Lessons to be learned from 15-year-old second-coat seals and reseals

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Abbreviations, acronyms and definitions

AADT	average annual daily traffic
ADT	average daily traffic
ALD	average least dimension
CRS-2P	cationic rapid set bituminous emulsion having a higher viscosity and containing some polymer
d0	pavement deflection (in microns) immediately below the FWD weight
ELV	equivalent light vehicle
first-coat seal	initial seal on a prepared unsealed surface, which is usually a basecourse
FWD	falling weight deflectometer
long-life	aged 15 years or older
LTPP	long-term pavement performance
NOC	network outcome contract (a maintenance contract)
RAMM	road asset maintenance and management system
SANRAL	South African National Road Agency Ltd
second-coat seal	previously the term given to a seal placed on top of a primed or first-coat sealed surface before subsequent reseals – the term is becoming obsolete as second-coat seals are now considered as reseals
SCRIM	sideways force coefficient routine investigation machine
TMH	technical methods for highways
Transport Agency	New Zealand Transport Agency
vpd	vehicles per day

Contents

Executive summary 6
Abstract 8
1 Introduction 9
2 Literature review 10
2.1 Introduction 10
2.2 Chip sizes 10
2.3 North America 11
2.4 South Africa 12
2.5 Australia 13
2.6 New Zealand 15
2.7 Conclusions from the literature 20
3 Review of the RAMM database 22
3.1 Site inspections 22
3.2 Confirmation of RAMM seal age using skid data 25
3.3 Seal design and workmanship 27
3.4 Treatment type 27
3.5 Prime coats 28
3.6 Chip size 28
3.7 Binder type 29
3.7.1 Single-coat seals 29
3.7.2 Binder in two-coat seals 30
3.8 Distribution of bitumen penetration grades throughout NZ 31
3.9 ADT 36
3.10 Site category for skid resistance 36
3.11 Timing of seal construction 38
3.12 Timing between first- and second-coat seals 39
3.13 Pavement strength 42
4 Geospatial comparisons 43
5 Discussion 49
5.1 International 49
5.2 Primes 49
5.3 Chip size and treatment selection 49
5.4 Binder type 50
5.5 Traffic 50
5.6 Climate 50
5.7 Timing 50
5.8 Pavement strength 50
5.9 Summary 50
6 Conclusions 52
7 Recommendations 52
8 References 53
Appendix A: 56

Executive summary

The purpose of this research was to isolate and identify the reasons why some reseals have very long lives, and to identify which of these factors could economically be applied to reseals in future contracts, thus leading to a reduction in the whole-of-life costs of chipsealing and pavement maintenance.

When investigating seal lives, the definition of failure becomes important. Unfortunately there appears to be no clarity or consistency of this within the literature. The most pragmatic approach has been that the life of the seal is equal to the age of the seal at time of reseal or renewal. This then relates to the maintenance strategies of various jurisdictions, and the triggers adopted to instigate a reseal.

A literature review of chipseals in South Africa, Australia and New Zealand found the longest life seals had the largest chip size and lower traffic.

Attention to detail at the time of construction was also been found to be important.

This study of the New Zealand road asset maintenance management database, verified by actual site inspections, found the importance of chip size and traffic still valid. A possible explanation for this is the larger size chipseals require a larger bitumen application rate which in turn leads to a larger bitumen film thickness. As bitumen ages through surface effects such as oxidation (exposure to air) and ultra violet radiation (sunlight), the deeper the film thickness the more of the bitumen remains un-aged, and thus the longer bitumen can last. Leaking seals also allow water to build up and strip the base of a seal, leading to flushing.

The research described in this report supports other recent New Zealand research that has found single seals are significantly over represented and two-coat seals significantly under represented for long-life seals, compared with the national average. The data suggests single seals were not performing longer than two-coat seals 25 to 30 years ago in New Zealand.

Forty-seven percent of all single seals and 35% of all two-coat seals in New Zealand use penetration grade 180/200 bitumen, which is a soft grade. However, the representation of this binder in aged seals is much higher than for the national average, being 62% for single seals and 58% in two-coat seals. Although it would be easy to say softer binders give longer lives and indeed softer binders are predominant in long-life seals, the survival of 80/100 bitumen in long-life seals is also above the national average. A conclusion on binder use, however, is made less certain because of the policies and guidelines that were in existence 15 to 20 years ago, as detailed in this report. In practice, long-life seals have been found to contain a range of binders.

The literature review found it is common for a long-life seal to be under the lower traffic loadings, which was confirmed by the research.

Comparing the spatial distribution of long-life seals with various climatic factors was also of interest. It could have been expected that low air and pavement temperature, low rainfall and low sunshine hours would favour long-life seals, as bitumen aging is minimised in these conditions. The data suggests, however, that long-life seals can be found equally in high or low pavement temperatures, in wider as much as in narrower temperature extremes, in high and low rainfall areas, and in high or low sunshine hours.

The research found long seal lives relate to a specific treatment selection (single coat) on a sound well-drained pavement with traffic less than 2,000 average daily traffic (ADT). To replicate this requires good quality pavement construction, good quality workmanship in seal construction and low traffic volumes.

To obtain longer lives in future work, repeating good quality pavement construction and good quality workmanship in seal construction remains vitally important. However, to extend long life to traffic volumes greater than 2,000 ADT will require more than repeating the best practices from the past, and possibly a quantum change in practices. This is of particular importance if traffic volumes are to continue to grow resulting in more and more roads carrying volumes greater than 2,000 ADT, and/or the percentage of heavy commercial vehicles grows.

The report recommends:

1. A pre-requisite for a long-life seal is a good quality pavement. The NZ Transport Agency has implemented a 'Quality right, no defects' project, and the momentum gained from this project should be maintained. Specific expectations for quality management on site should be applied to the sealing operations as well as pavement construction.
2. Continuing to undertake sealing during the months of November to March.
3. Encouraging the use of grade 2, 3 and 4 single seals.
4. Continuing research into what is necessary to extend long-life seals beyond the 2,000 ADT range.

Abstract

The purpose of this research was to isolate and identify the reasons why some reseals have very long lives, and to identify which of these factors could economically be applied to reseals in future contracts, thus leading to a reduction in whole-of-life costs of chipsealing and pavement maintenance.

The life of a seal can be influenced by the seal design, quality of workmanship at time of construction, and material properties such as bitumen, aggregate and the pavement.

This study of the New Zealand road asset maintenance management database has found a long-life seal is most likely to be:

- a single-coat seal
- a large chip size
- a 180/200 pen bitumen
- under less than 2,000 ADT
- on a good quality, strong, durable, well-drained pavement
- in a lower skid resistance demand category.

The aggregate mosaic is also usually flat and tightly packed, suggesting good quality of workmanship at the time of laying.

It was interesting to find long-life seals can be applied in any temperature extreme, in any rainfall category and in any degree of sunshine hours.

1 Introduction

Land transport represents a large part of the New Zealand Government's balance sheet, with an annual expenditure of over $3 billion. The *Government policy statement on land transport 2015/16 – 2024/25* (Ministry of Transport 2014) has value for money within its top three strategic directions. All funds available need to be used in a way that delivers best possible value to New Zealand. The primary long-term goal is the delivery of the right infrastructure and services to the right level, and to improve the returns from road maintenance.

New Zealand has a combined state highway and local road sealed length of some 62,000 centreline kilometres (NZ Transport Agency 2010). Of these sealed roads, an analysis of the road asset maintenance database (RAMM) shows the proportion of state highway sealed with chipseals has remained steady over the last seven years at 86%, with 14% sealed with dense grade asphalt or open grade asphalt (bituminous mixes). This proportion is likely to be very similar for local roads, also. Chipseals clearly comprise the backbone of the New Zealand sealed road network.

There are a number of 15-year-old second-coat seals and reseals in the various regions of New Zealand. There is an opportunity to improve value for money in the procurement of road maintenance if even more seals and reseals and renewals could be engineered to have such extended lives.

The purpose of this research was to isolate and identify the reasons why some reseals have very long lives, and to identify which of these factors could economically be applied to reseals in future contracts, thus leading to a reduction in whole-of-life costs of chipsealing and pavement maintenance.

2 Literature review

2.1 Introduction

A wide range of factors can influence chipseal performance and chipseal life. These include (SANRAL 2007, Shuler et al 2011; Testa and Hossain 2014):

- construction technique
- condition of contractor’s equipment
- skill and knowledge of contractor’s employees
- knowledge and training of inspection personnel
- condition of existing pavement
- binder and aggregate properties
- binder and aggregate application rates
- uniformity of application
- adhesion between the chipseal and the existing pavement
- aggregate interlock
- strength of the underlying base or condition of underlying pavement
- amount and type of traffic
- environmental and drainage conditions
- road geometry
- maintenance
- physical and social environment.

This literature review commences with some of the international experience before focusing on New Zealand.

2.2 Chip sizes

New Zealand uses ‘grades’ of aggregate specified by a mixture of either average least dimensions (ALD) or sieve gradings. The following conversion (table2.1) has been derived from information found in Standards Australia (2009) and Transit NZ et al (2005).

Table 2.1 Australian and New Zealand aggregate size conversion

New Zealand		Australia		
ALD (mm)	**New Zealand grade**	**Australian nominal size**	**ALD (mm)**	**Sieve grading (mm)**
9.5–12.0	2	16	Min. 8	-16.0, +9.5
7.5–10.0	3	14	Min. 7	-13.2, +9.5
5.5–8.0	4	10	Min. 5	-9.5, +6.7
Grading spec	5	7	Min 3.5	-6.7, +3.35
Grading spec	6	5	-	-4.75, +2.36

Note also there is some overlap in the New Zealand system, allowing a large grade 3 aggregate to be a small grade 2, or a small grade 2 to be a large grade 3.

2.3 North America

Chipsealing has been practised in North America for some time, with McLeod presenting a chipseal design method in 1969 (McLeod 1969). It is believed most chipseals in North America are applied using emulsified bitumen (CRS-2P is predominant) and very few with hot cutback bitumen (Pierce and Kebede 2015).

An analysis of chipseal lives in Kansas has shown the average service life of chipseals there is about four years with a maximum service life of nine years (Liu et al 2010).

In Ohio the weighted average service life of chipseals was found to be four years (Rajagopal 2010).

In Washington State, a chipseal is expected to last six to eight years if placed on a road surface with no or very limited distress (Mahoney et al 2014).

A wide-ranging study was undertaken (Liu and Gharaibeh 2013) using data extracted from the US long-term pavement performance (LTPP) database, and covering 40 states and eight Canadian provinces. To account for the effect of climate on treatment performance, separate failure curves were developed for four climatic zones: dry freeze; dry non-freeze; wet freeze; and wet non-freeze. The database included both failed and surviving treatments, with end of life defined as being the age at time of resurfacing. Because the database included treatments that had not yet failed, descriptive statistics such as mean and standard deviations were not useful in determining end of life and a survival curve analysis was undertaken. The median life expectancy was found to be 3.5 to 10 years for chipseals, depending on which climatic zone the treatment was located in.

A further survey of US agency practices and performance measures was conducted on chipseal pavements (Pierce and Kebede 2015). The agency survey was sent to the pavement management engineer at each US State Highway Agency and Canadian Provincial Government. These are actual reported lives, implying the 'end of life' definition is that it needed a reseal.

The results are summarised in table 2.2.

Table 2.2 Chipseal performance lives in USA and Canada (Pierce and Kebede 2015)

		Chipseal performance life (years)			
		Minimum	**Maximum**	**Mean**	**Std dev**
Interstate	Over new constructions	6	7	6.7	0.6
	Over existing	5	7	6.6	1.0
Urban arterial	Over new constructions	3	7	5.6	1.7
	Over existing	5	7	6.0	1.0
Rural arterial	Over new constructions	3	9	6.5	1.8
	Over existing	4	11	6.5	1.8
Urban collector	Over new constructions	5	8	6.6	1.5
	Over existing	4	8	6.3	1.5

		Chipseal performance life (years)			
		Minimum	**Maximum**	**Mean**	**Std dev**
Rural collector	Over new constructions	3	10	6.6	2.3
	Over existing	4	10	6.6	1.8
Urban local	Over new constructions	5	7	6.2	1.0
	Over existing	4	7	6.1	1.1
Rural local	Over new constructions	3	20	7.8	5.0
	Over existing	4	15	7.5	3.1

The relationship between construction practices and chipseal performance was studied by Gransberg (2006). He found agencies that had reported superior chipseal performance had paid more attention to the detail of construction. Some of the best practices he observed were:

- comprehensive pre-seal surface preparation
- specifying minimum ambient air temperatures
    - air temperature specification drops correlated with performance drops
- requiring contractors to use state-of-the-art equipment
- placing minimum conditions on aggregate rolling
- restricting sweeping while the seal is curing
- maintaining low-speed traffic control for as long as possible.

2.4 South Africa

South Africa, Australia and New Zealand can be regarded as the three countries with the most experienced and mature chipseal capabilities, although their climates vary significantly.

Typical seal lives for bituminous seals in South Africa as of 2007 are shown in table 2.3, where traffic is given in equivalent light vehicles (ELV) per lane and one heavy vehicle is regarded as being equivalent to 40 light vehicles. In New Zealand, one heavy vehicle is regarded as being equivalent to 10 light vehicles.

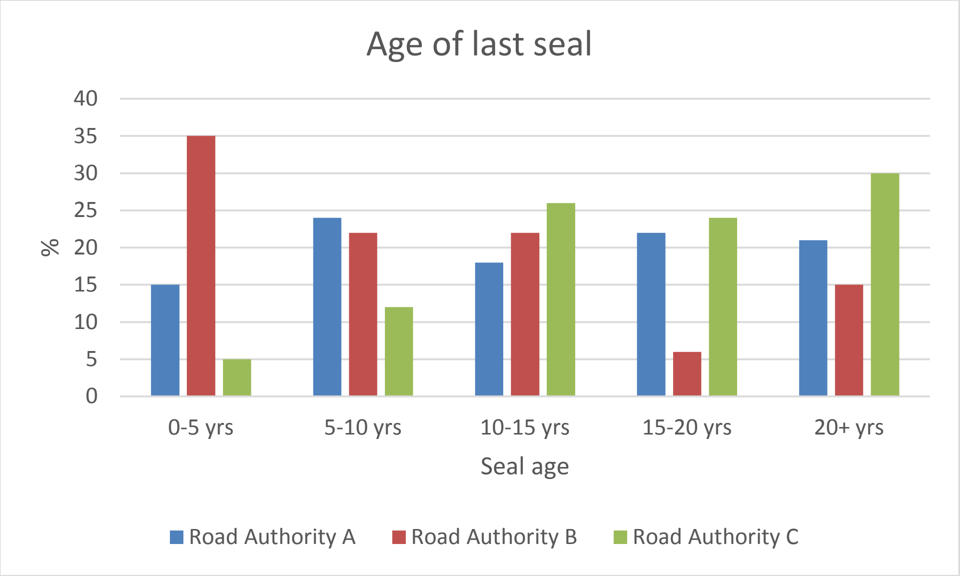
Table 2.3 Expected lifetimes for reseals (years) (SANRAL 2007)

Traffic level (ELV/lane)	**Substrate condition**	**<2,000**	**2,000 – 10,000**	**>10,000**
6.7mm seal (≈ grade 5)	Sound	6	4	
	Active cracks	4	2	
9.5mm seal (≈ grade 4)	Sound	10	6	
	Active cracks	6	3	
13.2mm seal (≈ grade 3)	Sound	12	9	6
	Active cracks	7	4	2
13.2mm PMB (≈ grade 3)	Sound	14	10	8
	Active cracks	8	6	3

It is also worth noting polymer modified binders are expected to give longer seal lives than unmodified binders.

Van Zyle and van der Gryp (2011) polled three road authorities in Southern Africa regarding seal ages and the results are shown in figure 2.1. In this case the authors do not assert these seals are performing well, but rather conclude a large backlog of resealing work has developed.

Figure 2.1 South African seal life ages in the 2010s (after van Zyle and van der Gryp 2011)



However, if it is considered that actual performance limits are equivalent to a score of 3 on the TMH9 standard visual assessment of the dry/brittleness of the binder (as per van Zyle and van der Gryp 2011), the seal lives can be assumed to be as shown in table 2.4.

Table 2.4 Expected seal lives using conventional binders (van Zyle and van der Gryp 2011)

South African seal size	Life (years)
7mm single seal	5–7
10mm single seal	≈ 8
13mm single seal	9–11

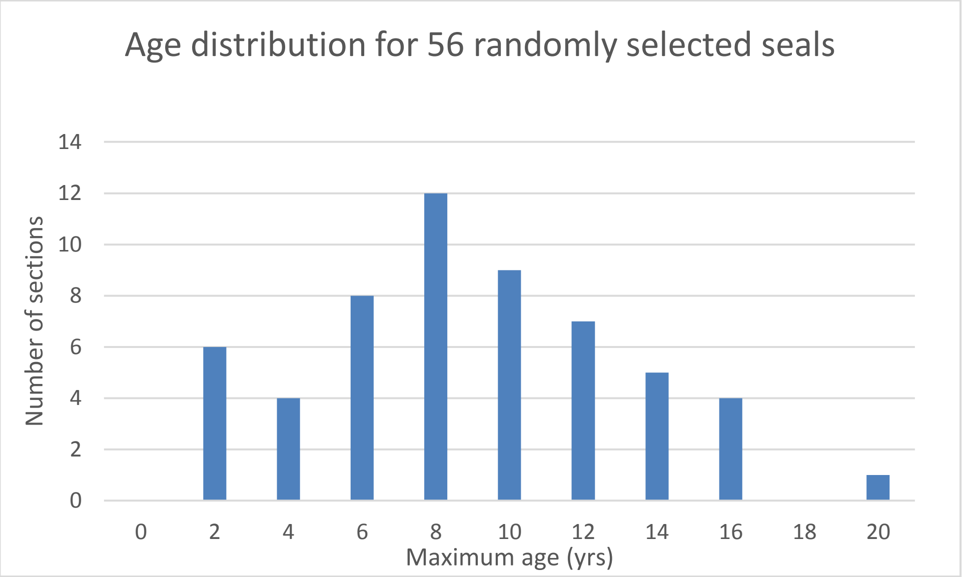
2.5 Australia

In the 1960s, a Western Australia study showed the maximum seal life achieved was about 15 to 16 years (Baker 1968), although the authors thought the 'desirable' design life was 20 to 25 years.

Baker selected 56 ½ inch (New Zealand grade 3 or Australian size 13mm) single initial seals for detailed examination. The age distribution of these seals is shown in figure 2.2.

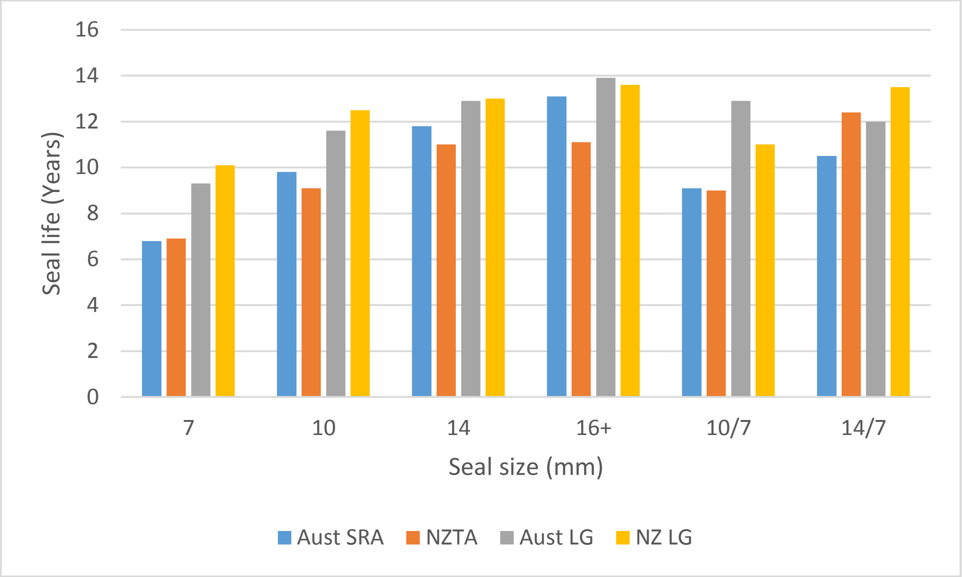
Baker's study concluded that the main cause of seal deterioration in Western Australia was the progressive hardening of the bitumen binder by the chemical action of atmospheric oxygen. The secondary cause was the polishing of surface aggregates (Baker 1968).

Figure 2.2 **Western Australian seal life ages in the 1960s (after Baker 1968)**



Oliver (1999) polled all state road authority regions and a small sample of municipalities in Australia and New Zealand. One of the questions he sought information on was the number of years between reseals, with the response to that question shown in figure 2.3, where it can be seen the larger seal sizes tended to show longer lives.

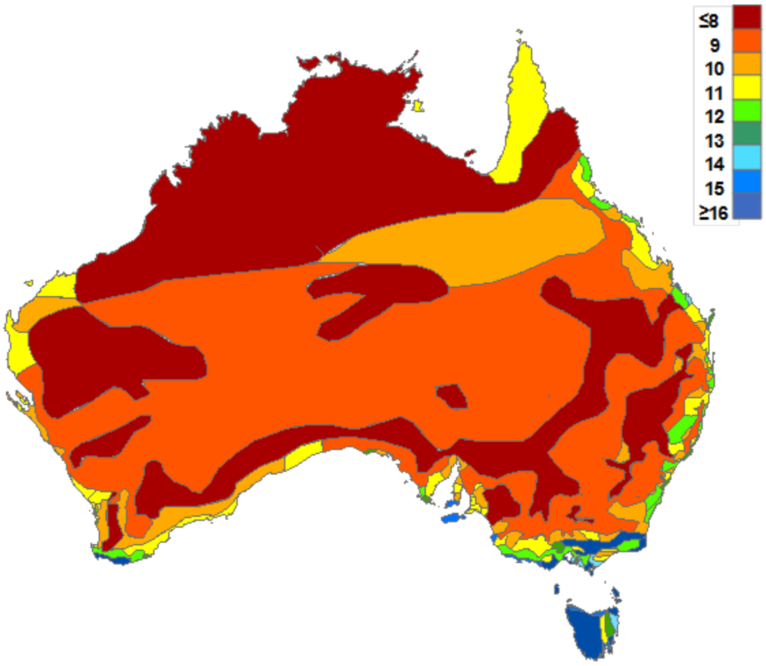
Figure 2.3 **Mean seal life reported by all respondents (after Oliver 1999)**



Oliver (1987) developed a mathematical model describing the rate at which the bitumen binder in a sprayed seal hardens in different areas of Australia, based on information from 10 specially arranged full-scale road trials and 13 non-trial sites. By default, the model was based on the single mid-eastern crude oil refined within Australia at the time to meet the Australian Standard AS2008. Inputs into the model were seal age at the time the seal was sampled, temperature at the seal site and the durability of the bitumen in the seal. The model was subsequently updated and expanded to include binder film thickness by introducing seal size as an input variable (Oliver 2004). He then added a critical distress viscosity component to the model (Oliver 2006).

Oliver asserted that a combination of the binder hardening and distress viscosity models permitted prediction of seal life in different climatic areas, where distress was related to bitumen ageing. His prediction is shown in figure 2.4.

Figure 2.4 Estimated seal lives in different temperature regions in Australia, assuming durability 9.5 days, seal size 10mm or grade 4, risk factor 6 (Oliver and Boer 2008)



For Western Australia, the Oliver model of 2006 portrays a different outcome from that of Baker (1968); however, it is noted that changes in climate, traffic, materials and work methods can occur over a 40-year period.

Tasmania, at the bottom of Australia, is at similar latitudes to the top half of the New Zealand South Island. It has been reported the average life of chipseals in Tasmania is 15–17 years (Booth 2016), and this is consistent with Oliver's model.

2.6 New Zealand

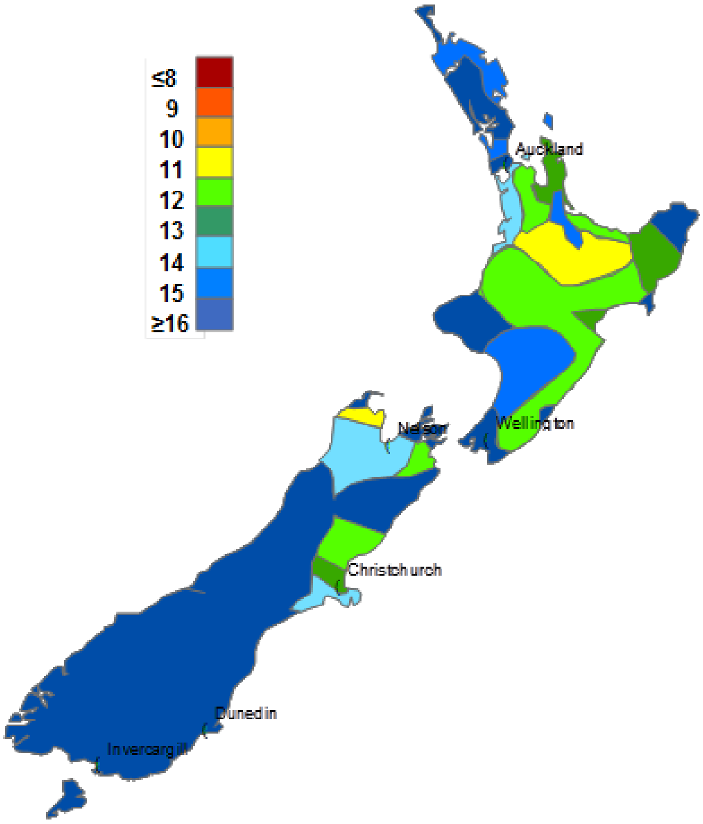
Ball and Owen (1998) analysed New Zealand RAMM data and found the smaller the chip size and the greater the average daily traffic level, the shorter the expected chipseal lifetime, as shown in table 2.5.

Table 2.5 Expected lifetimes for reseals (years) (Ball and Owen 1998)

Traffic level (ADT)	≤100	101-500	501-2,000	201-10,000	>10,000
Grade 4 seal	12	10	8	7	6
Grade 3 seal	14	12	10	9	8
Grade 2 seal	16	14	12	10	9

When Oliver's (2006) model was applied to New Zealand (Oliver and Boer 2008) it predicted a large portion of New Zealand would have seal lives of 15 years or more.

Figure 2.5 Estimated seal lives in different temperature regions in New Zealand assuming ARRB durability of 9.5 days, seal grade 4, risk factor 6 (Oliver and Boer 2008)

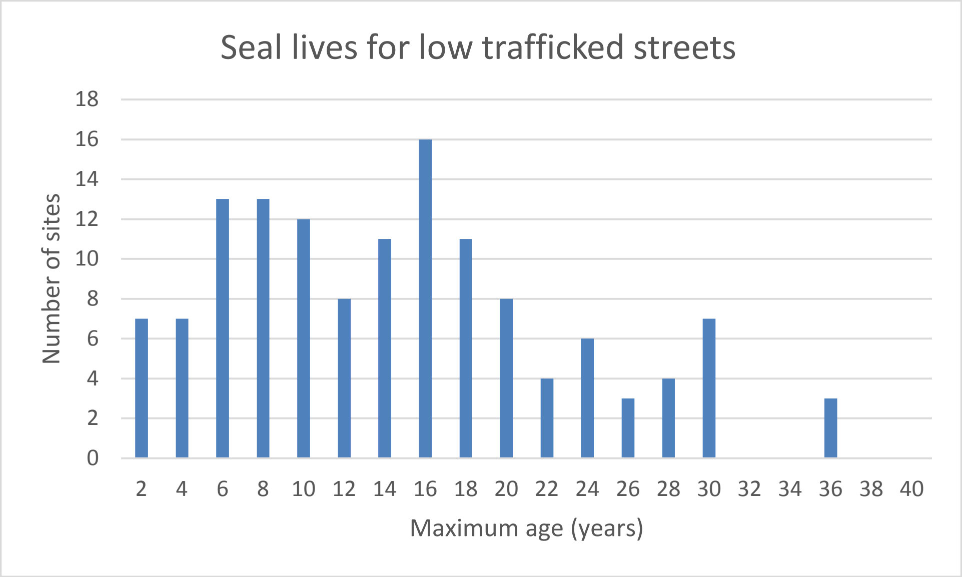


While the Oliver method utilises the modelling of a distress viscosity, Ball and Herrington (1996) concluded that the concept of a critical binder viscosity above which a seal fails is not appropriate in New Zealand, where ultimate seal failure may generally be from other causes. Laboratory high pressure oxidation of several bitumens revealed a variety of hardening relationships, some matching field behaviour and some not. The overall reaction mechanism was found to vary with temperature.

Failure modes and lifetimes of chipseals on New Zealand state highways were examined by Ball and Patrick (2005) again using the RAMM database. The fields within the database varied significantly between regions so only a tentative conclusion could be drawn, but the data present suggested reasons for resealing early were ranked as (1) a low sideways force coefficient routine investigation machine (SCRIM) coefficient, (2) texture loss and (3) cracking.

Herrington et al (2006), while studying bitumen durability, investigated low-trafficked streets in Lower Hutt to remove traffic as a dominant variable. Low traffic was defined as less than 100 vehicles/lane/day, and the seals were predominantly grade 4 or grade 3 chip using 180/200 binder. The ages of these 133 different seals are shown in figure 2.6.

Figure 2.6 New Zealand seal life ages for low- trafficked streets (after Herrington et al 2006)



A basic statistical analysis of these sites is shown in table 2.6.

Table 2.6 Seal lifetimes for low- trafficked streets

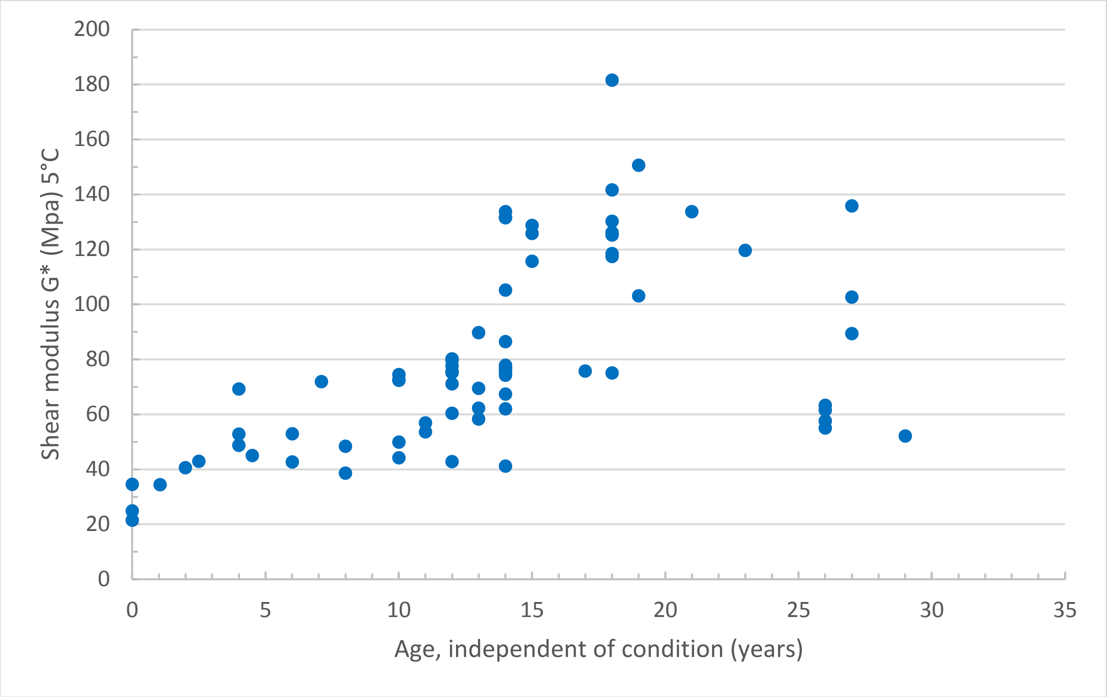
Property	Years
Mean lifetime	13.7
Minimum lifetime	1
Maximum lifetime	42.7
Lower quartile	6.4
Upper quartile	18.1
80th percentile	20.1
90th percentile	26.1
Sample size = 133	

To avoid distortion from outliers, the upper 80th percentile, being 20.1 years, was used as a reasonable estimate of the maximum seal age of ‘end of life’.

Bitumen from all sites was extracted and the complex shear moduli, as a surrogate for visco-elastic ‘stiffness’, was determined as shown in figure 2.7.

Although a general trend could be seen, no precise correlation was found between age of seal and any particular binder shear moduli.

Figure 2.7 **Shear moduli (G* at 5ºC at 9Hz) for bitumen extracted from aged seals (after Herrington et al 2006)**



Default seal lives are also calculated in New Zealand for use in performance-based specifications. Default seal lives for different traffic levels based on New Zealand pavements were devised from RAMM data and were given in Transit NZ et al (2005). These are shown in table 2.7, where traffic is in units of vehicles per day, which is roughly equivalent to average annual daily traffic (AADT).

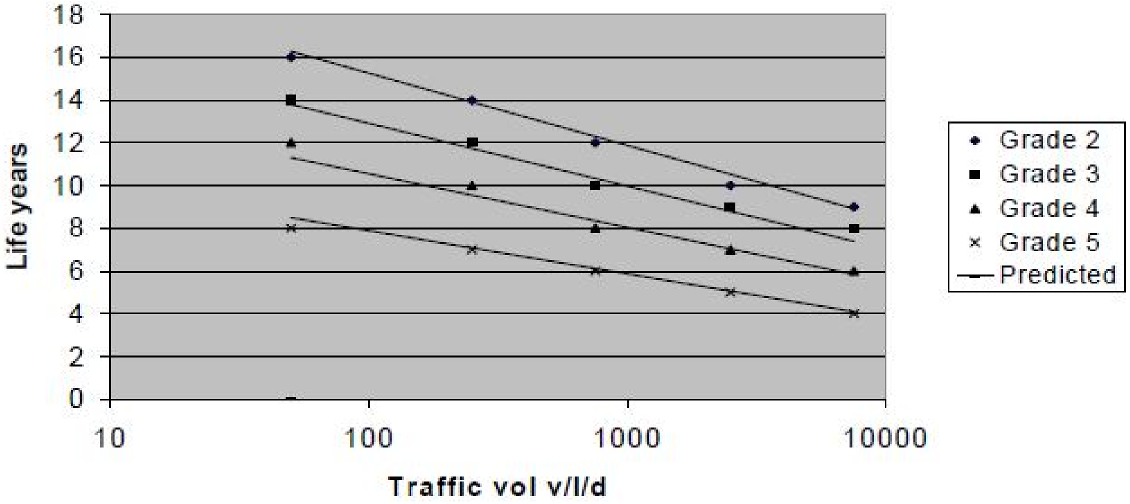
Table 2.7 **RAMM default seal lives 2005 (NZ Transport Agency et al 2005)**

Surfacing type	<100 vpd	100-500 vpd	500–2,000 vpd	2,000–4,000 vpd	4,000–10,000 vpd	10,000–20,000 vpd	>20,000 vpd
	Life in years						
Reseals							
Grade 5	8	7	6	5	4	3	2
Grade 4	12	10	8	7	6	5	4
Grade 3	14	12	10	9	8	7	6
Grade 2	16	14	12	11	10	9	8
Grade 4/6	14	12	10	9	8	6	4
Grade 3/5	16	14	12	11	10	8	6
Grade 2/4	18	16	14	13	12	10	9
First-coat seals							
Grade 5	1	1	1	1	1	1	1
Grade 4	3	2	1	1	1	1	1
Grade 3	4	3	2	1	1	1	1
Grade 4/6	6	4	3	2	2	1	1
Grade 3/5	8	6	5	4	3	2	1
Grade 2/4	10	8	6	5	4	3	2

Surfacing type	**<100 vpd**	**100–500 vpd**	**500–2,000 vpd**	**2,000–4,000 vpd**	**4,000–10,000 vpd**	**10,000–20,000 vpd**	**>20,000 vpd**
	Life in years						
Void fill seals							
Grade 6	6	5	4	3	2	1	1
Grade 5	8	7	6	5	4	3	2
Grade 4	12	10	8	7	6	5	4
Grade 3	14	12	10	9	8	7	6

The current default seal lives (NZ Transport Agency 2012) are shown in figure 2.8, where traffic is in units of vehicles per lane per day, rather than vehicles per day or AADT.

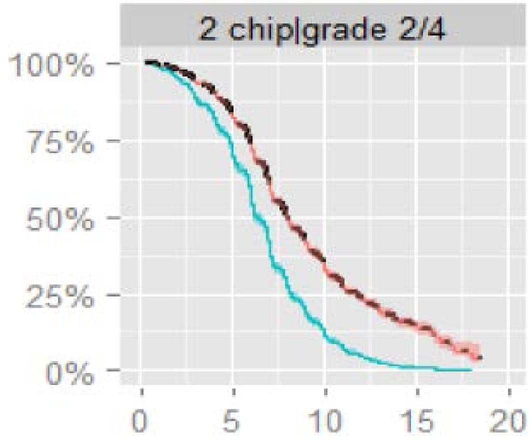
Figure 2.8 Single- coat seal design life (NZ Transport Agency 2012)



A surface longevity analysis for the NZ Transport Agency (the Transport Agency) was undertaken by McCracken and Cousins (2014). This concluded single chipseals appeared to have significantly better longevity than two-coat seals, which raised questions within the industry. There was industry concern that the difference in longevity could be explained by reseals undertaken due to low skid-resistance readings (ie SCRIM safety failures), and this could create a distorted view of surface longevity.

McCracken and Cousins (2015) and Cousins and McCracken (2015) undertook further work to isolate the effect of seal lives being affected by intervention due to low skid resistance readings, which is more specifically an aggregate selection issue. Initially a Kaplan-Meier (1958) estimate of the survivor function was calculated. These models (probability of survival vs age of seal) are cumulative and nonparametric functions and thus do not assume a normal distribution, as do the more common descriptive statistics.

Figure 2.9 Schematic of a Kaplan–Meier survival function (probability of survival vs age in years) (Cousins and McCracken 2015)



Following this a Cox proportional hazards survival model (Cox 1972) was built to account for partially observed lifetimes, and to assess the independent effects of more than 60 candidate risk factors after adjustment or correction for the other modelled covariates. The review, however, was blind to binder type survival models. Salient results from their study were:

- Two-coat chipseals fail at a rate 33.3% faster than single chipseals, after controlling for chip size, SCRIM deficiency and all other modelled covariates.
- Two-coat chipseals fail at a significantly faster rate than racked-in surfaces.
- Smaller chip sizes are prone to earlier failure, with this risk growing by 33.3% for each reduction in chip size.
- Failure risk varies widely by road attribute or geometry stress. It is estimated high-risk road sections have their lives reduced by 36% relative to low-risk roads.
- South Island and lower North Island regions have significantly better survival than areas in the central and upper North Island.
- Greater traffic volumes lead to reduced surface longevity, especially for heavy vehicles. For every additional 1,000 heavy vehicles, the risk of failure increases by 25.7%, compared with a change of 0.757% per 1,000 vehicle ADT increase.

A separate study was undertaken to investigate the contribution of sealing chip application rates to the early failure of chipseals (Waters 2011). Chip application in this study ranged from very light to very heavy. Waters found the chip application rate did not directly affect chipseal performance in the first two years after construction, but concluded that two years was insufficient time to measure the effect of chip application rates on chipseal lives.

2.7 Conclusions from the literature

It is difficult to report average seal ages, because these vary depending on many factors, including aggregate size, traffic volumes, substrate condition, quality of workmanship/attention to detail and reasons for resealing.

When investigating seal lives, the definition of failure becomes important. Unfortunately there appears to be no clarity or consistency of this within the literature. The most pragmatic approach has been that the life of the seal is equal to the age of the seal at the time of reseal or renewal. This relates to the maintenance strategies of various jurisdictions, and the various triggers adopted to instigate a reseal. If ride quality is the priority, a reseal is likely to be triggered once significant cracking occurs. If sideways force coefficient is the priority, a reseal will be triggered by SCRIM results or crash history. If funding is scarce, a reseal will be delayed by the financial priorities of Treasury, and it will appear that seal lives are long.

However for reasons of comparison, the following generalisations are made.

The mean chipseal life in the USA reportedly ranges from 3.5 to 10 years, with the longer lives believed to be where attention to detail was applied during construction.

In South Africa the expected seal lives using conventional binders range from five to seven years for 7mm (≈ New Zealand grade 5) seals to 9 to 11 years for 14mm (≈ New Zealand grade 3) seals. Seals older than this are not necessarily performing well, but are awaiting resealing work.

Two common findings emerge:

1. The larger the chip size, the longer the expected life of the chipseal.
2. The lower the traffic volume, the longer the life.

3 Review of the RAMM database

The following review of the Transport Agency’s road asset maintenance and management (RAMM) database is based on centreline (℄) lengths, as distinct from lane lengths.

The RAMM database as at March 2016 was interrogated to extract details of chipseals aged 15 years and above. Nine hundred and thirty individual treatment lengths were identified, which totalled some 780km. For the purposes of this report, seals aged 15 years and older are termed ‘long-life’ seals

While there are sites in RAMM for seals 15 years and older, there is no information on the condition of these seals. RAMM does not indicate if a 15-year-old seal remains because it is in excellent condition or it has deteriorated but left to ‘sweat the asset’.

In the review of the data, the characteristics of long-life seals are compared against the characteristics of the seal population in general. The data supporting the following graphs is tabulated in the appendices.

3.1 Site inspections

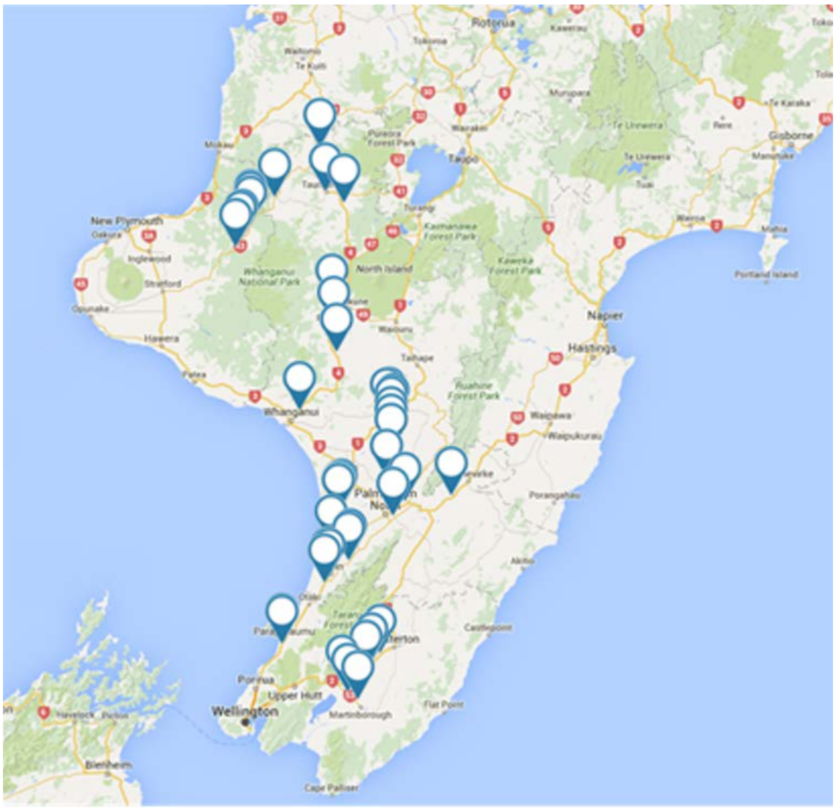
An initial field validation of RAMM data involved three long-life chipseal sites in the Christchurch area. One site was found to be asphalt, one site was non-existent due to a recent realignment, and one site was an old chipseal but was performing quite poorly.

To address concerns arising from this initial field validation, a larger field verification of the RAMM database was undertaken in the Wellington and Manawatu regions. The verification sites were chosen by filtering the database for:

- Wellington + Whanganui/Manawatu regions
- top surface only
- single/two-coat/racked-in
- greater than or equal to 15 years in age
- first coat with default life <5 years
- more than 500m in length.

This resulted in approximately 50km of centreline length, scattered across the regions as shown in figure 3.1.

Figure 3.1 Sites in the Wellington and Manawatu regions selected for verification



These sites were checked by an experienced chipseal technical specialist for likely age and actual performance. This larger review restored some confidence the RAMM data described sites that (a) were chipseals, (b) were quite old, and (c) were performing satisfactorily.

From the visual inspection, the sites were found to have the following factors in common:

- Very good to excellent condition pavements with good shape (no rutting, roughness or patching).
- Good to excellent drainage so pavements are kept dry. The exception to this are the sites on SH 01N RS 939 RP 7.44 to 11.23 where the shoulders are quite flat. However the surrounding ground is sand dunes so while there is surface water during heavy rain this drains away quite soon after the rain has stopped.
- Stable pavement surfaces with minimal flushing.
- Generally second-coat seals or the first reseal following a second coat but no thick layers of seal.
- Higher penetration binders (mostly 180/200 penetration with 3 or 4pph of kerosene) that still appear (figure 3.3) quite lively even in cooler winter conditions (ie soft, sticky, uncontaminated).
- Binder that is 60–90% up the chip. Binder appears harder on sites where it is low to medium (40–70%) up the chip.
- Chipping rates appear to have been generally good at the time of construction. The chip is mostly oriented so the average greatest dimension is horizontal and is interlocked with adjacent chip (figure 3.2). It is very difficult to lever chip out of the seal. Although most seals are recorded as single coat rather than two coat, there did appear to be a build-up of small locking chip in many of the seals.

Some sites appear to have a dry-lock at the time of construction (particularly in areas demanding high skid resistance), while the small chip at other sites appears to be generated by breakdown in the chip.

- Long-life seals generally exist at sites demanding lower skid resistance; however, the skid site category and traffic volumes appear to have less impact on the success of the seal than the quality and strength of the pavement.
- Although there is a percentage of softer chip, which has tended to break down on some sites, there is generally good quality hard stone mixed between being angular and round and usually showing moderate polishing.
- Cracking is not obvious.

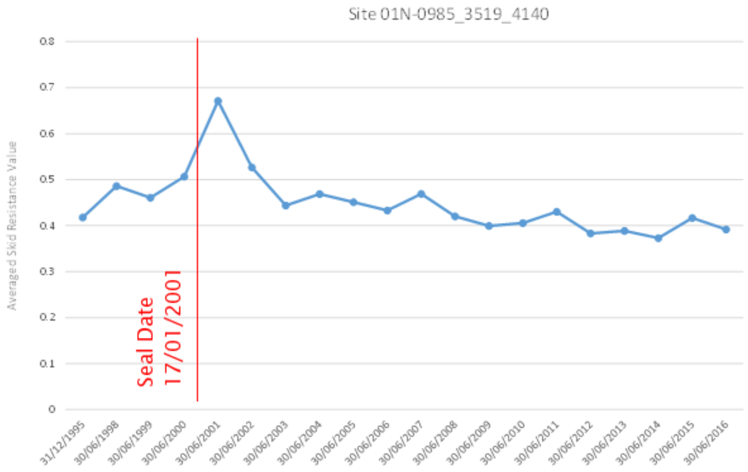
Figure 3.2 Typical excellent aggregate mosaic

Figure 3.3 Binder is plastic rather than brittle

3.2 Confirmation of RAMM seal age using skid data

Skid data from the RAMM database was used to confirm the age of the seals inspected in the Whanganui, Manawatu, Wairarapa and Wellington regions, which were considered to be long-life seals from the construction dates extracted from the RAMM top surface table. RAMM skid data was averaged for the length of each site. This included data from all lanes and for all site categories. The data was not adjusted for different measuring equipment or correctional factors introduced over the years of measuring and recording skid resistance. The intention was to identify significant rises in skid resistance throughout the life of the seal that would suggest the application of a more recent chipseal than recorded as the top surface in RAMM. This would make the top surface younger than was currently shown in RAMM and potentially remove the site from the list of long-life seals. The graphs showed minor fluctuations in skid resistance between years but clearly confirmed the age of the top surface was correct for the majority of sites investigated. An example is shown in figure 3.4, where this particular seal was constructed on 17 January 2001and sits between 30 June 2000 and 30 June 2001 averaged skid data where there is a significant rise in the measured skid resistance.

Figure 3.4 Averaged skid resistance data from RAMM for site SH 01N RP 985/3.519 – 4.140



Of the 31 long-life seals inspected and graphed:

- Twenty-four clearly confirmed the year of construction shown in the RAMM top surface table is correct.
- Three appeared to confirm the year of construction shown in the RAMM top surface table is correct. These are older seals where the accuracy of the skid data pre-2000 is somewhat uncertain and due to the absence of any later top surface records are accepted as correct.
- Four indicated a rise in skid resistance post the date of the top surface record filtered from RAMM. A further review of the top surface data in RAMM revealed two sites had been incorrectly filtered from RAMM and were in fact narrow strips that did not exist due to recording a narrow but later top surface record. Both were removed from the list of long-life seals. The other two sites did not have a later top surface record in RAMM but one did have a new pavement record approximately 12 months prior to the rise in skid performance indicating the application of first- and second-coat seal. The other had no later records. However, as the skid resistance increase for both of these sites occurred prior to June 2000 they remain on the list of long-life seals.

It can be seen from table 3.1 that in general the skid data is able to confirm the RAMM data for pavement age.

Table 3.1 Seal age confirmation based on RAMM skid resistance measurement

SH	RS	Start (m)	End (m)	Length (m)	Width (m)	Function	1st chip size	2nd chip size	Surfacing date	Confirmation of age using SCRIM data
1	885	0	673	673	11.6	2nd coat	3		16/03/2000	Agree
1	885	1,684	2,281	597	11.6	2nd coat	3		16/03/2000	Agree
1	939	7,435	8,560	1,125	10.7	Reseal	2		5/12/2000	Agree
1	939	8,600	9,316	716	10.7	Reseal	2		5/12/2000	Agree
1	939	9,591	10,120	529	10.7	Reseal	2		5/12/2000	Agree
1	939	10,160	11,230	1,070	10.7	Reseal	2		5/12/2000	Agree
1	954	11,666	12,757	1,091	9	Reseal	3		27/02/1998	Likely
1	985	3,519	4,140	621	14.5	Reseal	3		17/01/2001	Agree
2	788	72	735	663	9.2	2nd coat	2		7/03/1995	Likely
2	883/5.78	10,243	11,550	1,307	13.5	Reseal	2	4	13/11/2000	Agree
2	883/20.34	20,650	21,260	610	10	Reseal	3		3/02/1996	Increase in 2000
3	474/2.96	10,598	12,839	2,241	11.5	Reseal	2		24/02/1999	Agree
4	35	7,870	8,530	660	7.9	Reseal	4		3/03/2000	Agree
4	77	7,830	9,523	1,693	8.3	2nd coat	3		7/12/2000	Agree
4	140	5,750	7,849	2,099	7.9	Reseal	3	5	6/12/2000	Agree
4	158	0	2,734	2,734	6.8	Reseal	2		17/11/1999	Agree
4	223	6,850	7,770	920	8.8	2nd coat	3		11/03/2000	Agree
53	0	2,435	3,030	595	9	2nd coat	3	5	11/03/1999	Agree
53	0	7,450	8,447	997	8.5	Reseal	2		12/03/1999	Agree
53	0	14,952	15,626	674	8.5	Reseal	4		31/01/2000	Agree
54	1	3,140	3,782	642	1.8	Reseal	3		10/02/1995	Increase in 2005
54	1	5,224	5,880	656	6.9	Reseal	3		26/02/2001	Agree
54	1	12,538	14,830	2,292	6	Reseal	3		27/02/2001	Agree
54	17	270	928	658	6.7	2nd coat	3		14/02/2000	Agree
54	17	5,223	7,080	1,857	7.3	Reseal	3		28/02/2001	Agree
54	38	108	1304	1196	0.7	Reseal	3		9/12/1995	Increase in 2005
57	0	114	1075	961	7.3	Reseal	3		15/02/2000	Agree
57	0	1,075	2,030	955	9.1	Reseal	3		10/03/1999	Agree
57	0	15,160	16,800	1,640	12.1	2nd coat	2		29/01/2001	Agree
57	0	17,200	17,700	500	11.2	Reseal	3		23/01/1991	Increase in 2000
57	50	2,353	3,113	760	9	2nd coat	3		27/11/1995	Likely

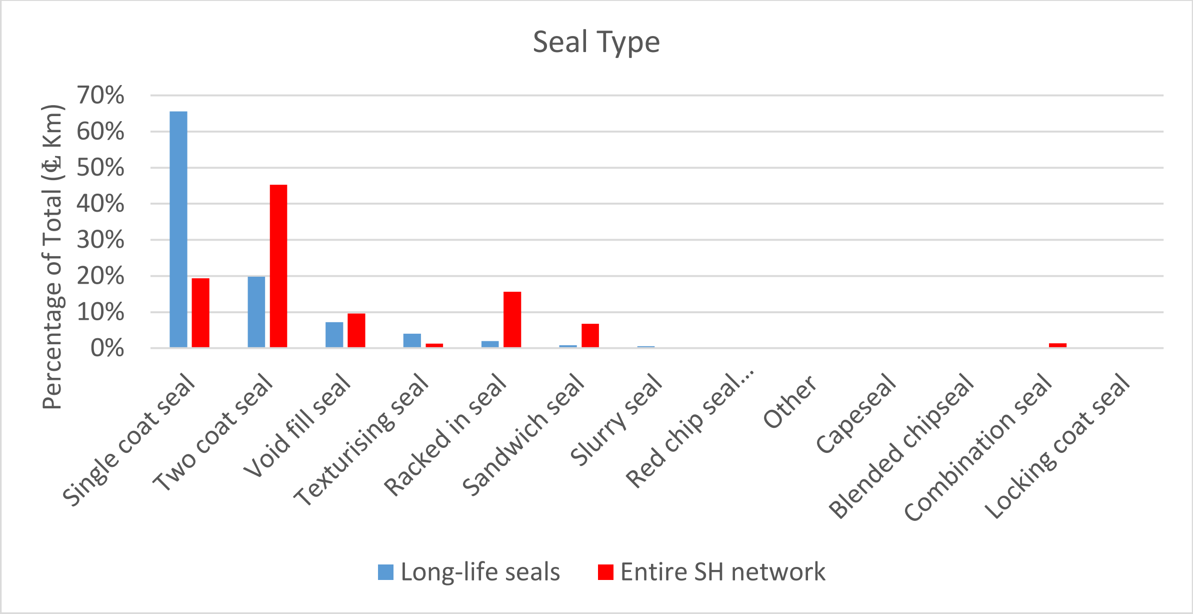
3.3 Seal design and workmanship

As discussed in the literature review, quality of workmanship and quality/appropriateness of the seal design are an important consideration in chipseals attaining a long life. The condition of the surface before sealing, the appropriateness of the treatment selection and design, and the quality of the workmanship for seals constructed over 15 years ago is not held in the RAMM database, and could not be examined within the scope of this research.

3.4 Treatment type

Figure 3.5 is a representation of the relative proportion of surface types across the entire state highway network. The data is further broken down into long-life treatments.

Figure 3.5 Seal type



It can be seen that single-coat seals are clearly over represented in the aged seals when compared with the entire state highway network. While single-coat seals comprise 19% of the general network, they make up 66% of the long-life treatments.

Upon first inspection, a valid explanation for this could be that the majority of two-coat seals on the network have not reached their end of lives. It may be that a greater portion of two-coat seals are constructed post-2000s, and many are under 15 years old and still functional.

A survivor analysis is a useful tool in resolving this question. As noted in the literature review a Cox proportional-hazards survival model analysis was undertaken (McCracken and Cousins 2015; Cousins and McCracken 2015) and found two-coat chip seals fail faster than single-coat seals, which is supported by the trend shown in figure 3.5.

In 1994, a pilot specification *TNZ P/17 Performance based specification for bituminous reseals* (Transit NZ 2002) was first developed and trialled, and the basic specification has been in use ever since (Towler and Dawson 2008). The key performance criteria are surface texture and chip loss, with the contractor responsible for repair in the first 12 months. It is understood some contractors opted to use more two-coat seals to alleviate early risk, and to minimise the need for pre-seal repairs, void fills and texturising.

3.5 Prime coats

Prime coats using low viscosity coal tar were widely used from the 1930s to 1950s. When production of coal tar ceased, a cut back bitumen (100:100 parts bitumen: kerosene) was introduced; however, this did not have the same penetration capabilities of tar, and also had a very low (49°C) flash point, and so was discouraged (Transit NZ et al 2005). It is also believed:

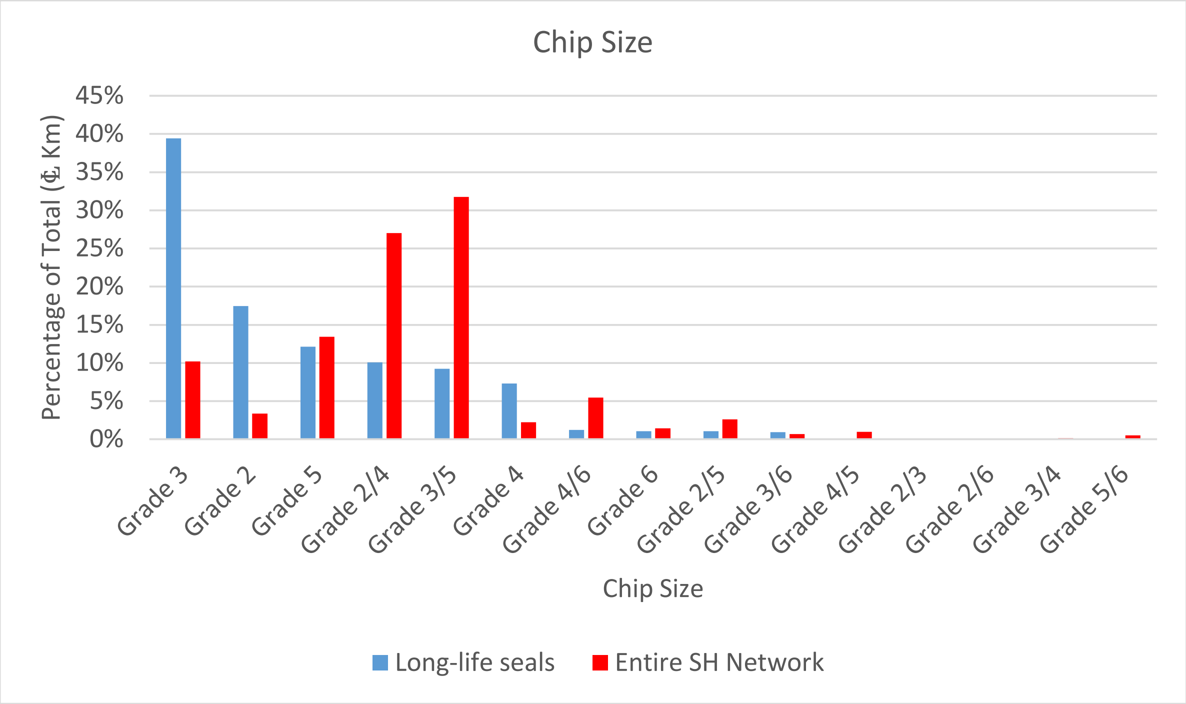
> *Improvements in the quality of basecourse materials and construction techniques have resulted in cleaner and tighter surfaces on which to seal, which means that prime coats are no longer needed* (Transit NZ et al 2005).

RAMM does not contain prime coat surfacing records so the effectiveness of prime coats could not be examined in this review.

3.6 Chip size

In terms of chip size, the results shown in figure 3.6 support the suggestion that higher portions of long-life seals are represented by single-coat seals, as can be seen for grades 3, 2 and 4.

Figure 3.6 Chip size



The data shows that aged:

- grade 2 chipseals are 570% of the network average, thus are well over represented
- grade 3 chipseals are 400% of the network average, thus are over represented
- grade 4 chipseals are 350% of the network average, thus are over represented
- grade 5 chipseals are about the same as the network average.

Assuming all these grades of chip sizes have been in use for over 20 years, this indicates the larger chipseals last longer.

3.7 Binder type

3.7.1 Single-coat seals

The RAMM data extracted for binder type for the various surfacing treatments is shown in detail in appendix C. As single-coat seals have been shown to predominate in aged seals, single-coat seals are discussed further in this section.

The percentages of various binders found in aged seals are shown in figure 3.7 and the percentages of various binders found in the entire state highway network are shown in figure 3.8. From these it can be seen:

- 180/200 pen bitumen in aged seals is 130% of the network average, thus is over represented
- 130/150 pen bitumen in aged seals is 77% of the network average, thus is under represented
- 80/100 pen bitumen in aged seals is 150% of the network average, thus is over represented.

Figure 3.7 Binder in long- life single- coat seals

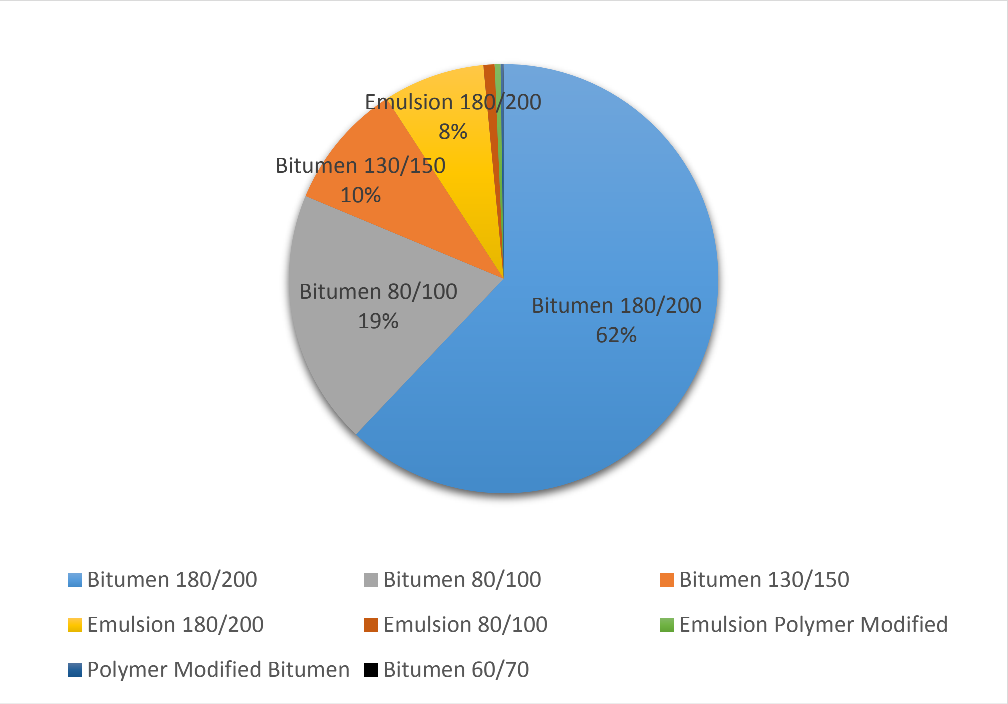
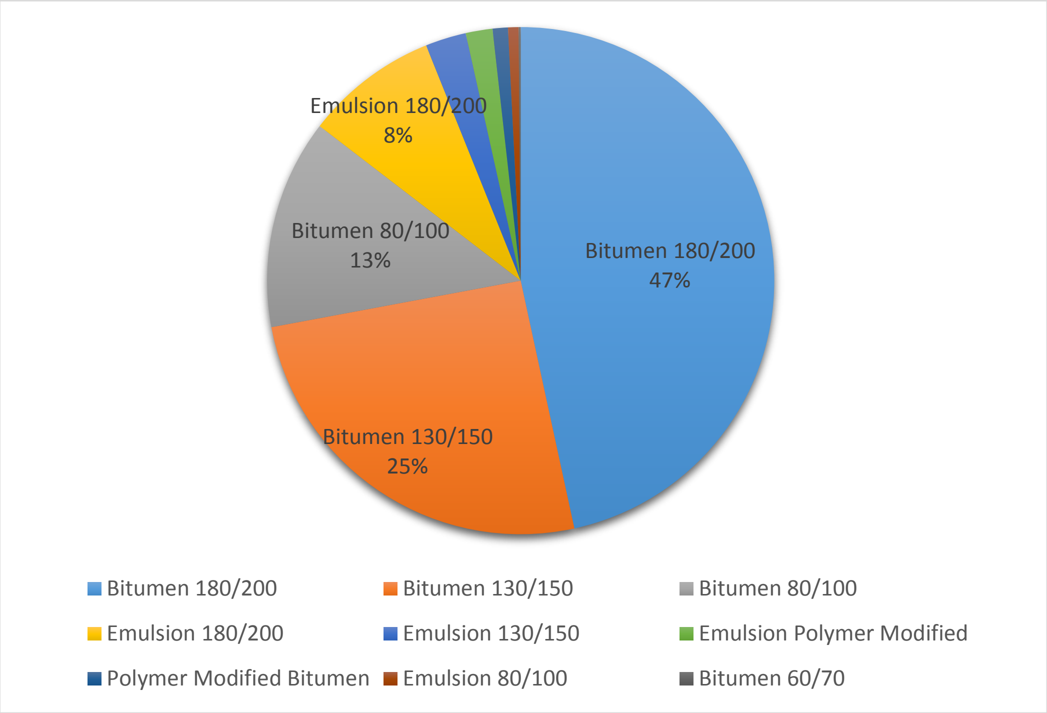


Figure 3.8 Binder in network single- coat seals



3.7.2 Binder in two-coat seals

The percentages of various binders found in long-life seals are shown in figure 3.9 and the percentages of various binders found in the entire state highway network are shown in figure 3.10.

Figure 3.9 Binder in long- life two- coat- seals

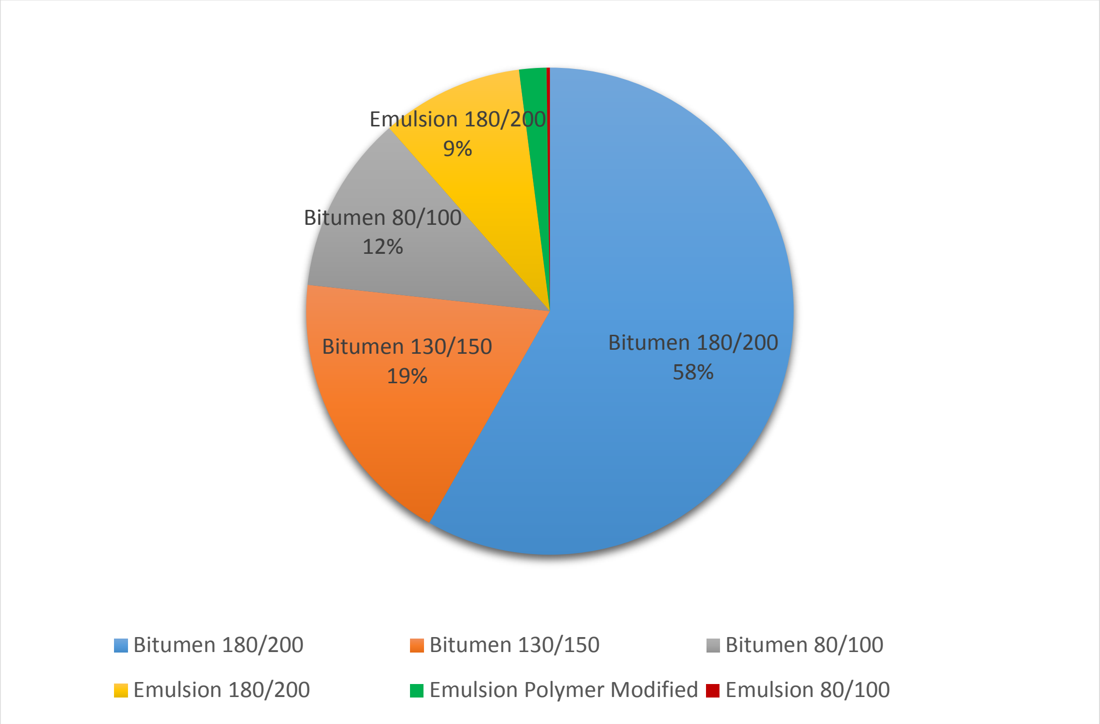
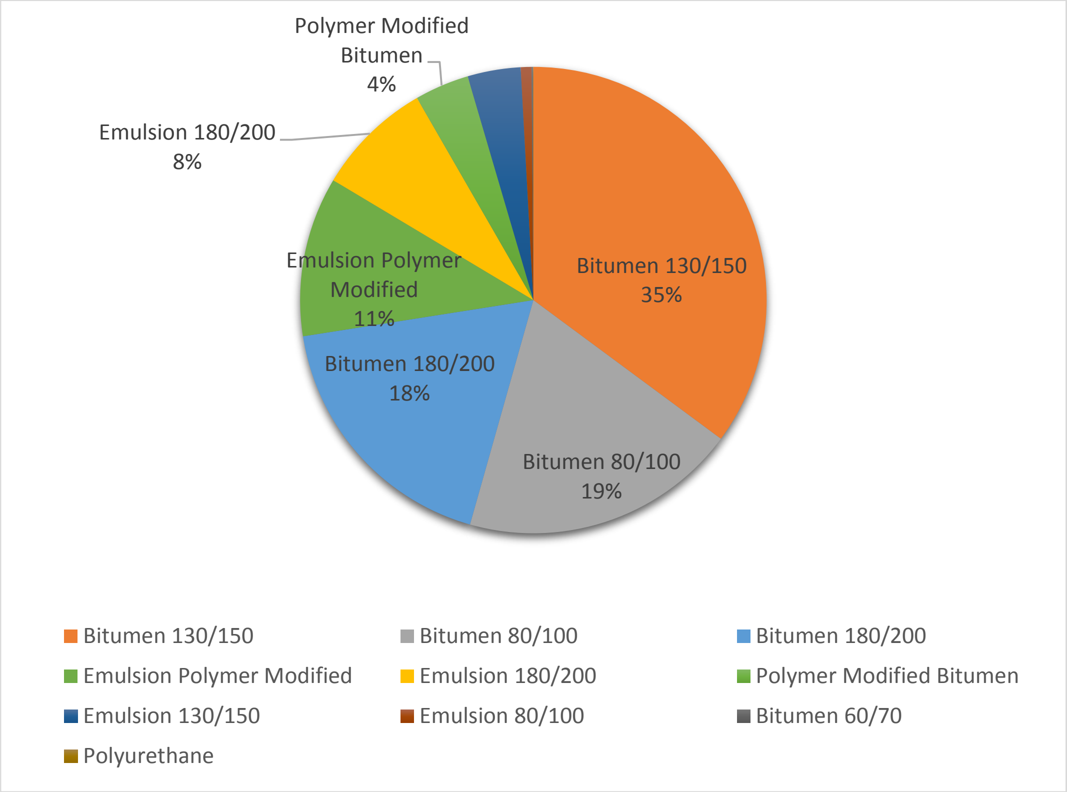


Figure 3.10 Binder in the state highway network's two- coat seals



From these it can be seen:

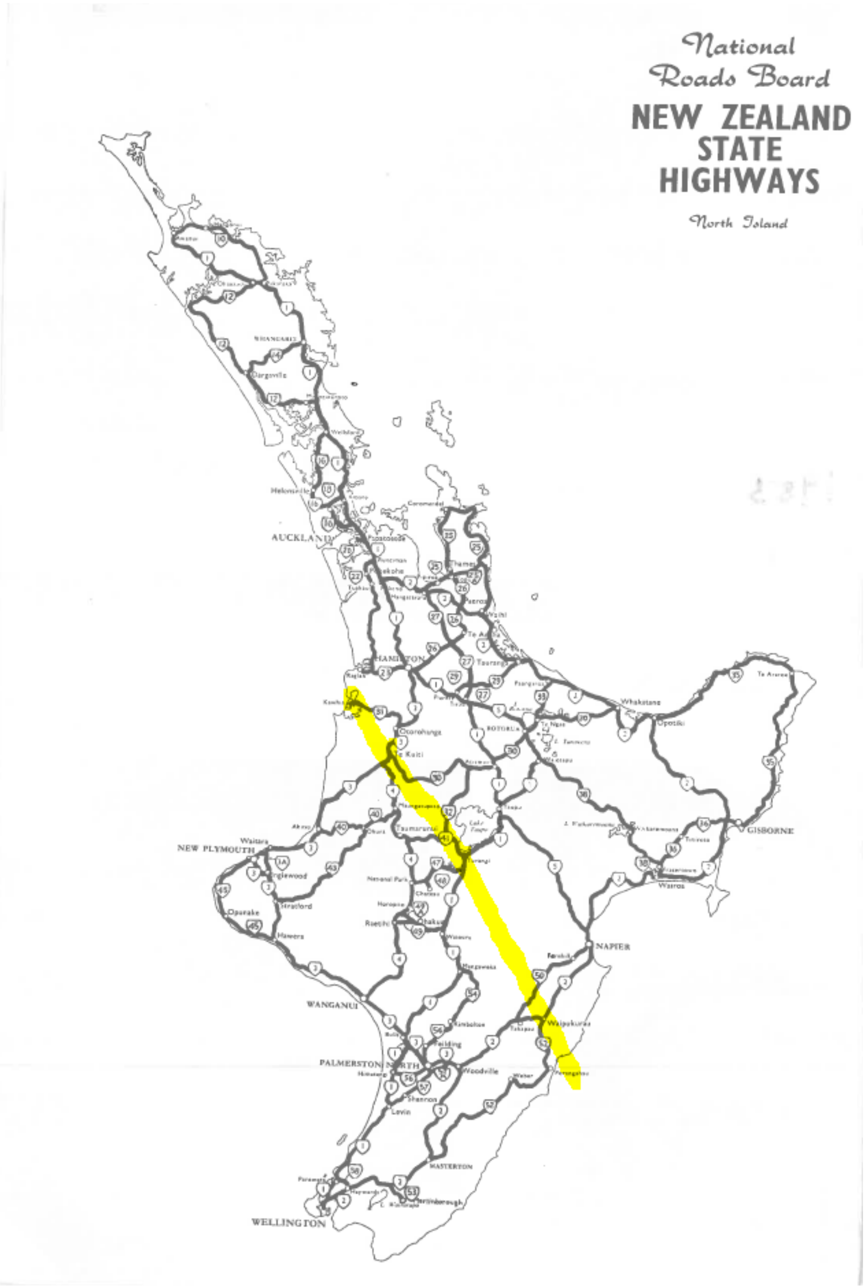
- 180/200 pen bitumen in long-life seals is 322% of the network average, thus is over represented
- 130/150 pen bitumen in long-life seals is 54% of the network average, thus is under represented
- 80/100 pen bitumen in long-life seals is 63% of the network average, thus is under represented.

3.8 Distribution of bitumen penetration grades throughout New Zealand

As a guideline for the use of appropriate bitumen penetration grades, New Zealand was historically divided into northern and southern climatic zones, with 80/100 pen recommended north of 'the line' and 180/200 pen south of 'the line'. This is illustrated in figure 3.11 and described in the following quotation from the National Roads Board (1968).

> *New Zealand can be divided broadly into two climatic areas by a boundary through Kawhia, Te Kuiti, Turangi, and Waipukurau. In the southern area 180/200 pen bitumen should be used as a basic binder, fluxed with a small percentage of Automotive Gas Oil if traffic volumes are low or sealing is in an area where severe winter frosts are expected. In the Northern area 80/100 pen grade should be used, again fluxed with Automotive Gas Oil for low traffic volumes* (National Roads Board (1968, clause 5.3.2 (iii)).

Figure 3.11 The 1968 concept of 80/100 pen above the line and 180/200 pen below the line



Transit NZ (1991 and 1993 update) *Bituminous sealing manual* encouraged the use of 180/200 penetration bitumen for all sealing.

> *Two bitumen grades are commonly used for sealing. They are 180/200 penetration grade and 80/100 penetration* [pen.] *grade and their uses are as follows:*
>
> *First coat sealing and priming.*
> *The bitumen grade used for all first coat seals and priming should be 180/200 pen.*
>
> *Reseals*
> *180/200 pen bitumen tends to be more durable than 80/100 pen. For this reason all resealing should use 180/200 pen. wherever possible.*
> *The two reasons for using the harder 80/100 pen. bitumen are:*

1. *In hot climates 180/200 pen. Can often be too soft to prevent chip loss due to chip rollover during the first summer.*
2. *If seals with 180/200 pen. binder flush prematurely, the use of a harder binder may solve this problem.* (Transit NZ 1991, chapter 6, p6/24)

The selection of the bitumen penetration used in the construction of these long-life seals would have been made by consultants and contractors influenced by the regional state highway network engineers. However, over the years most regions have trialled alternative penetration grade bitumens in an effort to reduce reseal deficiencies observed in their region, eg the use of 130/150 penetration bitumen or polymer modified binders.

While it was expected that in general the bitumen penetration distribution for long-life seals would most likely reflect the 1968 climatic line separation, there is a greater mix of bitumen grades than expected, as shown in figures 3.12 and 3.13.

The legends in these figures utilise the RAMM binder codes as described in table 3.2.

Table 3.2 RAMM binder codes

RAMM code	Meaning
B80	80/100 penetration hot-applied bitumen
B130	130/150 penetration hot-applied bitumen
B180	180/200 penetration hot-applied bitumen
E80	Emulsified 80/100 pen bitumen
E180	Emulsified 180/200 pen bitumen
EPM	Polymer modified emulsion
PMB	Polymer modified hot-applied bitumen
UNKN	Unknown

Figure 3.12 Distribution of bitumen penetration grades for long- life seals, North Island

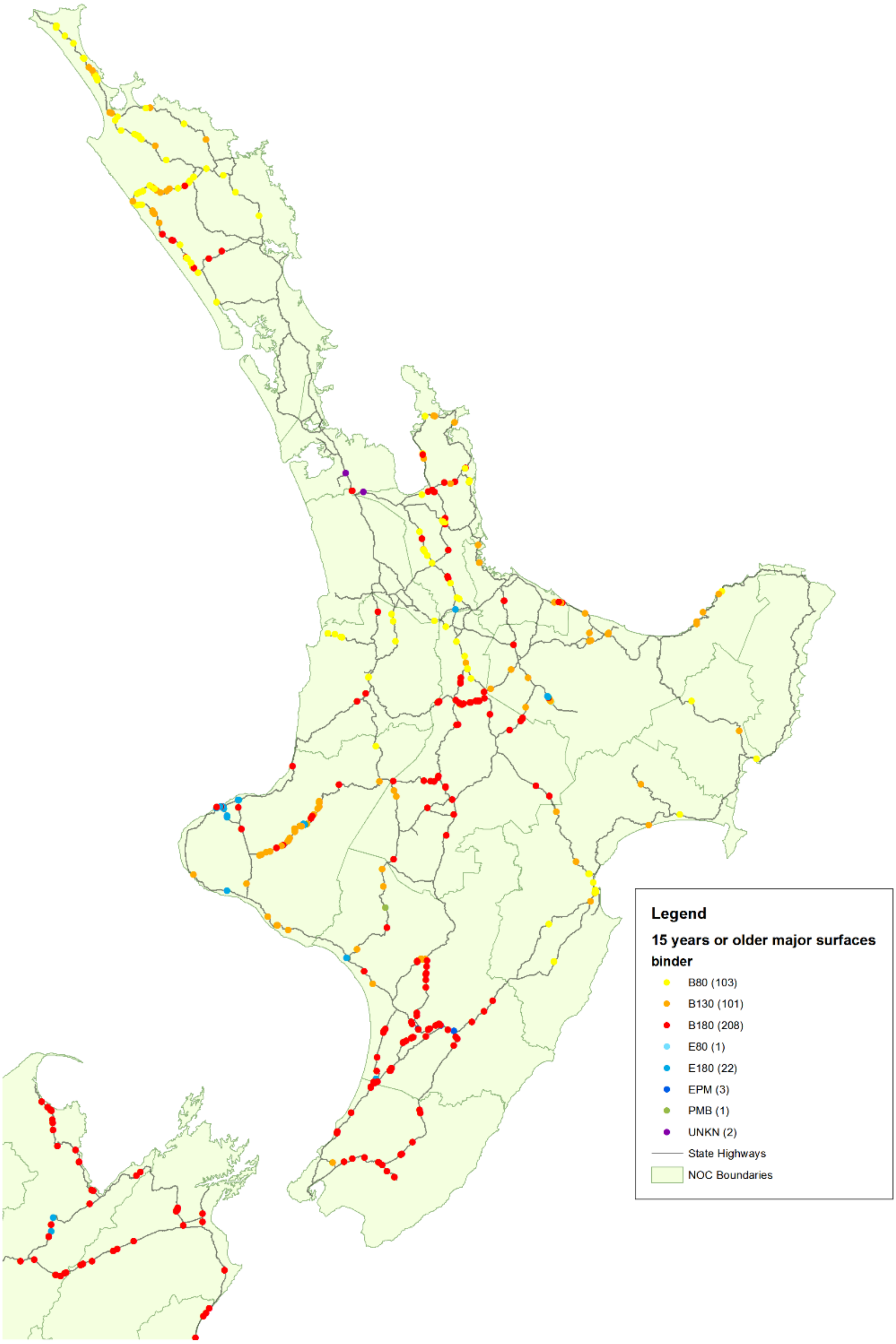
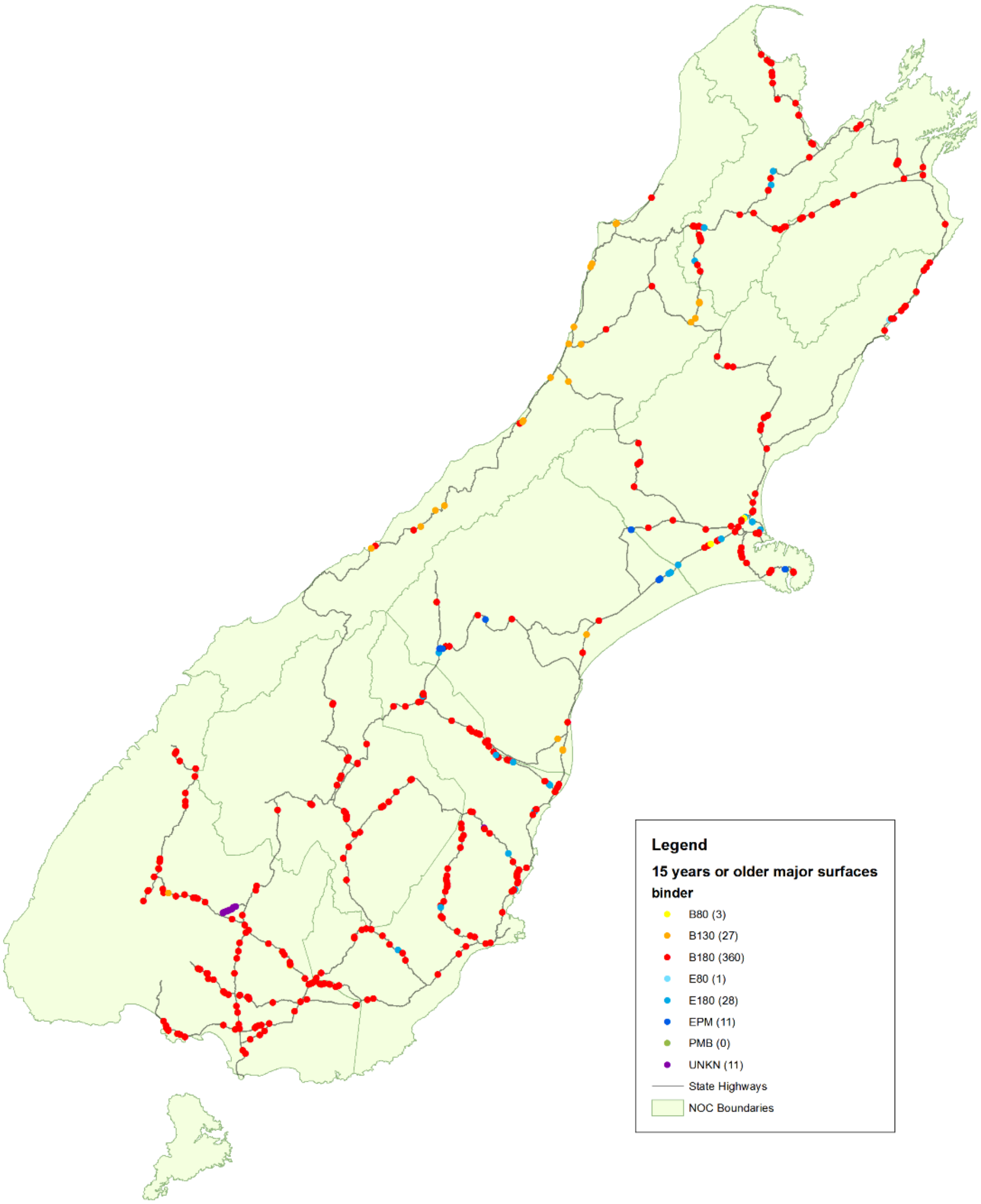


Figure 3.13 Distribution of bitumen penetration grades for long- life seals, South Island



3.9 ADT

Average daily traffic (ADT) is obtained as the raw data collected at a particular count site over a period of four weeks or so. This data is then seasonally adjusted to take into account the time of year the count was taken to obtain an average annual daily traffic volume (AADT) which provides a more robust estimate (NZ Transport Agency 2016). The data available for this study was ADT.

To investigate the relationship between the ADT volume and seal lives, data from the RAMM database was extracted based on the length of seals under the ADT categories. In figure 3.14 the proportion of seals under various traffic categories across the entire network (all ages) is compared with the proportion of long-life seals under the same categories.

Figure 3.14 Long- life chips and traffic volume

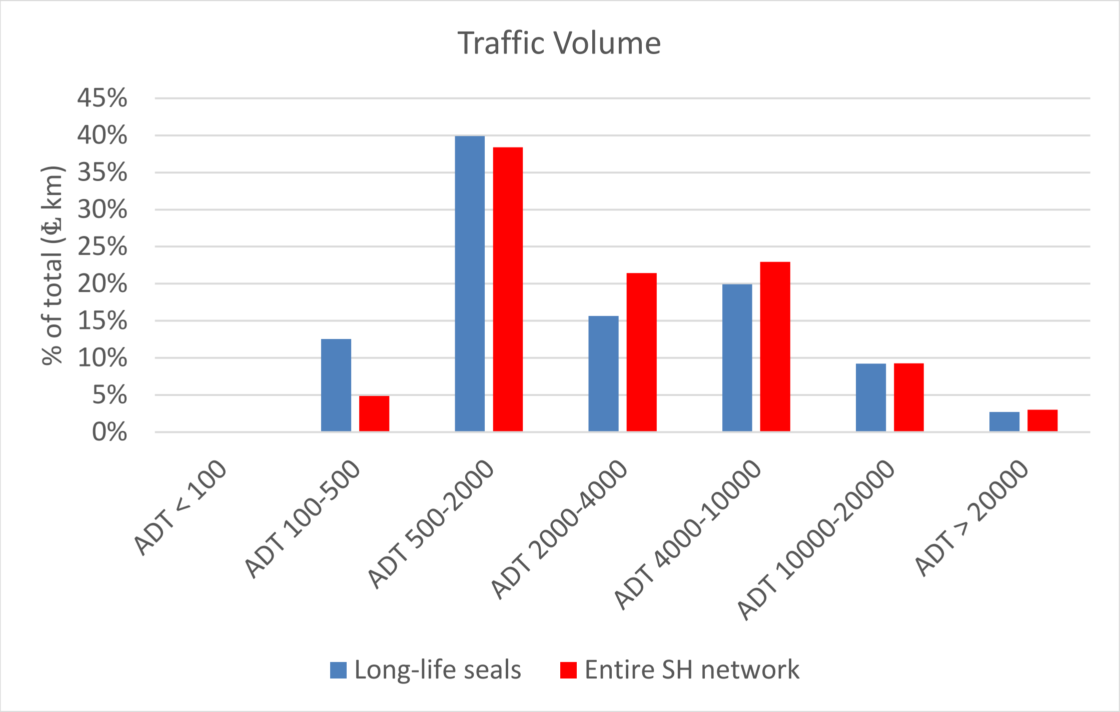


Figure 3.14 shows an over representation of low trafficked roads (ADT 100–500) for the long-life seals, where their occurrence is 260% of the national average. At other traffic levels there is no clear divergent trend.

3.10 Site category for skid resistance

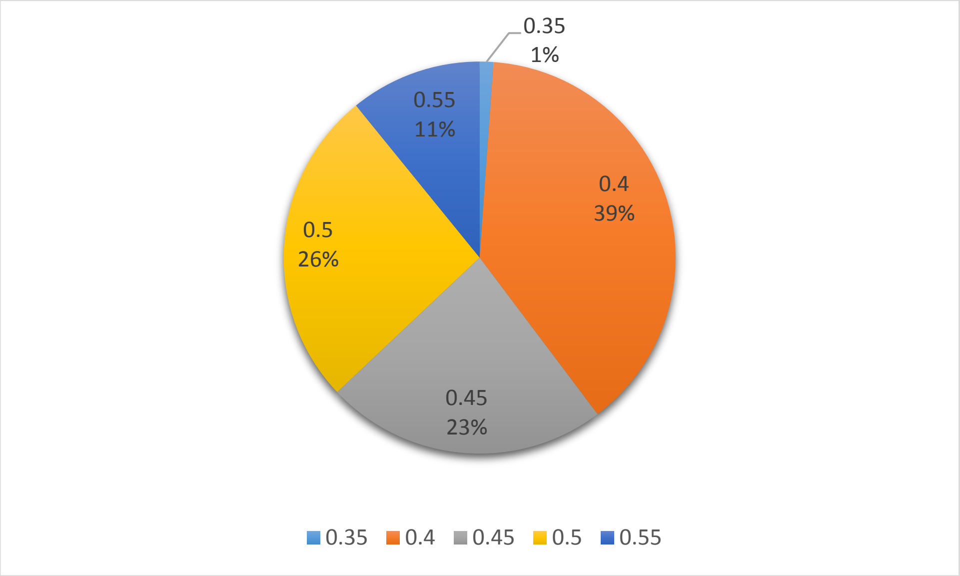
Skid site categories from RAMM have been reviewed for all long-life seals to understand the likely skid resistance demands placed on these seals. The skid resistance investigatory levels used in New Zealand are shown in table 3.3

Table 3.3 Skid resistance investigatory levels (NZ Transport Agency 2013)

Site category	Skid site description	Investigatory level (IL), units ESC					
		0.35	0.40	0.45	0.50	0.55	0.60
1	Approaches to: a) Railway level crossings b) Traffic signals c) Pedestrian crossings d) Stop and Give Way controlled intersections (where state highway traffic is required to stop or give way) e) Roundabouts. One lane bridges: a) Approaches and bridge deck.				▨	■	▨
2	a) Urban curves <250m radius			▨	■	▨	
	b) Rural curves <250m radius			L	M	H	
	c) Rural curves 250-400m radius		L	L	M	H	
	a) Down gradients >10%. b) On ramps with ramp metering.			▨	■	▨	
3	a) State highway approach to a local road junction. b) Down gradients 5-10% c) Motorway junction area including on/off Ramps d) Roundabouts, circular section only.		▨	■	▨		
4	Undivided carriageways (event-free).	▨	■	▨			
5	Divided carriageways (event-free).	■	▨				

SCRIM measurements of the long-life seals have been reviewed (figure 3.15) and reveal that where an appropriate sealing chip is used in higher-demand areas long lives can be achieved, even with a resurfacing policy driven by poor skid resistance.

Figure 3.15 Sideways- force coefficients (ESC) of long- life seals



3.11 Timing of seal construction

New Zealand did not have a specified construction season for sealing when using tar products during the 1960s as they appear to have been successful year round. However with the introduction of bituminous binders a construction window was introduced as described in National Roads Board (1968):

> *Weather limitations. Second coat sealing and resealing with asphaltic (bituminous) binders should be timed so that the initial trafficking can complete the embedment of the chip in the binder under reasonably warm conditions. The work should be carried out in the period October to mid-March, with a preference for early season work. Sealing operations should not be commenced unless the road surface is dry, the shade temperature at least 50 °F (10 °C) and the prospects good for continued fine weather for the next three days* (National Roads Board 1968, clause 5.5.1).

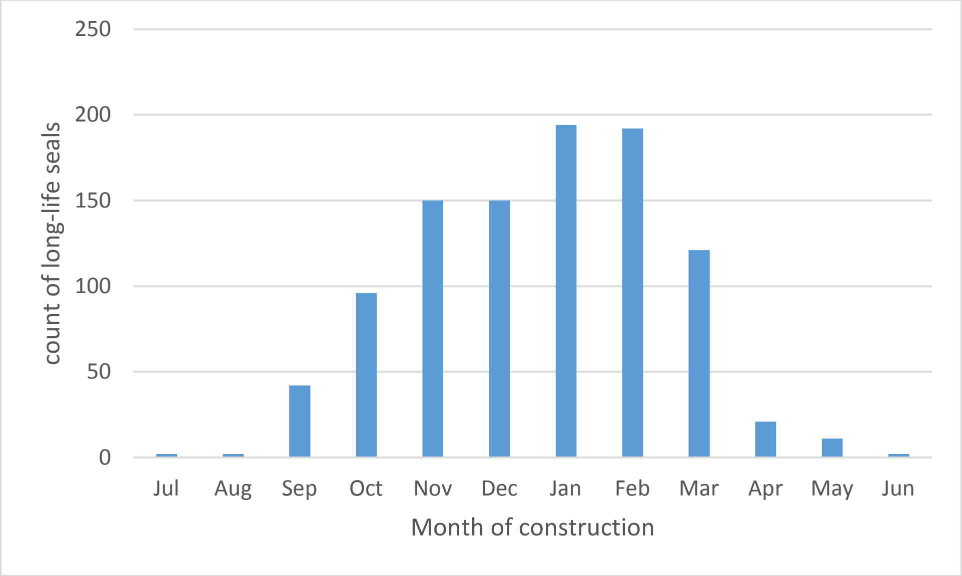
This was revised in 1995 to give:

> *Sealing in accordance with this specification shall be carried out during the period between the first day of October and the fifteenth day of March, except where an emulsified asphalt binder, complying with TNZ M/1, Specification for Asphaltic Bitumens, is specified as the sealing binder. Where such emulsified asphalt binders are used, sealing may be carried out during any period of the year when fair, settled weather conditions are being experienced, provided there is no frost present anywhere within the area to be sealed* (TNZ P/4:1995 Specification for resealing).

Transit New Zealand et al (2005) does not specify the months, but does recommend early summer.

The data for all long-life seals has been graphed in figure 3.16. It shows a very small number of sites constructed outside the recognised good-practice construction window, and become long-life seals.

Figure 3.16 Month of seal construction for the total of long- life seals



3.12 Timing between first- and second-coat seals

The RAMM database lacked many of the historical surfacing records required to fully research the time period between first- and second-coat seals for long-life seals.

Table 3.4 shows of the 31 sites inspected in the Whanganui, Manawatu, Wairarapa and Wellington regions, there was only sufficient RAMM data to evaluate six sites. The range for these six sites was 6 to 22 months with an average of 11.5 months.

The average 11.5 month period is expected, as common practice during the 1980s and 1990s was to apply second-coat seals in the construction season following the construction of the first-coat seal.

> *(1) Seal with Grade 4, followed the next year by a Grade 3 re-seal*
>
> *This option is Transit New Zealand's policy for all State Highway work and should be chosen for any work where the risks and degree of problems are high or unknown.*
>
> *(2) Seal with Grade 3, followed in the next year by a Grade 5 or 6*
>
> *For roads with medium to heavy traffic, and not considered a high risk, this option can be used. Transit New Zealand allows use of this system where experience has shown that a Grade 4 has generally become too coarse a texture after one or two years' use* (Transit NZ 1993, section 2.3.2.1).

Transit NZ et al (2005, section 6.2.2) follow the Transit NZ (1993, section 2.3.2.1) principle of applying a second-coat seal one year following the construction of the first-coat seal.

This philosophy has been put to the test over recent years as a number of regions have tried different combinations of first- and second-coat seal systems with differing periods of time between the two treatments in an effort to provide more waterproof and durable chipseal surfaces.

Table 3.4 Time between first- and second- coat seals for the inspected long- life seals

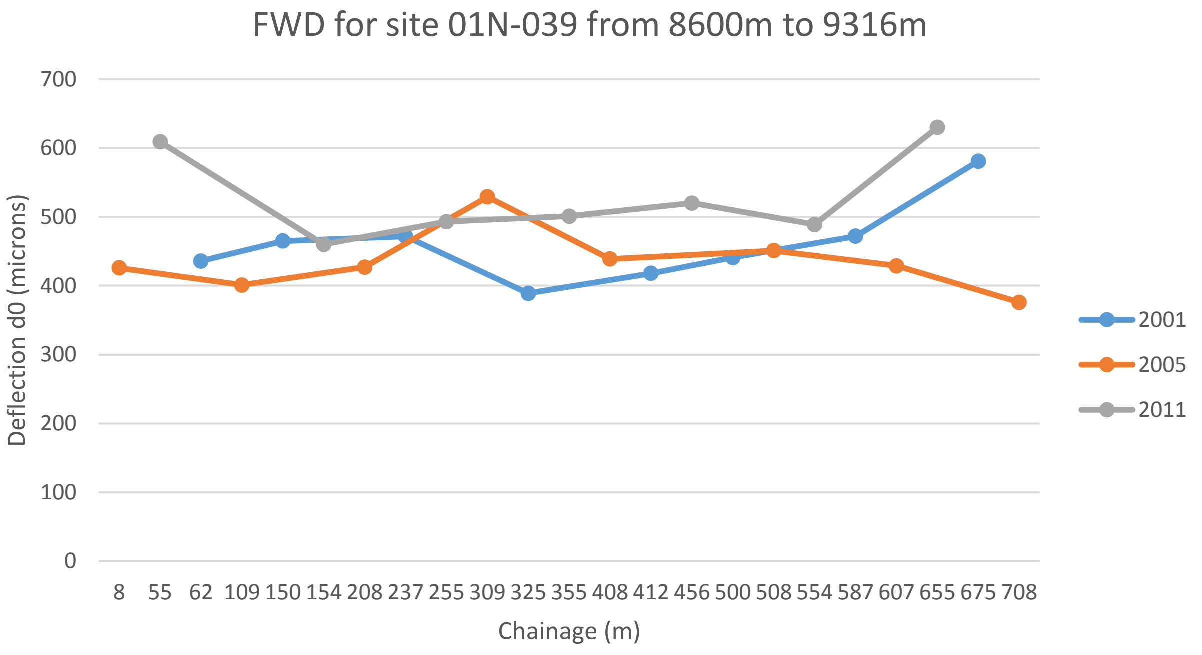
SH	RS	Start	End	Length	Width	Function	1st chip size	2nd chip size	Surfacing date	Date of pavement renewal	Date of 1st coat seal	Date of 2nd coat seal	Time between 1st and 2nd coat
1	885	0	673	673	11.6	2nd coat	3		16/03/00	Incorrect data	No data	16/03/00	
1	885	1,684	2,281	597	11.6	2nd coat	3		16/03/00	Incorrect data	No data	16/03/00	
1	939	7,435	8,560	1,125	10.7	Reseal	2		5/12/00	No data	No data	No data	
1	939	8,600	9,316	716	10.7	Reseal	2		5/12/00	No data	No data	No data	
1	939	9,591	10,120	529	10.7	Reseal	2		5/12/00	No data	No data	No data	
1	939	10,160	11,230	1,070	10.7	Reseal	2		5/12/00	No data	No data	No data	
1	954	11,666	12,757	1,091	9	Reseal	3		27/02/98	Bridge	No data	No data	
1	985	3,519	4,140	621	14.5	Reseal	3		17/01/01	1/03/89	Assume 03/89	Assume 1990	
2	788	72	735	663	9.2	2nd coat	2		7/03/95	Age of 05/00	No data	No data	
2	883/5.78	10,243	11,550	1,307	13.5	Reseal	2	4	13/11/00	No data	06/2000	As shown	
2	883/20.34	20,650	21,260	610	10	Reseal	3		3/02/96	25/02/89	18/02/89	15/01/90	11 mth
3	474/2.96	10,598	12,839	2,241	11.5	Reseal	2		24/02/99	Unknown	No data	No data	
4	35	7,870	8,530	660	7.9	Reseal	4		3/03/00	28/02/98	17/03/98	3/03/00?	
4	77	7,830	9,523	1,693	8.3	2nd coat	3		7/12/00	01/01/00?	No data	7/12/00	
4	140	5,750	7,849	2,099	7.9	Reseal	3	5	6/12/00	Unknown	2/02/89	30/11/89	10 mth
4	158	0	2,734	2,734	6.8	Reseal	2		17/11/99	No data	No data?	No data?	
4	223	6,850	7,770	920	8.8	2nd coat	3		11/03/00	14/05/99	14/05/99	11/03/00	10 mth
53	0	2,435	3,030	595	9	2nd coat	3	5	11/03/99	No data	No data	11/03/99	
53	0	7,450	8,447	997	8.5	Reseal	2		12/03/99	No data	No data	No data	
53	0	14,952	15,626	674	8.5	Reseal	4		31/01/00	25/03/88	31/03/88	7/02/90	22 mth
54	1	3140	3782	642	1.8	Reseal	3		10/02/95	No data	No data	No data	
54	1	5,224	5,880	656	6.9	Reseal	3		26/02/01	Unknown	No data	25/12/90?	

SH	RS	Start	End	Length	Width	Function	1st chip size	2nd chip size	Surfacing date	Date of pavement renewal	Date of 1st coat seal	Date of 2nd coat seal	Time between 1st and 2nd coat
										1989?			
54	1	12,538	14,830	2,292	6	Reseal	3		27/02/01	No data	No data	15/10/94	
54	17	270	928	658	6.7	2nd coat	3		14/02/00	6/04/99	31/03/99	14/02/00	10 mth
54	17	5,223	7,080	1,857	7.3	Reseal	3		28/02/01	25/04/00?	No data	25/12/88?	
54	38	108	1,304	1,,196	0.7	Reseal	3		9/12/95	25/04/00?	No data	No data	
57	0	114	1075	961	7.3	Reseal	3		15/02/00	25/12/55?	No data	No data	
57	0	1,075	2,030	955	9.1	Reseal	3		10/03/99	25/12/55?	No data	No data	
57	0	15,160	16,800	1,640	12.1	2nd coat	2		29/01/01	31/10/99	Assume 11/99	29/01/01	
57	0	17,200	17,700	500	11.2	Reseal	3		23/01/91	1/02/99	Assume 02/99	No data	
57	50	2,353	3,113	760	9	2nd coat	3		27/11/95	No data	27/05/95	27/11/95	6 mth
	Total			33.73	km								

3.13 Pavement strength

Falling weight deflectometer (FWD) data from RAMM has been plotted and reviewed to assess the pavement strength underlying the long-life seals that were inspected in the Whanganui, Manawatu, Wairarapa and Wellington regions. Twenty-six sites had at least three years of FWD results. Twelve sites had a total average of all FWD results (d0 in microns) below 500, and 27 sites had a total average of all FWD results below 1,000. Four sites fell between 1,000 and 1,224. All these pavements would be considered excellent to good based on the FWD data. An example graph is shown in figure 3.17.

Figure 3.17 Typical FWD result



It is worth noting the four sites with the highest pavement deflections had the lowest ADT and number of heavy commercial vehicles. The question is would these seals have survived sufficiently well to become long-life seals with higher traffic volumes, particularly heavy traffic.

4 Geospatial comparisons

Figure 4.1 shows the locations of chipseals aged 15 years and older. The ‘count roads’ table is the total number of long-life seals within that region, eg a total of 0–4 or a total of 35–45 long-life seals. Figures 4.2 to 4.10 show geospatial comparisons between the locations of chipseals 15 years and/or older, and the locations of:

- maximum pavement temperatures:
  - no clear trend is evident of either high or low maximum pavement temperatures favouring seals functioning to 15 years and beyond
- surface temperature extremes:
  - no clear trend is evident that high pavement temperatures in summer, coupled with low air temperatures in winter, have an influence on seals functioning to 15 years and beyond
- minimum air temperatures:
  - no clear trend is evident that extreme minimum air temperatures have an influence on seals functioning to 15 years and beyond
- annual rainfall:
  - no clear trend is evident that either high or low rainfall has an influence on seals functioning to 15 years and beyond
- annual sunshine hours:
  - no clear trend is evident that either high or low sunshine has an influence on seals functioning to 15 years and beyond.

As the visual geospatial analysis did not reveal definite trends, resources were not tasked with calculating statistical multivariate correlations between these factors.

Figure 4.1 Locations of chipseals 15 years or older

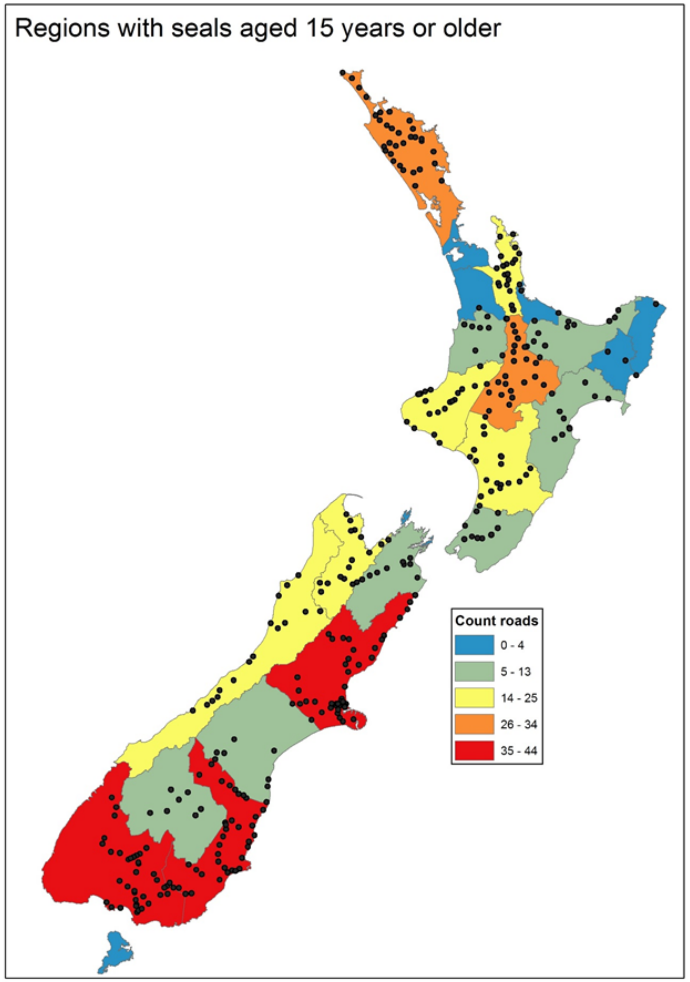


Figure 4.2 Maximum pavement temperature

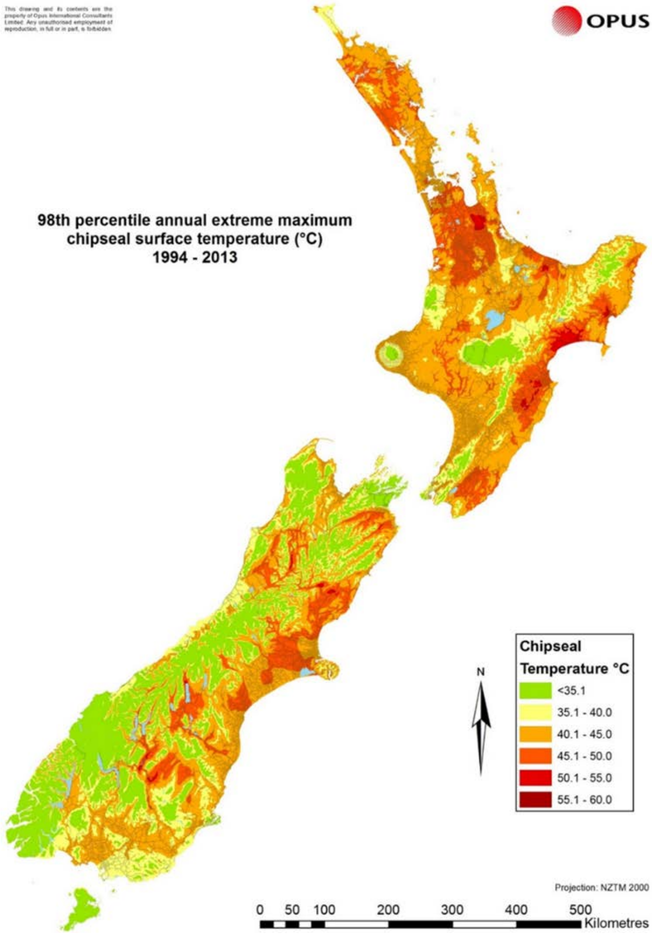


Figure 4.3 Locations of chipseals 15 years or older

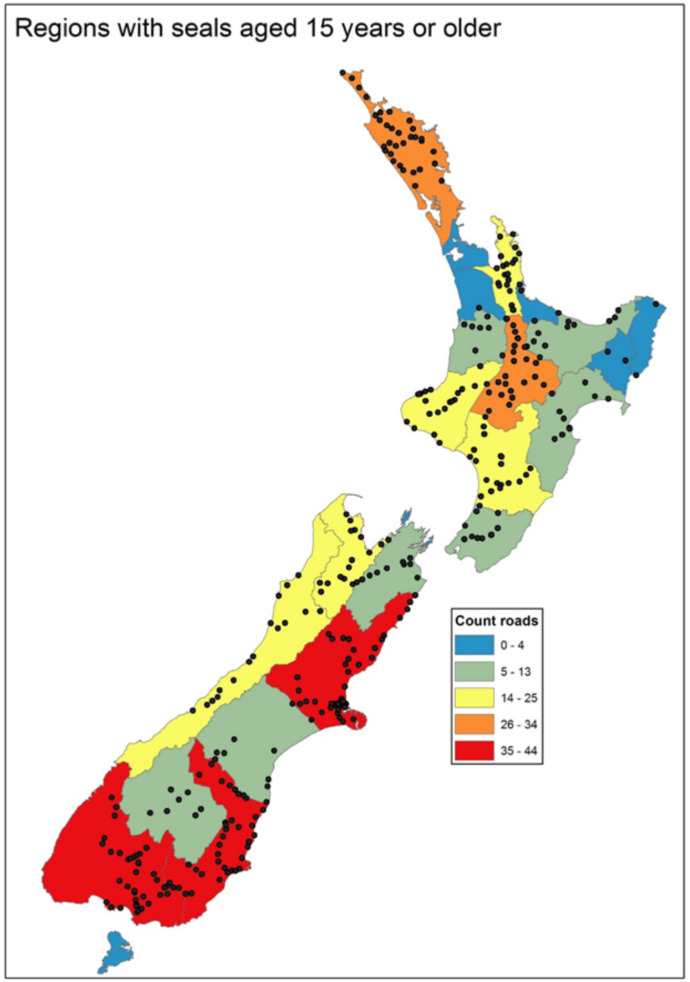


Figure 4.4 Temperature extremes

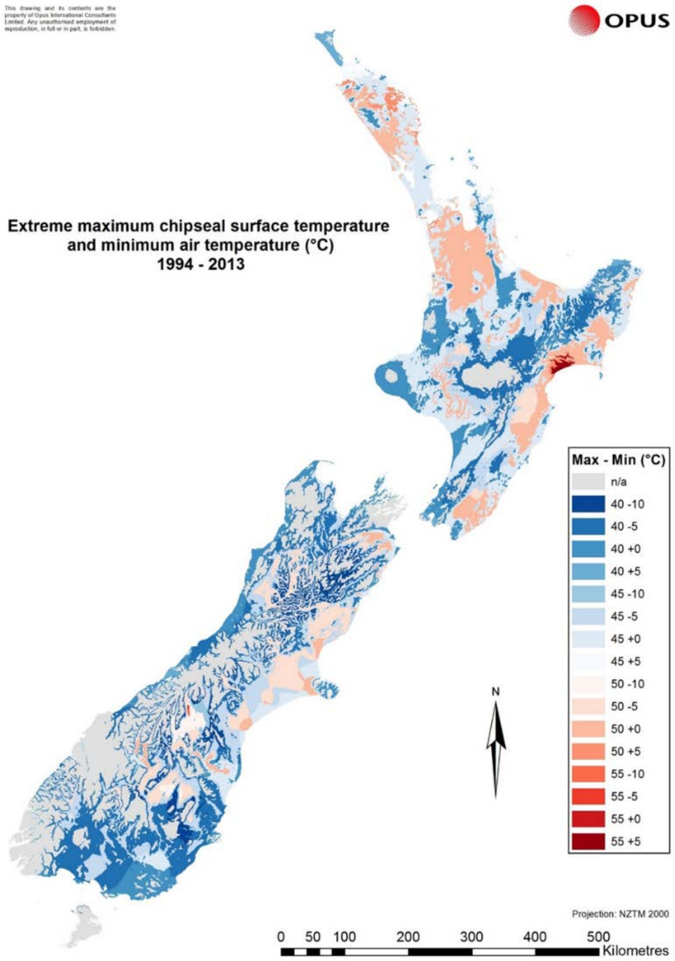


Figure 4.5 Locations of chipseals 15 years or older

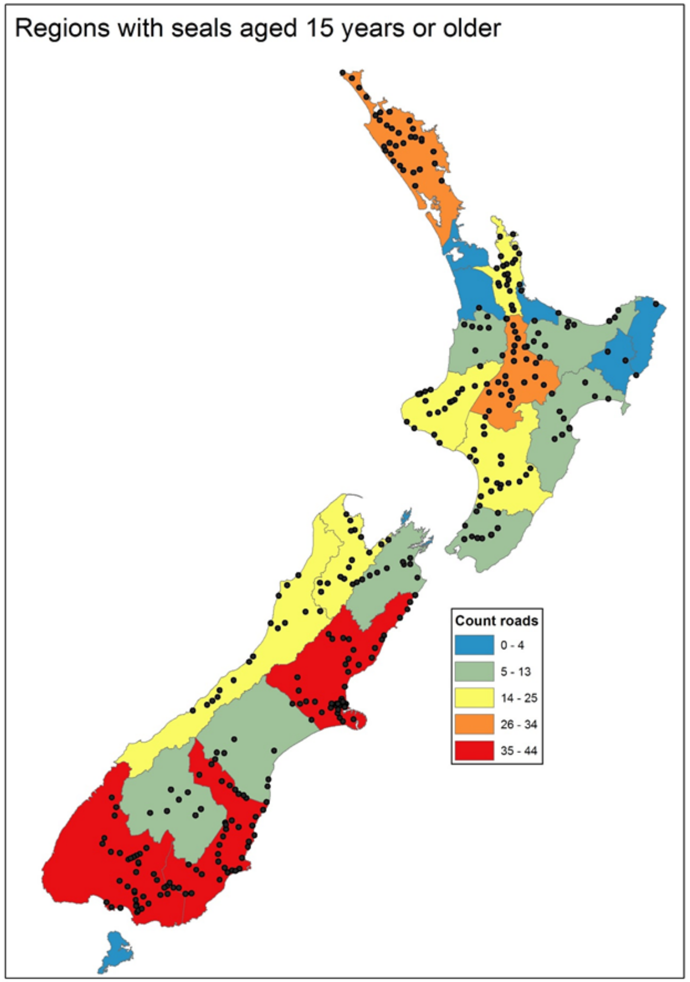


Figure 4.6 Minimum air temperature extremes

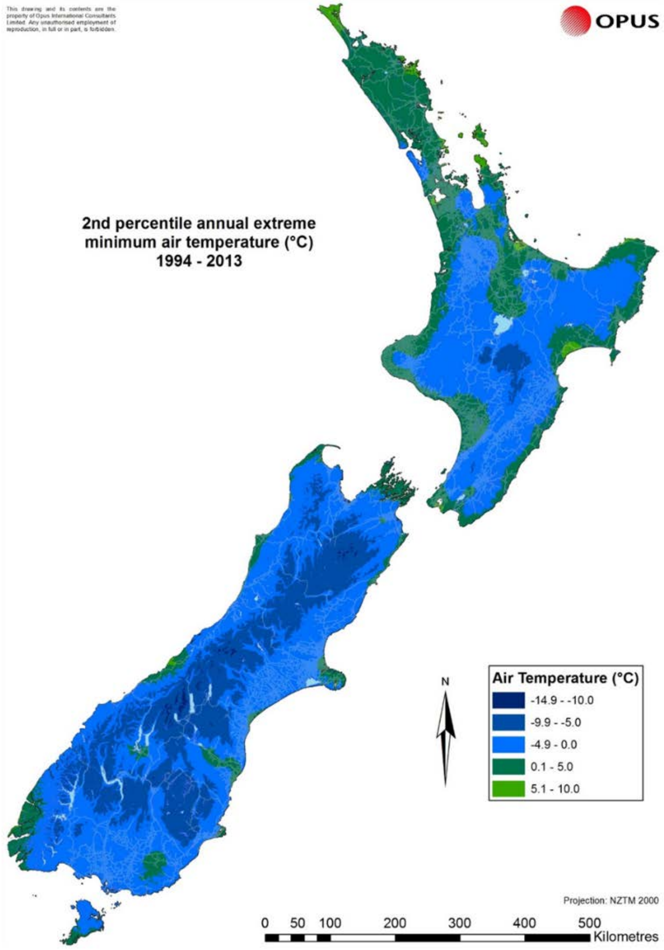


Figure 4.7 Locations of chipseals 15 years or older

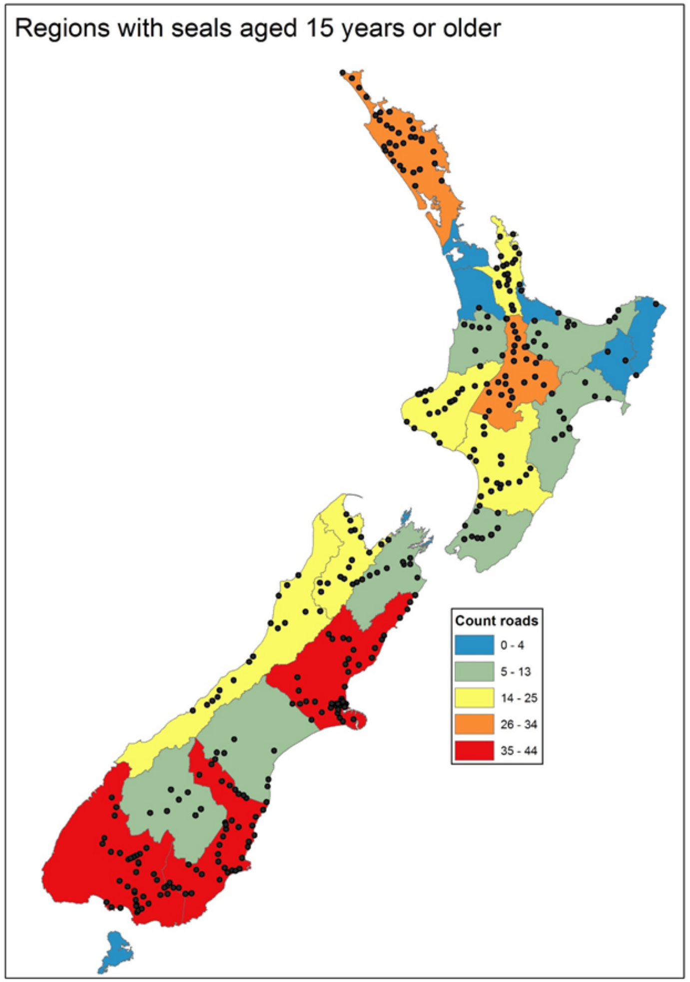


Figure 4.8 Annual rainfall

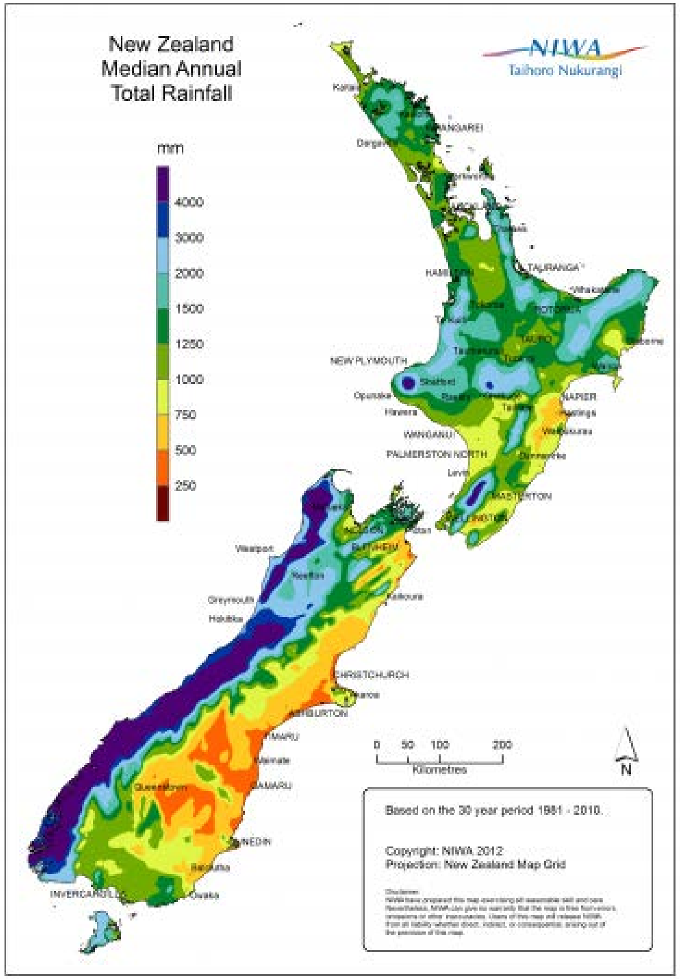


Figure 4.9 Locations of chipseals 15 years or older

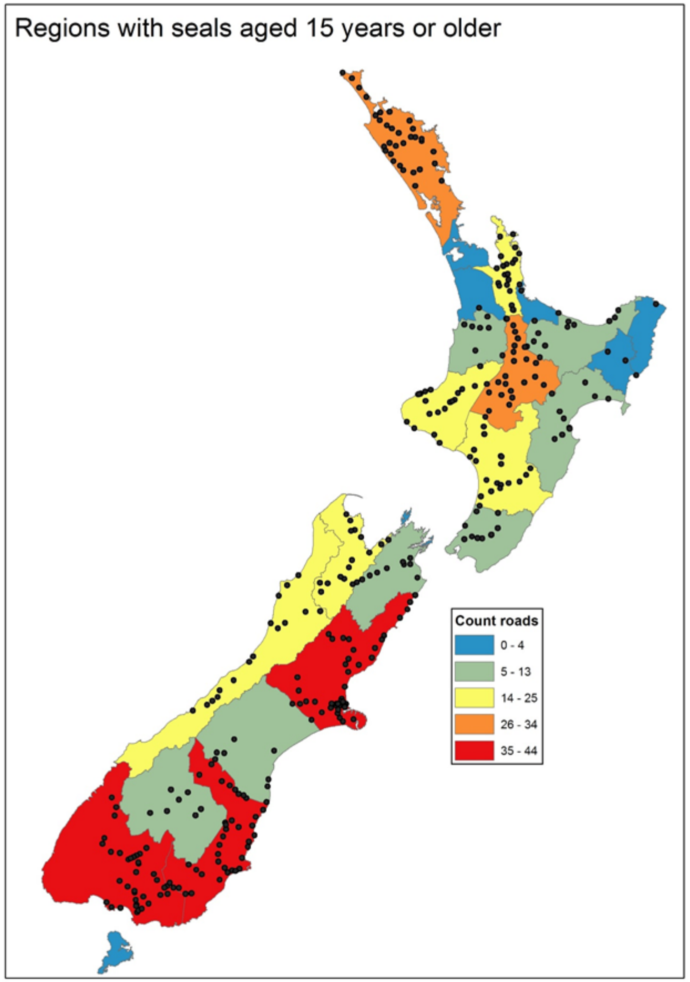
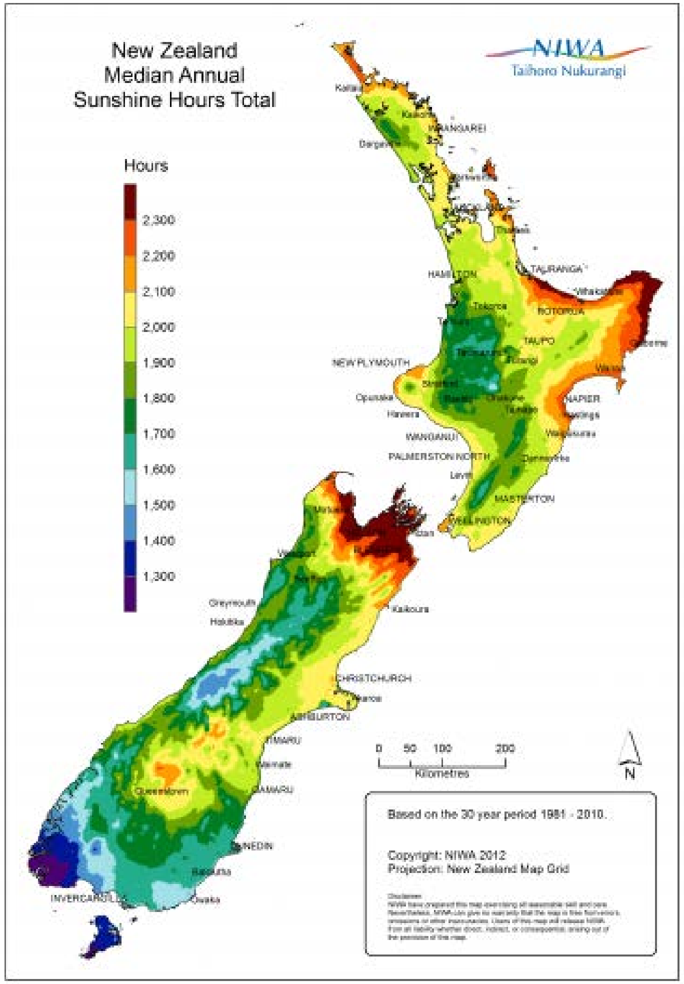


Figure 4.10 Annual sunshine hours



5 Discussion

5.1 International

The literature review of chipseals in South Africa, Australia and New Zealand found the longest life seals were those with the largest chip size and low traffic.

Attention to detail at the time of construction was also found to be important.

The study of the Transport Agency's RAMM database, verified by a selection of actual site inspections, found the dominance of large chip size and low traffic still valid for New Zealand.

5.2 Primes

The Transit NZ et al (2005) assertion that 'improvements in construction techniques mean that prime coats are no longer needed' may need to be re-affirmed in light of current experience. If construction quality is not maintained at 2005 levels, a field trial and subsequent analysis of the advantages of priming would be recommended, in line with international practice. Maintenance of the level of construction quality is currently being addressed by the Transport Agency through the 'construction right, no defects' projects.

5.3 Chip size and treatment selection

Assuming chip grades of chip sizes have been in use for over 20 years, this research has indicated that the larger chipseals last longer. A possible explanation for this is the larger chipseals require a larger bitumen application rate which in turn leads to a larger bitumen film thickness. As bitumen ages through surface effects such as oxidation (exposure to air) and ultra violet radiation (sunlight), the deeper the film thickness the more of the bitumen remains un-aged, and thus the longer it can last. When bitumen ages it becomes brittle and crystalline, losing its plastic/elastic properties and then cracks under movement caused by either moving traffic loads, or thermal summer – winter expansion and contraction. Once the bitumen cracks water is able to enter the pavement, which lowers the resilient modulus of the pavement allowing pavement deformation to occur. Also, hydrostatic pressure from passing tyres can cause the fines within the basecourse to pump to the surface, initiating the development of potholes. Leaking seals also allow water to build up and strip the base of a seal, leading to flushing (Herrington et al 2015).

The research agreed with the findings of previous New Zealand research (Cousins and McCracken 2015; McCracken and Cousins 2015) that for long-life seals, single-coat seals are significantly over represented and two-coat seals are significantly under represented compared with the national average. An inspection of figure 2.3 when comparing the lives of 10mm (grade 4) with 10/7mm (grade 4/5), and 14mm (grade 3) with 14/7mm (grade 3/5), suggests single-coat seals were not performing longer than two-coat seals 25 to 30 years ago in New Zealand. Analysis of the same figure shows that in Australia, however, in the 1990s single-coat seals were attaining longer lives than two-coat seals, as appears to be happening in New Zealand now.

The contention that treatment selection (eg single-coat or two-coat seal) may be influenced by changes in contractual conditions and changes in risk sharing is noted, but the RAMM data examined in this report could neither confirm nor contradict this contention.

5.4 Binder type

Forty-seven percent of all existing single seals and 35% of all existing two-coat seals in New Zealand have penetration grade 180/200 bitumen, which is a soft grade. However the representation of this binder in aged seals is much higher than for the national average, being 62% for single seals and 58% in two-coat seals. Although it would be easy to conclude softer binders give longer lives – and indeed softer binders are predominant in long-life seals – the survival of 80/100 bitumen in long-life seals is also above the national average. A conclusion on binder use, however, is made less certain because of the policies and guidelines that were in existence 15 to 20 years ago, as detailed in section 3.8. In practice, long-life seals have been found to contain a range of binders.

5.5 Traffic

The literature review found it is common for a long-life seal to be under the lower traffic loadings, and this study has confirmed that finding.

5.6 Climate

Comparing the spatial distribution of long-life seals with various climatic factors was also of interest. It could have been expected that low air and pavement temperature, low rainfall and low sunshine hours would favour long-life seals, as bitumen aging is minimised in these conditions. The data suggests, however, that long-life seals can be found equally in high or low pavement temperatures, in wider as much as in narrower temperature extremes, in high and low rainfall areas, and in high or low sunshine hours. The fact that no clear trend exists suggests these are not key variables.

5.7 Timing

The majority of the long-life seals were constructed from November to March. It is important chipseals are laid in the summer months, as the air and pavement temperatures are higher, which means the bituminous binder stays warmer. This in turn leads to a lower bitumen viscosity which enables the chip particles to re-orient sooner, to lie on their average greater dimensions. This is the stable position the binder application rate has been designed for, with the binder coming half to two thirds up the chip and able to hold the chip securely in place. Sealing in summer also means less cutter is required. When large amounts of cutter are used to lower the viscosity for winter, the seal will have a strong tendency to flush and bleed the following summer.

5.8 Pavement strength

Neither pavement deformation nor potholing was found in long-life seals. FWD data indicated long-life seals were supported by a good to excellent strength basecourse.

5.9 Summary

The purpose of this research was to identify the reasons why some reseals have very long lives, and to identify which of these factors could economically be applied to reseals in future contracts, thus leading to a reduction in the whole-of-life costs of chipsealing and pavement maintenance. The research has instead found that long lives relate to a specific treatment selection on a sound well-drained pavement with traffic less than 2,000 ADT. To replicate this requires good quality pavement construction and good quality workmanship in seal construction, and low traffic volumes.

Some of these key variables are not held in the RAMM database.

To obtain longer lives in future work, repeating good quality pavement construction and good quality workmanship in seal construction remains vitally important. However, to extend long life to traffic volumes greater than 2,000 ADT would require more than repeating the best practices from the past, and possibly a quantum change in practices. This is of particular importance if traffic volumes are to continue to grow, so more and more roads carry volumes greater than 2,000 ADT, and/or the percentage of heavy commercial vehicles grows.

6 Conclusions and recommendations

6.1 Conclusions

The life of a seal can be influenced by many things, such as the seal design, quality of workmanship at time of construction, and material properties such as bitumen, aggregate and the pavement.

Based on the data available in the New Zealand RAMM data-base, a long-life seal is most likely to be:

- a single-coat seal
- a large chip size
- a 180/200 pen bitumen
- under less than 2,000 ADT
- on a good quality, strong, durable well-drained pavement
- in a lower skid resistance demand category.

The aggregate mosaic is also usually flat and tightly packed, suggesting good quality workmanship at the time of laying.

It was interesting to discover long-life seals can equally be found in any temperature extreme, in any rainfall category and in any degree of sunshine hours.

6.2 Recommendations

1. A pre-requisite for a long-life seal is a good quality pavement. The Transport Agency has implemented a ‘quality right, no defects’ project, and the momentum gained from this project should be maintained. Specific expectations for quality management on site should be applied to the sealing operations as well as to the pavement construction.
2. Sealing should continue to be undertaken during the months of November through to March.
3. The use of grade 2, 3 and 4 single seals is to be encouraged.
4. There should be ongoing research into how to extend long-life seals beyond the 2,000 ADT range.

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Appendix A: Summary of the RAMM data

A1 Chip size

Chip size	**Age ≥15 years centreline length (km)**		**Entire state highway network centreline length (km)**	
Grade 3	305.82	39%	1,114.96	10%
Grade 2	135.44	17%	365.41	3%
Grade 5	94.15	12%	1,466.22	13%
Grade 2/4	78.13	10%	2,947.36	27%
Grade 3/5	71.67	9%	3,465.37	32%
Grade 4	56.65	7%	244.54	2%
Grade 4/6	9.54	1%	594.21	5%
Grade 6	8.23	1%	158.05	1%
Grade 2/5	8.18	1%	286.73	3%
Grade 3/6	7.34	1%	75.73	1%
Grade 4/5	0.11	0%	107.1	1%
Grade 2/3	0	0%	6.14	0%
Grade 2/6	0	0%	0.74	0%
Grade 3/4	0	0%	17.04	0%
Grade 5/6	0	0%	58.3	1%
	775.26		10,907.9	

A2 Seal type

	Age ≥ 15 years		**Entire state highway network**	
Treatment type	**Centreline length (km)**		**Centreline length (km)**	
Single-coat seal	510.59	66%	2,114.48	19%
Two-coat seal	153.84	20%	4,944.93	45%
Void fill seal	56.05	7%	1,048.48	10%
Texturising seal	31.41	4%	139.29	1%
Racked in seal	15.45	2%	1,711.36	16%
Sandwich seal	6.09	1%	735.62	7%
Slurry seal	4.63	1%	22.59	0%
Red chip seal (McCullum)	0.21	0%	19.8	0%
Other	0.16	0%	3.28	0%
Cape seal	0.02	0%	16.85	0%
Blended chipseal	0	0%	12.15	0%
Combination seal	0	0%	145.05	1%
Locking coat seal	0	0%	1.15	0%
	778.45		10,915.03	

A3 Binder type

Seals greater than or equal to 15 years	Subtotal centreline km	Centreline km each	
Single- coat seal	505		
Bitumen 180/200		313.50	62%
Bitumen 80/100		97.05	19%
Bitumen 130/150		48.16	10%
Emulsion 180/200		38.69	8%
Emulsion 80/100		4.25	1%
Emulsion polymer modified		2.25	0%
Polymer modified bitumen		1.11	0%
Bitumen 60/70		0.03	0%
Two- coat seal	142		
Bitumen 180/200		82.84	58%
Bitumen 130/150		26.29	18%
Bitumen 80/100		16.81	12%
Emulsion 180/200		13.41	9%
Emulsion polymer modified		2.58	2%
Emulsion 80/100		0.31	0%
Void fill seal	69		
Bitumen 180/200		36.27	53%
Emulsion 180/200		12.02	17%
Bitumen 80/100		11.27	16%
Bitumen 130/150		6.72	10%
Emulsion polymer modified		2.07	3%
Emulsion 80/100		0.33	0%
Texturising seal	39		
Bitumen 180/200		22.08	56%
Bitumen 130/150		6.52	17%
Emulsion 180/200		5.82	15%
Bitumen 80/100		4.73	12%
Slurry seal	11		
Bitumen 180/200		4.62	42%
Emulsion 180/200		2.55	23%
Bitumen 130/150		2.40	22%
Bitumen 80/100		1.06	10%
Emulsion 80/100		0.37	3%
Racked in seal	6		
Bitumen 180/200		3.63	62%
Bitumen 80/100		2.10	36%

Seals greater than or equal to 15 years	**Subtotal centreline km**	**Centreline km each**	
Emulsion 180/200		0.06	1%
Bitumen 130/150		0.06	1%
Polymer modified bitumen		0.03	0%
Sandwich seal	1		
Bitumen 80/100		0.50	37%
Bitumen 130/150		0.49	36%
Bitumen 180/200		0.36	27%
Total centreline km		773.31	

Seals from the entire SH network	**Subtotal centreline km**	**Centreline km each**	
Single- coat seal	2,065		
Bitumen 180/200		962	47%
Bitumen 130/150		526	25%
Bitumen 80/100		276	13%
Emulsion 180/200		175	8%
Emulsion 130/150		54	3%
Emulsion polymer modified		35	2%
Polymer modified bitumen		20	1%
Emulsion 80/100		14	1%
Bitumen 60/70		3	0%
Two- coat seal	4,430		
Bitumen 130/150		1,557	35%
Bitumen 80/100		853	19%
Bitumen 180/200		803	18%
Emulsion polymer modified		490	11%
Emulsion 180/200		359	8%
Polymer modified bitumen		167	4%
Emulsion 130/150		163	4%
Emulsion 80/100		33	1%
Bitumen 60/70		4	0%
Polyurethane		1	0%
Void fill seal	1,012		
Bitumen 130/150		501	50%
Bitumen 80/100		191	19%
Bitumen 180/200		174	17%
Emulsion 180/200		83	8%
Emulsion polymer modified		22	2%
Emulsion 80/100		20	2%

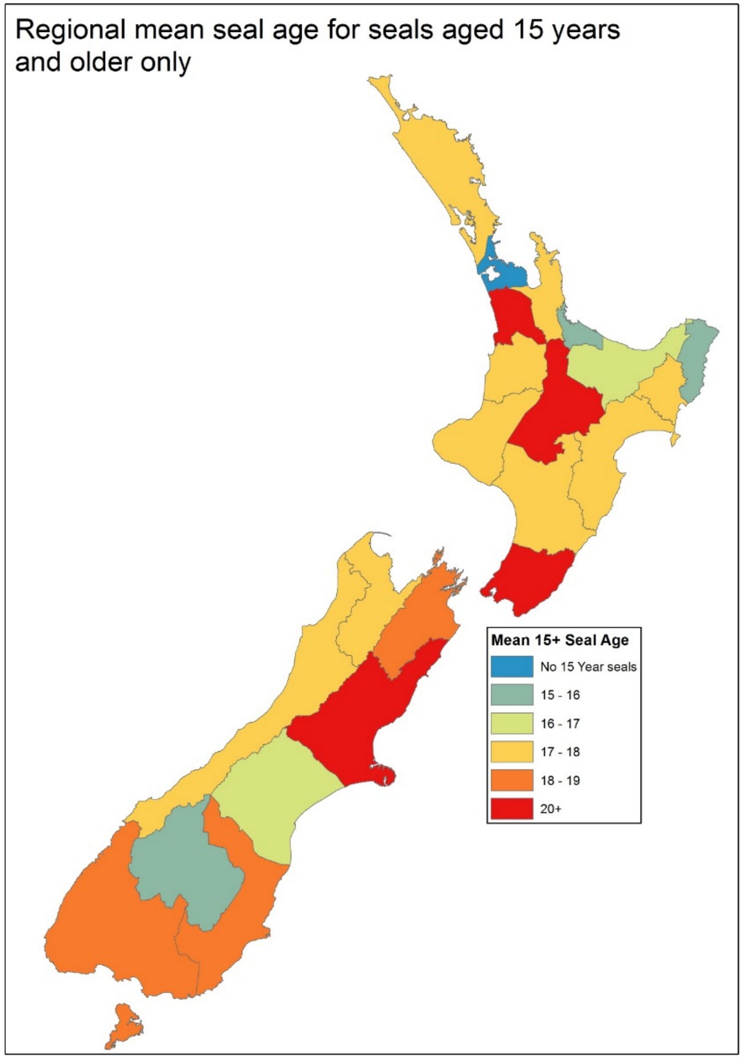
Seals from the entire SH network	**Subtotal centreline km**	**Centreline km each**	
Emulsion 130/150		14	1%
Polymer modified bitumen		7	1%
Bitumen 60/70		0	0%
Texturising seal	149		
Bitumen 130/150		51	34%
Bitumen 180/200		40	27%
Emulsion 180/200		39	26%
Bitumen 80/100		8	6%
Emulsion 80/100		5	3%
Emulsion polymer modified		4	3%
Emulsion 130/150		1	1%
Bitumen 60/70		0	0%
Slurry seal	36		
Emulsion 180/200		16	44%
Emulsion 80/100		7	20%
Bitumen 180/200		7	19%
Bitumen 130/150		4	12%
Bitumen 80/100		2	5%
Racked in seal	1,577		
Bitumen 130/150		687	44%
Bitumen 80/100		251	16%
Emulsion 180/200		236	15%
Bitumen 180/200		200	13%
Emulsion polymer modified		101	6%
Polymer modified bitumen		59	4%
Emulsion 130/150		29	2%
Emulsion 80/100		13	1%
Sandwich seal	700		
Emulsion polymer modified		197	28%
Emulsion 180/200		161	23%
Bitumen 80/100		134	19%
Bitumen 130/150		105	15%
Emulsion 130/150		69	10%
Polymer modified bitumen		14	2%
Bitumen 180/200		13	2%
Emulsion 80/100		7	1%
Total centreline km		9,969	

A4 ADT

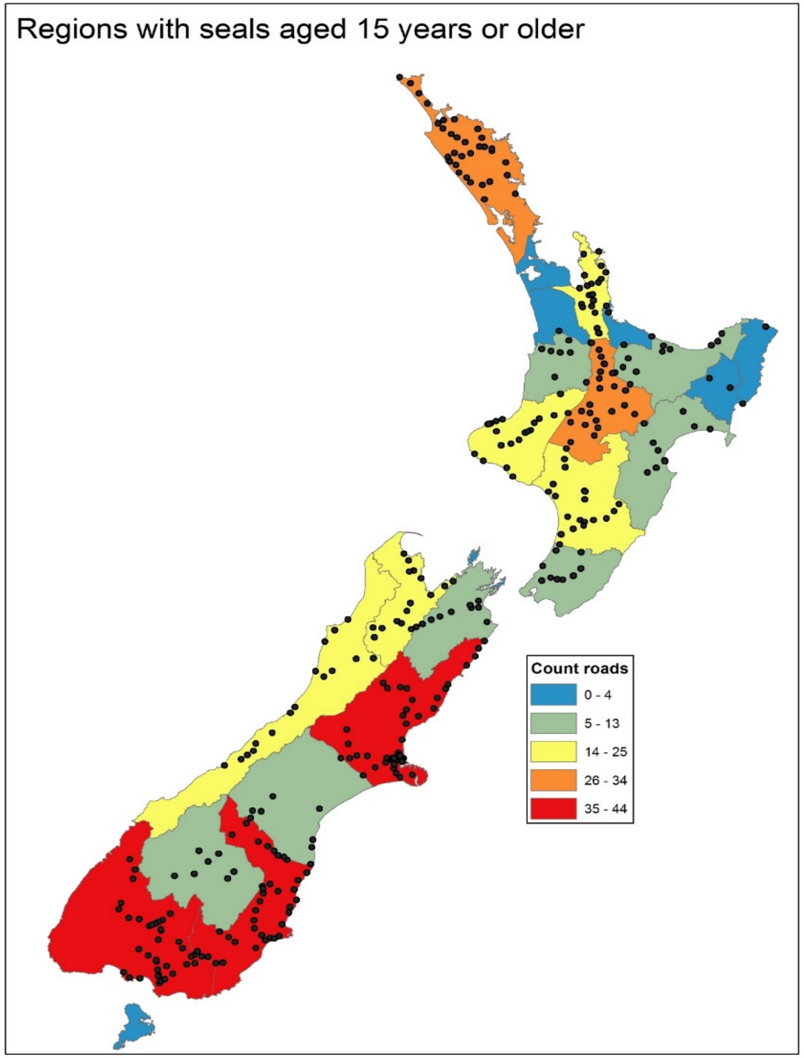
	Centreline km ≥ 15 years		Entire SH network	
ADT < 100	0.52	0%	10.09	0%
ADT 100–500	104.83	13%	582.63	5%
ADT 500–2,000	333.83	40%	4,614.28	38%
ADT 2,000–4,000	130.87	16%	2,573.57	21%
ADT 4,000–10,000	166.9	20%	2,754.22	23%
ADT 10,000–20,000	77.06	9%	1,113.39	9%
ADT > 20,000	22.68	3%	363.16	3%
	836.69		12,011.34	

Note: This data set contains non-chipseal surfacings. Included in this data: 48km of asphaltic concrete are 15 years or older, 236km are less than 15 years old; 36km of OGPA are 15 years or older, 780km are less than 15 years old; ~2km of SMA are 15 years or older, 351km are less than 15 years old.

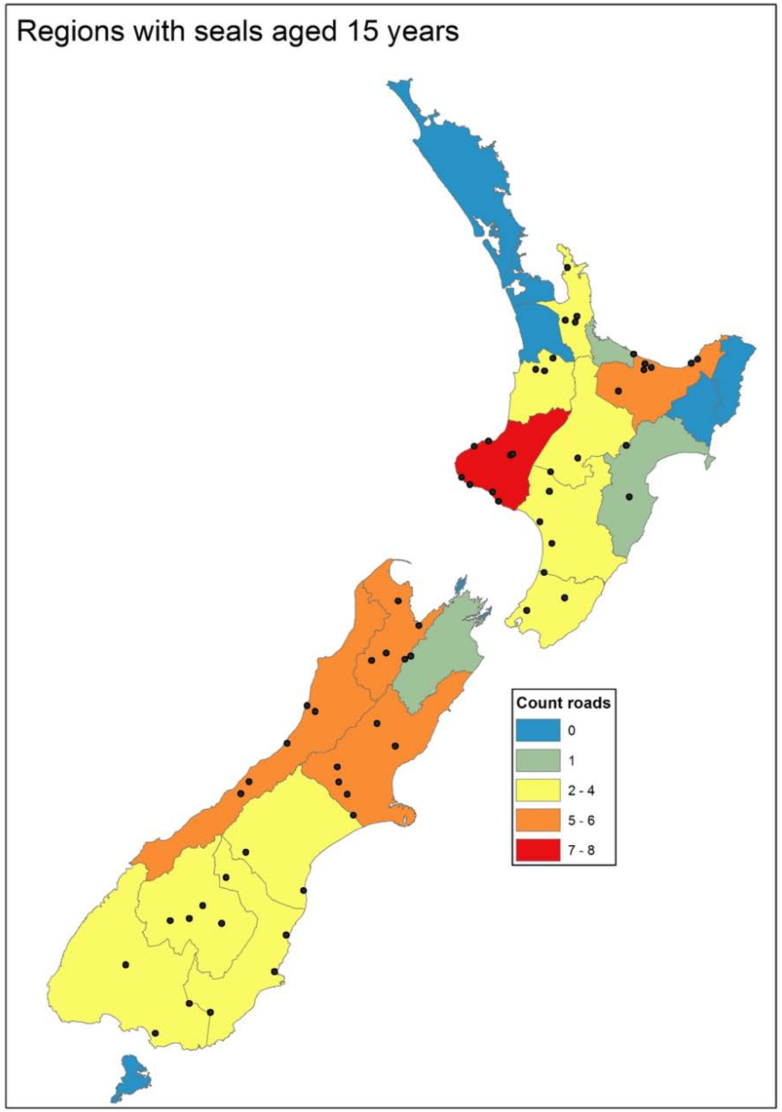
A5 Geospatial locations of long-life seals

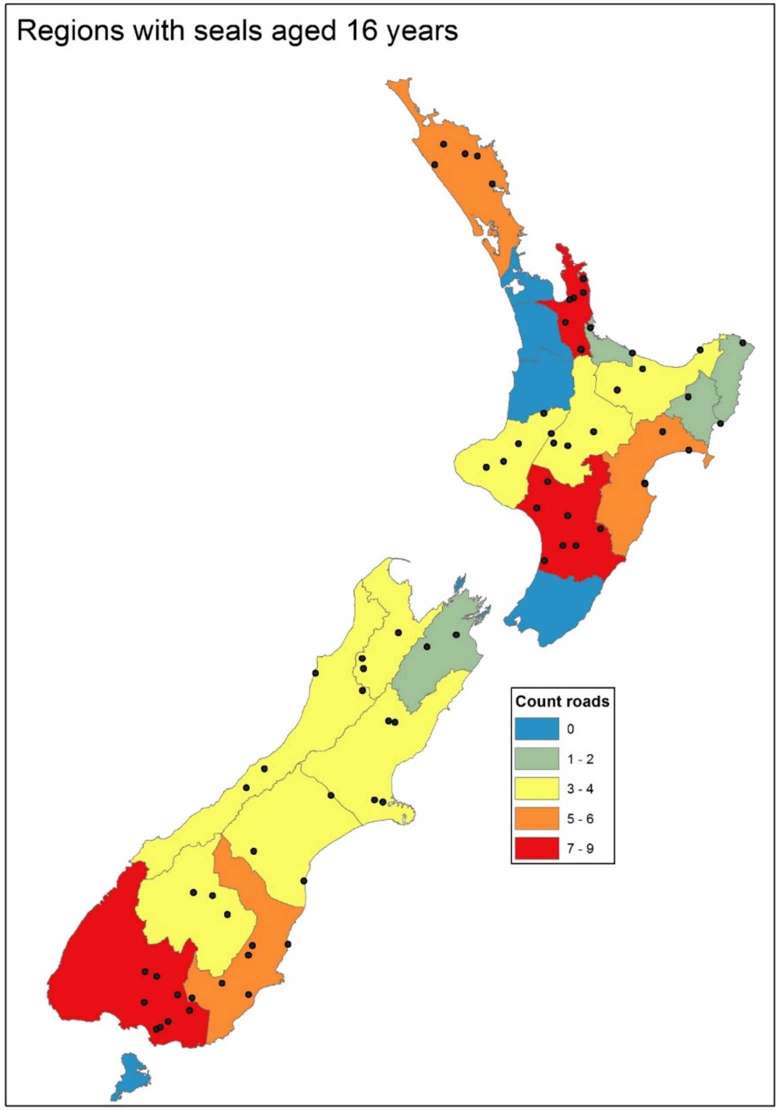


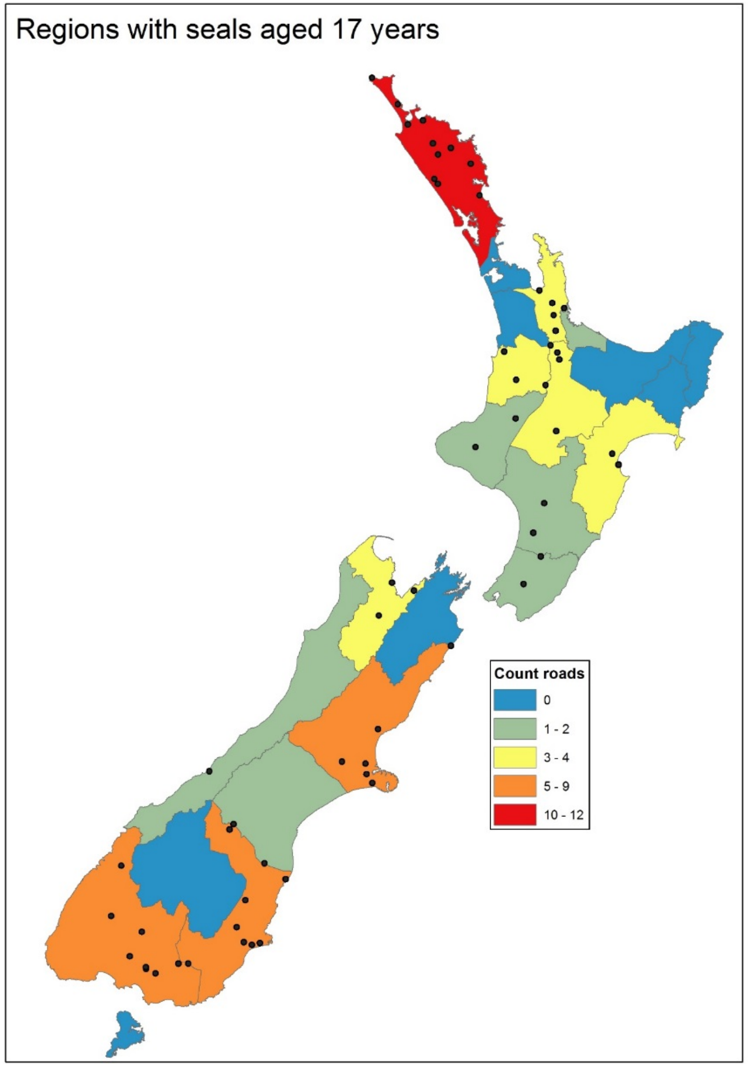
Regional mean seal age for seals aged 15 years and older only

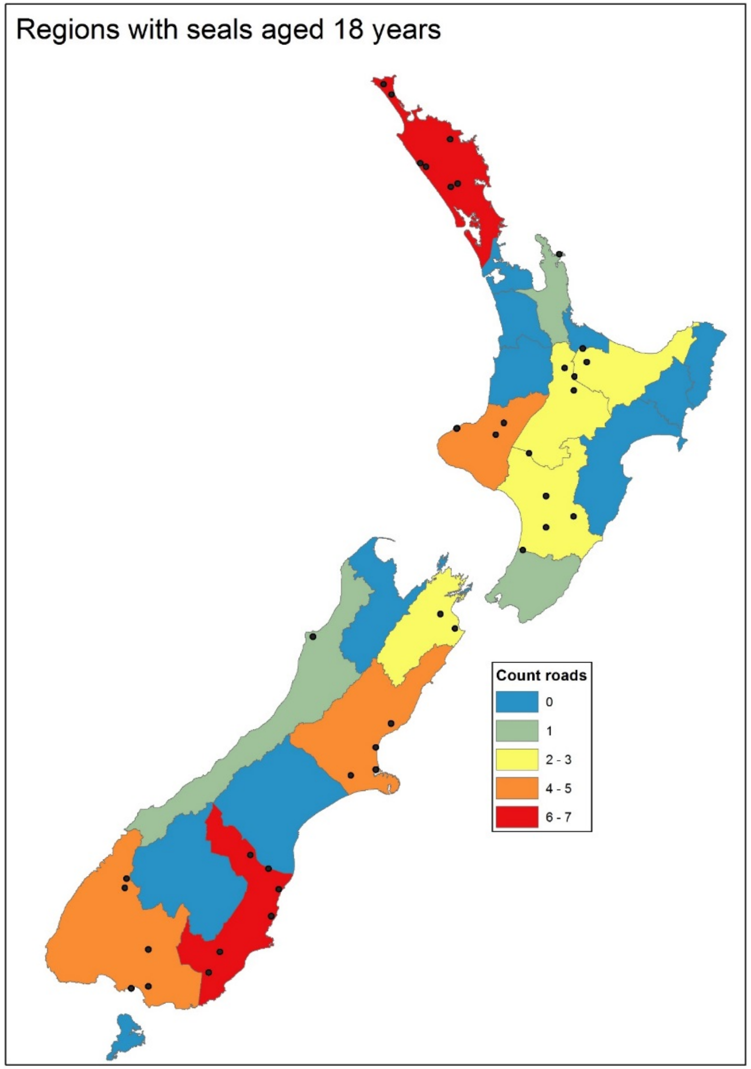


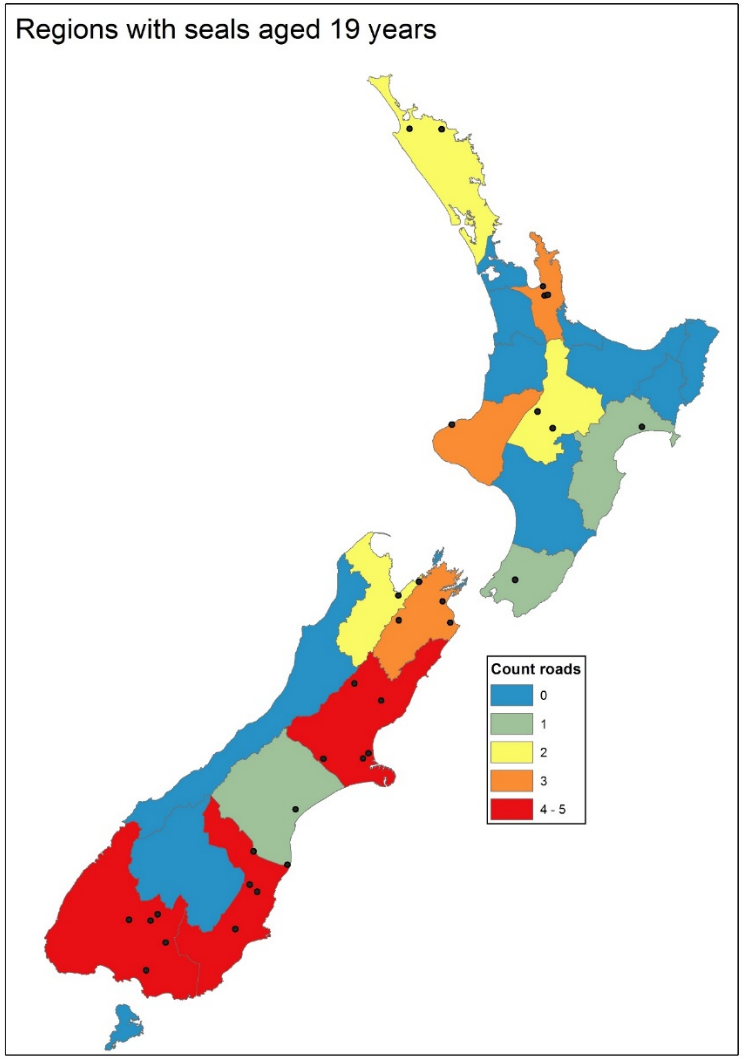
Regions with seals aged 15 years or older


Regions with seals aged 15 years

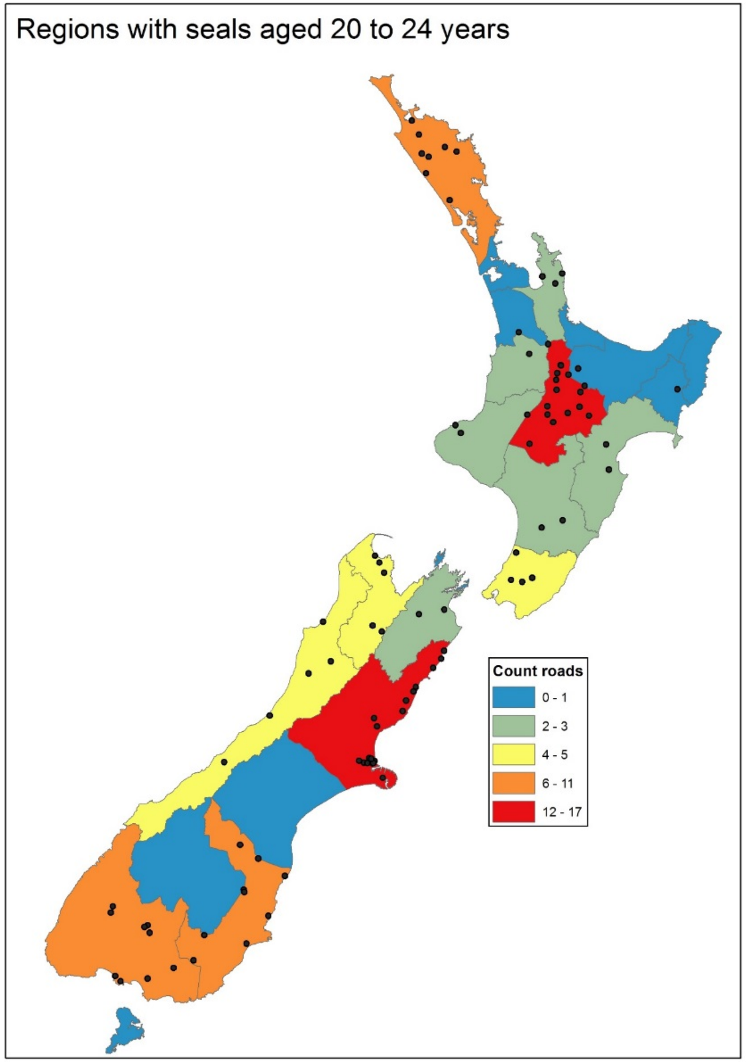

Regions with seals aged 16 years


Regions with seals aged 17 years
Count roads
0
1 - 2
3 - 4
5 - 9
10 - 12

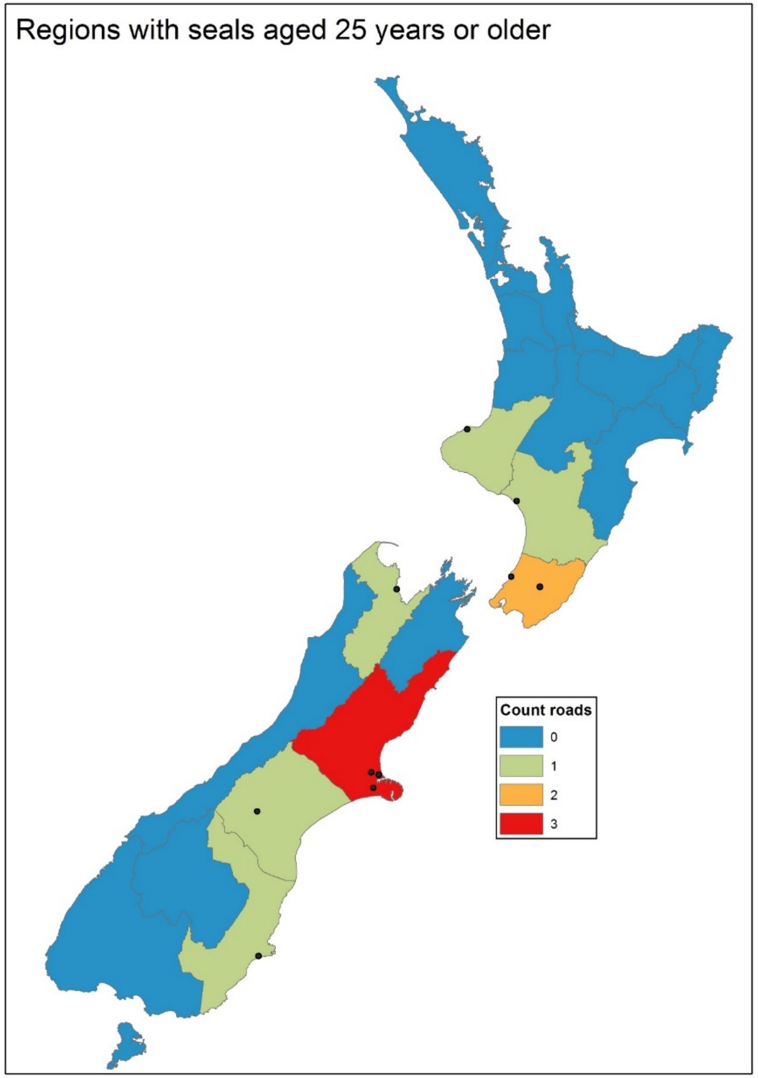

Regions with seals aged 18 years
Count roads
0
1
2 - 3
4 - 5
6 - 7



Regions with seals aged 19 years



Regions with seals aged 20 to 24 years


Regions with seals aged 25 years or older