58	1.76
Auckland	OGPA-Wispa 2.5m	Wispa	22	77.68	1.18	11	87.93	1.90
Auckland	W-W Site 1 RP 389-1.4	Wispa 1	20	77.47	1.23	12	86.21	2.56
Auckland	W-W Site 1 RP 389- 1.4	Wispa 2	20	77.52	1.30	12	86.09	2.54
Auckland	W-W Site 2 RP 398-2.0	Wispa 1	22	76.03	0.96	11	87.29	3.09
Auckland	W-W Site 2 RP 398-2.0	Wispa 2	22	76.29	1.22	11	87.41	3.08
Dunedin	Conv 30 mm OGPA-UTA	OGPA	19	77.30	0.91	8	89.80	0.50
Dunedin	Conv 30 mm OGPA-UTA	UTA	19	80.66	1.17	8	88.37	0.56
Dunedin	Dual Layer OGPA-Macadam	OGPA	20	74.65	1.36	11	89.47	1.79
Dunedin	Dual Layer OGPA-Macadam	Macadam	20	81.15	1.35	11	86.38	2.01
Dunedin	High strength OGPA-Wispa	HS OGPA	20	77.88	1.47	11	90.12	1.43
Dunedin	High strength OGPA-Wispa	Wispa	20	75.65	1.36	11	88.60	1.39
Dunedin	Conventional OGPA-Macadam	Conv. OGPA	17	80.29	1.06	11	90.10	2.80
Dunedin	Conventional OGPA-Macadam	Macadam	17	82.26	1.33	11	91.65	2.42
Dunedin	PMB OGPA-Dual OGPA	Dual OGPA	20	77.51	1.29	11	89.28	1.67
Dunedin	PMB OGPA-Dual OGPA	PMB OGPA	20	76.43	1.24	11	88.60	1.61
Dunedin	Wispa-PMB OGPA	Wispa	21	77.12	0.88	10	88.33	1.55
Dunedin	Wispa-PMB OGPA	PMB OGPA	21	78.04	0.98	10	89.70	1.18
L/Hutt	North Cambridge-Treadwell	AC-10	20	73.18	1.15	10	85.39	0.96
L/Hutt	South Cambridge-Treadwell	AC-10	21	72.27	1.36	11	83.74	2.06
L/Hutt	North 87(1) Cambridge	PMB OGPA	20	73.25	1.39	10	84.89	2.16
L/Hutt	South 87(1) Cambridge	AC-10	21	72.77	1.59	10	84.12	1.96
L/Hutt	Wainuiomata Road	AC-10	17	73.17	1.64	10	85.10	2.83
Porirua	SH 1 increasing lane	Tech	20	76.13	0.91	12	87.76	2.00
Porirua	SH 1 increasing lane	High PSV	20	77.21	0.88	12	88.13	1.83
Porirua	TNZ P11-Higgins	Higgins	22	75.78	1.60	11	88.14	1.81
Porirua	TNZ P11-Higgins	TNZ P11	22	78.21	1.13	11	89.11	1.78
U/Hutt	SH 1 2.5 m	-	7	77.69	1.11	11	86.10	1.59
	AVERAGE				1.22			1.89

This statistical relationship used to make an estimate of 95% confidence limits of the mean of a number of measurements the following relationship is used.

95% confidence limits = ± 1.96 s/√n*

Where:

S = standard deviation of the sample

N = number of test results

From Table 12 the average standard deviation of approximately 20 results is 1.22. Therefore the 95%confidence limits are:

$$\pm 1.96 * 1.22/\sqrt{20} = 0.53$$

For trucks where approximately 10 reading are taken and the standard deviation is 1.89 the corresponding precision is ±1.17.

The above analysis helps explain some of the variation in the year to year results. The precision of the method is however sufficient to distinguish the very real differences between surfaces.

A4. Effect of rain

In the year 2007 extra noise measurements were undertaken at Porirua sites to determine effects of rain on traffic noise levels. On the first stage noise measurements were carried out after a prolonged period of dry weather (12 – 14 days). Further noise measurements were undertaken after heavy rain over the period of three days from 13th of March to 15th of March with clean intervals of 12 – 15 hours. The last set of noise measurements was carried out on 16th of March 2007, about 25 hours after last rain event. Intervals of dry weather and rainfalls are shown in Table A6.

Noise measurements after rain event took place for the period from 2.00pm to 4.00pm. Rainfall for previous 3 days was about 26 mm.

Table A6: Weather characteristics and rainfall (mm) over period of measurements

Date	Rainfall			Noise measured
	start	finish	(mm)	
14 February				1.00 – 3.30 pm
13 March	09:00	23:00	10	
14 March	02:00	08:00	6	
14 March	17:00	24:00	9	
15 March	00:00	01:00	1	14:00 – 16:00
16 March				14:00 – 16:00

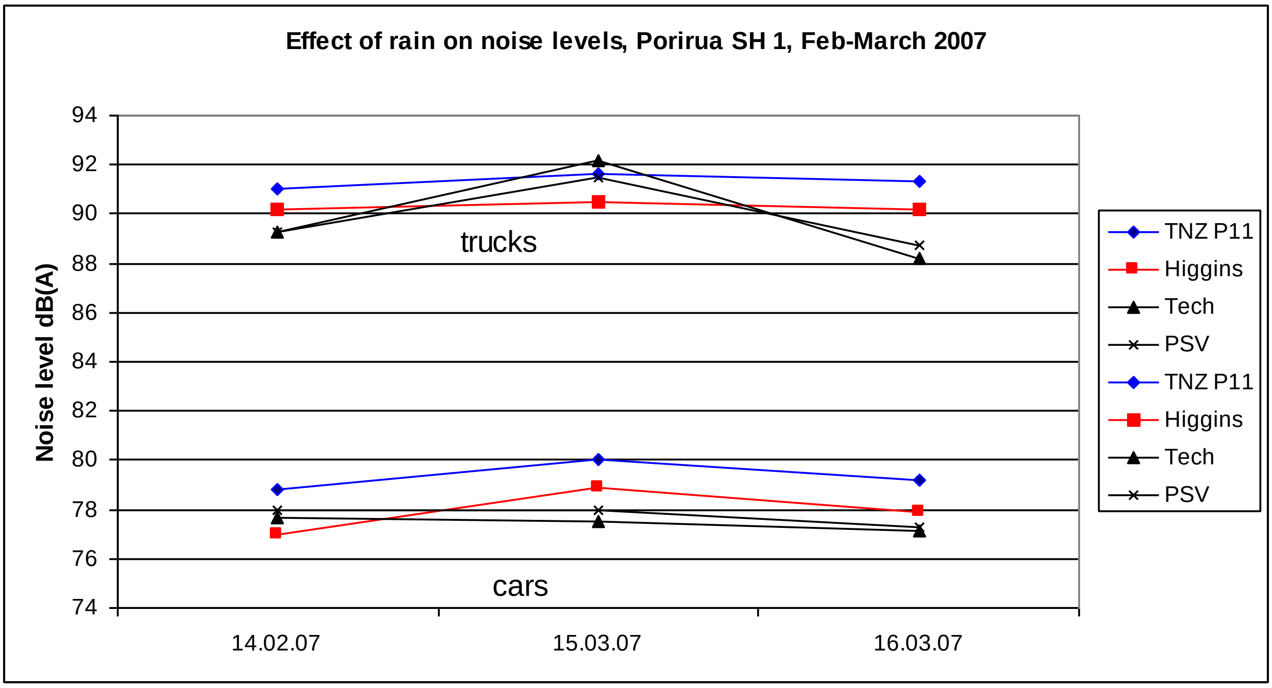
Measured noise levels after prolonged period of dry weather and after rain events are shown in Table A7 and on the diagram in Figure A5. Measurements show that noise levels from cars and trucks increased after rain events for TNZ P/11, Higgins and High PSV pavements, for Technics noise levels increased for trucks only. The increased noise levels were in the range from 0.5 d(A) to maximum of 2.9 dB(A) from trucks travelling over Technics. Changes of noise levels from cars travelling over Technics were insignificant for dry and wet weather conditions.

Table A7: Porirua SH 1 March 2007 noise monitoring data

Date	Noise level dB(A)							
	TNZ P/11 (laid 2/99)		Higgins Flexiphalt 150 A (laid 4/99)		Technics (laid 4/99)		TNZ p/11 (High PVS) (laid 4/99)	
	cars	trucks	Cars	trucks	cars	trucks	cars	trucks
14.02.07 dry	78.8	91.0	77.0	90.2	77.7	89.3	78.0	89.3
15.03.07	80.0	91.6	78.9	90.7	77.5	92.2	78.0	91.5
16.03.07	79.2	91.3	77.9	90.2	77.1	88.2	77.3	88.7

The diagrams in Figure 1 show clearly increased traffic noise levels measured in15 hours interval after three days of rain weather resulted in 26 mm of rainfall.

Figure A5: Effect of rain on traffic noise levels



A5. Microphone position for effect of aerodynamic noise

Aerodynamic noise effect for heavy articulated trucks has been assessed using the following methodology.

Noise levels from pass-by trucks and four-wheel drive cars were measured at the distance of 2.5 and 5.0 m from the edge of traffic line. The average speed of traffic flow was from 90 km/h to 100 km/h. It is expected that aerodynamic effect of heavy trucks, if occurs could be noticeable at the distance of 2.5 m and negligible at the distance of 5.0 m. Meanwhile this effect is negligible for four-wheel drive cars at the both distance, because of modern aerodynamic design of these cars.

Results of measurements in Table A8 show that the deference in noise levels from cars at the distance of 2.5 m and 5.0 m was 3.0 dBA, and it was equal to the deference in noise levels from heavy trucks. It is obvious, that in the case of aerodynamic noise effect from heavy trucks the difference should not be equal.

The conclusion made is that aerodynamic noise around heavy articulated trucks does not affect pass-by noise measurements performed at the distance of 2.5 m from the edge of traffic line.

Table A8: Comparison of noise levels at the distance 2.5 and 5.0 m

Heavy trucks				4 wheel drives			
Vehicle type	Noise levels dB(A)		Difference dB(A)	Vehicle	Noise levels dB(A)		Difference dB(A)
	2.5 m	5.0 m			2.5 m	5.0 m	
Art. 7 axels	85.5	82.6	2.9	3.0 L	80.5	77.7	2.8
3 ax.	85.5	82.7	2.8	3.0 L	79.4	76.2	3.2
Art. 7ax.	86.5	83.2	3.3		78.0	74.9	3.1
4 ax.	86.6	83.7	2.9		81.2	77.7	3.5
5 ax.	87.5	84.2	3.3		78.9	76.0	2.9
Tanker 6ax.	87.5	84.6	3.1		78.4	75.2	3.2
Art. 6 ax.	84.3	81.3	3.0		79.4	76.4	3.0
Art .6 ax.	88.9	86.1	2.7		77.1	74.6	2.5
5 ax.	83.1	80.4	2.7		80.8	77.6	3.2
6 ax.	85.3	82.2	3.1		77.5	74.5	3.0
Art. 6ax.	86.5	83.5	2.9				
Average	**86.4**	**83.4**	**3.0**		**79.3**	**76.3**	**3.0**

A6. Lower Hutt photographs

Lower Hutt, Cambridge Terrace asphaltic concrete

Lower Hutt, Wainui Road asphaltic concrete (note cracking)

Lower Hutt, Waiwhetu Road asphaltic concrete

Lower Hutt, Waterloo Road asphaltic concrete

A7. Porirua site photographs

Porirua site, high PSV section

Porirua site, Technics section

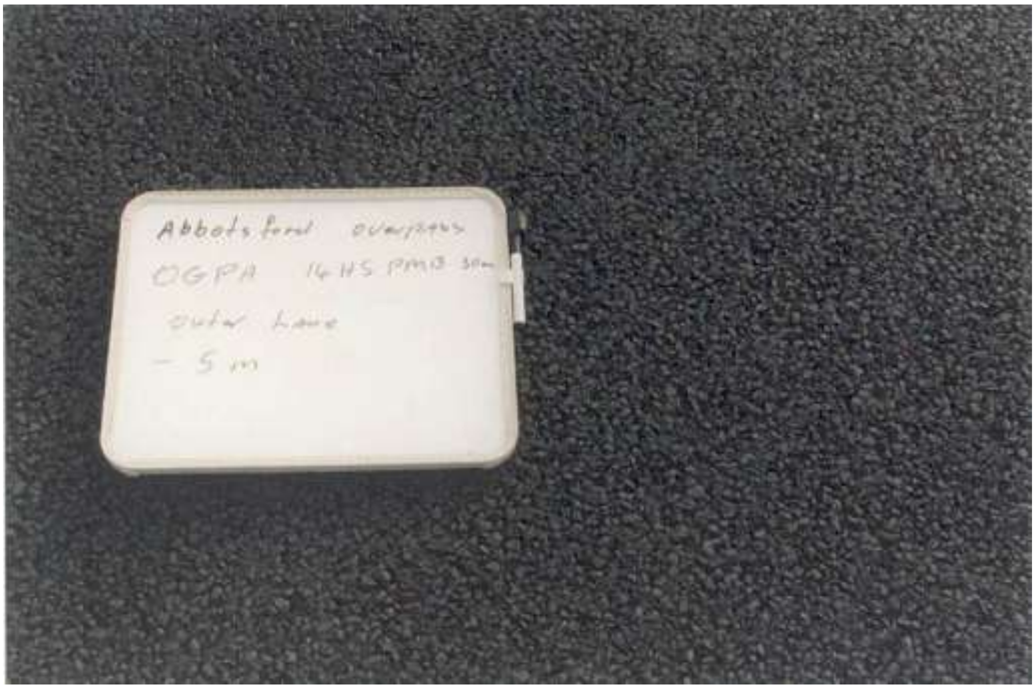
Porirua site, Higgins section

Porirua Higgins – Technics Distress

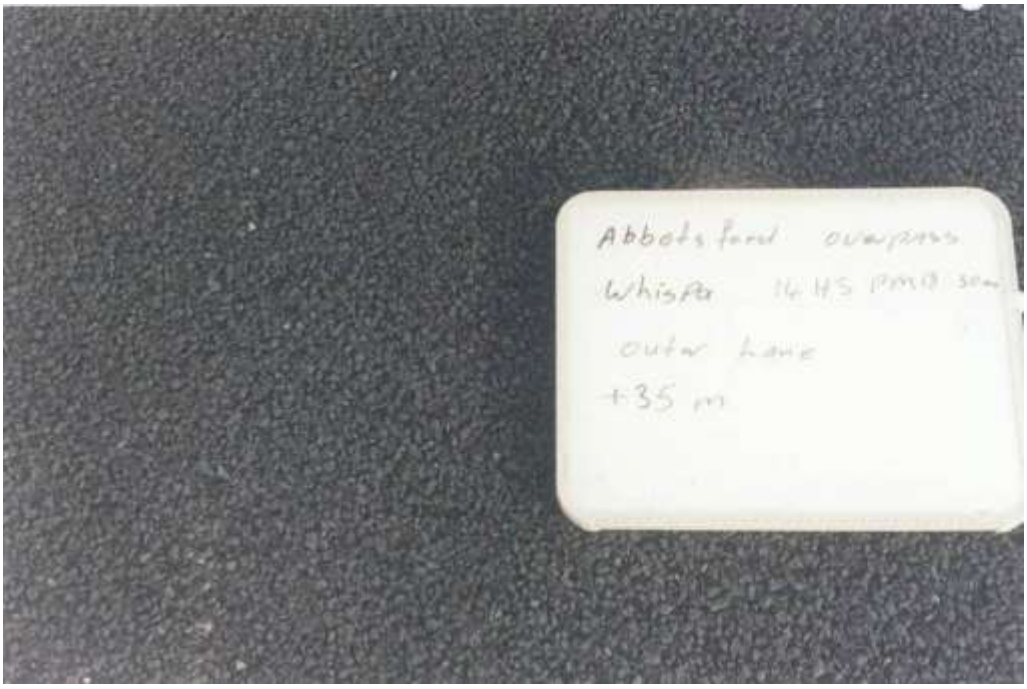
Porirua site, Old P11

A8. Dunedin site photographs

Dunedin site, OGPA 14HS PMB 30 mm



Dunedin site, Wispa A (adjacent to OGPA 14HS PMB 30 mm)



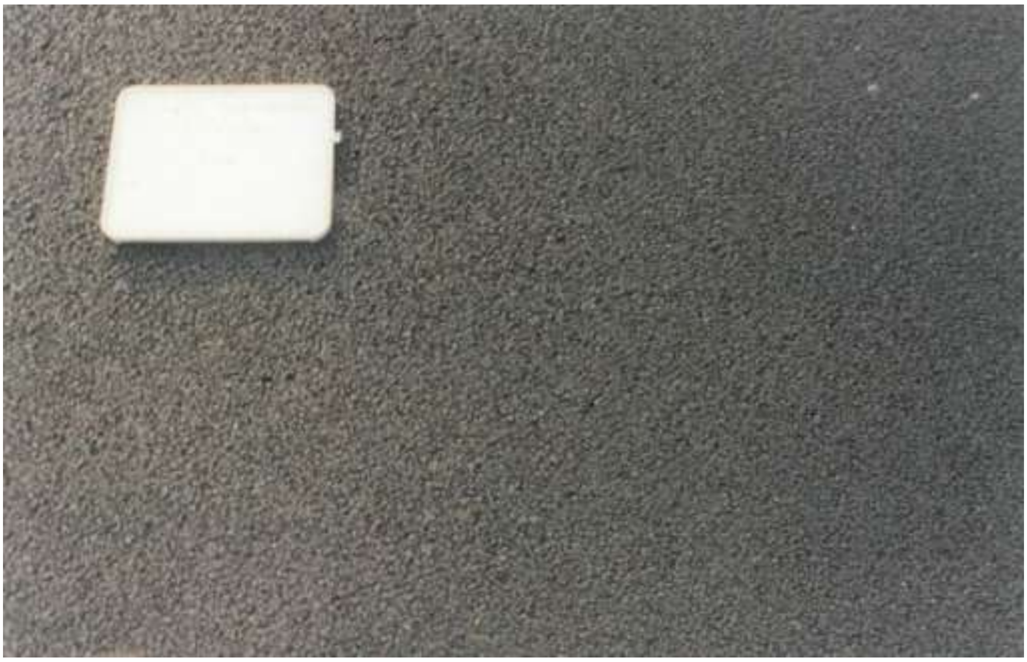
Dunedin site, Wispa (adjacent to OGPA 14 PMB)

Dunedin site, OGPA 14 PMB (adjacent to Wispa A)

Dunedin site. dual layer (adjacent to OGPA 14 PMB)

Dunedin site, Macadam over concrete (adjacent to dual layer)

Dunedin site, OGPA 14 (adjacent to Macadam)



Dunedin site, ultra-thin asphalt Pavetex (adjacent to OGPA 14)

A9. Permeability measurements at the Porirua site

Porirua SH 1 - Permeability tests summary for the year 2004 - 2007 (all times in seconds)

Location	Left wheel path				Between wheel path				Right wheel path			
(Relative to seal)	2004	2005	2006	2007	2004	2005	2006	2007	2004	2005	2006	2007
TNZ P11 Mix	>180	>180	>180	>180	>180	>180	>180	>180	>180	>180	>180	>180
Higgins (20 m South of join)	4.0	4.5	4.0	8.0	6.0	3.6	7.5	15.4	26.0	4.1	3.1	6.6
Higgins (40 m South of join)	6.3	4.1	3.5	15.8	9.9	7.0	8.3	30.8	4.1	4.4	5.6	12.8
Higgins (60 m South of join)	7.3	*patch*	*patch*	*patch*	5.6	6.0	6.7	28.9	4.0	4.4	3.2	16.3
Technics (15 m South of join)	5.3	6.0	8.4	16.5	5.6	5.8	6.9	29.0	5.8	4.4	8.3	19.1
Technics (50 m South of join)	9.0	7.3	17.9	30.9	13.1	13.4	40.3	33.6	8.5	7.7	17.7	28.0
Technics (85 m South of join)	8.7	10.1	10.2	24.0	13.5	9.4	19.0	29.5	7.3	5.5	11.1	17.8
Technics (120m South of join)	6.9	4.5	6.0	11.1	4.7	5.0	7.6	17.3	8.1	6.9	8.5	14.4
High PSV (30 m South of join)	30.6	19.3	25.3	37.8	27.2	33.1	20.4	41.8	46.0	67.6	46.1	54.3
High PSV (60 m South of join)	23.5	14.4	23.3	42.4	96.0	28.5	50.9	98.8	51.3	57.7	22.9	54.1
High PSV (90 m South of join)	24.5	17.4	15.4	49.8	41.1	66.0	35.7	64.0	60.0	28.1	32.5	106.8

[1] More than 3 minutes, hardly any water went through

[2] This site patched over

[3] Severe fatigue crashing 10 m north of this site localised spots and pumping fines

[4] Severe fatigue crashing - localised pumping fines

A10. Permeability measurements at the Dunedin site

Permeability: Dunedin, Fairfield motorway (2004 – 2007)

Surface type	Location	Position	Permeability to Water (seconds)							
			Between Wheel Track				Wheel track closest top edge line (outer line)			
			2004	2005	2006	2007	2004	2005	2006	2007
OGPA 14 HS PMB	Abbotsford Overpass	-45m		>180				>180		
		-35m		>180				60		
		-25m	123	>180	<180	>180	>180	50	<180	>180
		-15m	>180	40	<180	>180	39	20	<180	>180
		-5m	>180		<180	>180	29		136	>180
		+5 m			171	>180			<180	249
		15m	55		<180	>180	29		<180	>180
		25m	34				53			
		Average	114	imprm	imprm	imprm	66	78	imprm	imprm
WHISPA	Abbotsford Overpass	45m		18				15		
		35m		>180				>180		
		25m		5				15		
		-20m	102		75	136	178		29	112
		-10m	16		131	93	13		48	151
		0m	12		171	168	13		36	59
		10m	9		132	>180	17		118	85
		15m		7				13		
		20m	15	18	<180	>180	9		142	100
		Average	31	46	127	151	46	56	75	101
WISPA	Abbots Creek Bridge	-20m	14		83	86	13		153	83
		-15m		20				18		
		-10m	16		111	118	8		68	88
		-5m		18				22		
		0m	10	19	73	130	12	20	27	85
		5m		10				11		
		10m	11		57	58	12		38	105
		15m		18				18		
		20m	11		125	150	17		171	81
		Average	12	17	90	108	12	18	91	88
OGPA 14 PMB	Abbots Creek Bridge	-20m	13		59	24	13		110	102
		-15m		8				7		
		-5m		7				13		
		-10m	6		27	27	8		41	30
		0m	8	9	18	41	12	18	25	22
		5m		10				17		
		10m	7		6	64	12		6	22
		15m		8				7		
		20m	7		6	50	17		15	95
		Average	8	8	23	41	12	12	39	54

Surface type	Location	Position	Permeability to Water (seconds)							
			Between Wheel Track				Wheel track closest top edge line (outer line)			
			2004	2005	2006	2007	2004	2005	2006	2007
OGPA 14 PMB	Adjacent Dual Layer	-20m	6	9	8	35	10	14	5	19
		-10m	8	12	7	19	7	17	7	23
		0m	8	6	7	15	7	7	8	20
		5m		10				14		
		10m	6	10	7	29	5	16	5	24
		20m	6		9	23	6		8	12
		Average	7	9	8	24	7	14	7	20
Dual Layer	Adjacent OGPA	-20m	8	28	8	75	17	106	6	156
		-10m	21	39	12	85	49	145	9	87
		0m	12	12	8	29	12	15	7	27
		10m	9	11	11	20	11	15	11	23
		20m	4	13	8	39	12	21	9	45
		Average	11	21	9	50	20	60	8	68
Dual Layer	Adjacent Macadam	20m	4	8	12	14	8	9	7	17
		-10m	6	11	12	12	10	16	13	26
		0m	7	12	7	13	6	14	9	20
		10m	4	12	18	14	4	14	8	10
		20m	10	10	12	16	8	8	10	18
		Average	6	11	12	14	7	12	9	18
OGPA Conventional 30mm	Adjacent Macadam	-20m	63		<180	>180	>180		<180	>180
		-15m		135				>180		
		-10m	170		<180	>180	163		100	>180
		-5m		137				>180		
		0m	74	>180	38	>180	71	110	38	>180
		10m	23	115	83	>180	76	>180	111	166
		20m	41	30	64	121	32	137	45	>180
		Average	74	119	109	imprm.	104	157	95	imprm.
OGPA Conventional 30mm	Adjacent UTA Pavetex	-20m	97	120	<180	178	35	18	23	114
		-10m	177	>180	<180	133	23	103	32	123
		0m	>180	40	67	>180	22	30	12	>180
		10m	28	20	42	>180	24	12	7	107
		20m	26	69	47	137	8	29	28	103
		Average	102	86	103	162	22	38	20	125

1. Position is relative to the microphone position for noise measurement
2. High reading at some -20 metre positions may be caused by proximity to pavement join
3. Permeability on Macadam and UTA not measured as they are not permeable surfaces

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